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AVIAN INFLUENZA OUTBREAKS IN GERMANY AND THE USA – COMPARISON AND ANALYSIS

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AVIAN INFLUENZA OUTBREAKS IN GERMANY AND THE USA – COMPARISON AND ANALYSIS

AUSBRÜCHE DER GEFLÜGELPEST IN DEUTSCHLAND UND DEN VEREINIGTEN STAATEN – VERGLEICH UND ANALYSE

Dissertation zur Erlangung des Grades eines Doktors der Philosophie (Dr. phil.)

angenommen vom Senat der Universität Vechta

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Harm Böckmann, February 2021

Abstract

Outbreaks of Highly Pathogenic Avian Influenza (HPAI) are common today all across the world. The occurrence of the virus in wild and domestic birds is neither limited to a certain avian species or to any species for that matter. The global poultry community needs to find a way to live with the constant threat and reoccurring outbreaks.

This paper sheds light on two major outbreaks in the USA in 2015 and in Germany in 2017. For both countries, these outbreaks were the largest up until then and were therefor equally challenging for authorities and the poultry industry. The dissertation analyses the spatial development of the outbreaks and includes an economic impact assessment for each country. Locally applied virus mitigation methods are compared with regard to effectiveness and cost efficiency. The quantitative analysis is backed up by expert interviews in both the USA and Germany. The interviews validate quantitative results and improve the understanding of the industry and its key stakeholder. The statements of the interviews were categorized and further analyzed using inductive category formation. Through quantification of statements in each category, comparatability between results of both countries is achieved.

Results show a clear and distinct spatial development of both outbreaks around clearly defined epicentres in areas with exceptionally high densities of poultry production. After a first line of small outbreaks, the virus spread wildly affecting a majority of operations in the areas. The devastating progression of the virus can be linked to ineffective, faulty or slow mitigation measures. In Germany, efficient mitigation processes were in place before the outbreak, yet small mistakes led to a cascade of ensuing outbreaks nonetheless. Overall, the poultry industry of the USA was affected more severely. Mitigation processes in Germany used financial resources more efficiently and indemnification payments for farmers were quicker and higher. At the same time, mitigation efforts were relatively cheaper in the USA. The secondary industry was impacted more severely in the USA due to longer idle production times. Experts supported these findings and demanded more commitement to biosecurity in the future.

Keywords: HPAI outbreaks, international poultry industry, spatial analysis, economic impact assessment

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List of abbreviations

African Swine Fever	ASF
Aftermath costs	AC
Animal Plant and Health Inspection Service	APHIS
Bovine Spongiform Encephalopathy	BSE
Calendar Week	CW
Center for Epidemiology and Animal Health	CEAH
Classical Swine Fever	CSF
Contagious Bovine Pleuropneumonia	CBPP
Direct consequential costs	DCC
Direct costs	DC
Foot-and-Mouth Disease	FMD
Friedrich-Löffler-Institut	FLI
Highly Contagious Livestock Disease	HCLD
Highly Pathogenic Avian influenza	HPAI
Incident Coordination Group	ICG
Indirect consequential costs	ICC
Low Pathogenic Avian Influenza	LPAI
Movement Restriction Zone	MRZ
Multi Agency Coordination Group	MAC
National Animal Health Emergency Response Corps	NAHERC
National Incident Management Team	NIMT
National Veterinary Service Laboratory	NVSL
Newcastle Disease	ND
Non-governmental Organization	NGO
Notifiable Avian Influenza	NAI
Observation Zone	OZ
Peste des petits ruminants	PPR
Qualitative Content Analysis	QCA
Regulatory control area	RCA
Rift Valley Fever	RVF
Small and medium sized entreprise	SME
The Food and Agriculture Organisation of the United Nations	FAO
Tierseuchenkasse Niedersachsen	TSK
Transboundary Animal Disease	TAD
United States Department of Agriculture	USDA
World Organisation for Animal Health	OIE

1 Introduction

The Food and Agriculture Organisation of the United Nations (FAO) has determined that highly pathogenic avian influenza (HPAI) is a "potentially explosive problem at the global level". The FAO (2016a) further states that the virus can spread rapidly, becoming an immediate problem for the affected countries, their neighboring countries, and the global community. The disease has both immediate and long-lasting negative effects on the local and international poultry industry (FAO, 2016a). Its consequences are equally devastating in the third world, developing, and developed countries. The international mass occurrence of the HPAI virus has additional dramatic implications for public health on an international scale because some HPAI virus strains are known to be zoonotic (WHO, 2016). The FAO (2016a) demands responses on local, national, and global levels as a result. The World Organisation for Animal Health defines HPAI as a highly contagious livestock disease (HCLD) because HPAI has a high morbidity rate with mortality impacts on both domesticated and wild animals (OIE, 2018), with the OIE even noting that the currently circulating strains of HPAI are a global public health concern. Hirsch (2010) used the data of the insurance company Munich Re[1], comparing the long-lasting impact of HCLDs with natural disasters such as floods and winter storms, finding that HCLD outbreaks in comparison with natural disasters have the potential to be significantly more disastrous, as they can potentially last longer and spread internationally. With several avian influenza cases known to have crossed the species barrier, causing human fatalities, the international community has acknowledged the disease as a major threat to the global health of animals and humans alike. Rushton et al. (1999) mention that, while crop disease and their impacts on society have been and are still researched thoroughly, animal diseases such as avian influenza are "comparatively understudied". Rushton repeated this concern in 2009.

In 1997, an HPAI outbreak of H5N1 in Guangdong, China affected 1.4 million chickens, causing 18 human infections, six of which resulted in death (WHO, 2005). This outbreak drove the call for more research in this area. Starting in 2003, the HPAI H5N1 strain developed into a worldwide pandemic affecting 61 countries, again increasing the demand for in-depth research. Today, HPAI is the focus of many studies and research institutes, and will remain so for the coming years. This study is part of the international effort to shed more light on the topic of avian influenza and the possibilities to reduce its drastic impacts.

1.1 The focus of the paper

There were several large HPAI outbreaks in recent decades, each differing in the extent of their economic and social impacts. This research focuses on two significant outbreaks occurring in 2014 and 2015 in the USA, and in 2016 and 2017 in Germany.

Although the outbreak in the USA started in 2014, it is referred to as the "2015 outbreak" or simply the "US outbreak" in this thesis. This is also the case for the outbreak in Germany that started in 2016 and lasted until 2017, and is referred to as the "2017 German outbreak" in this thesis. In December 2014, the H5N8 and H5N2 strains of HPAI were confirmed in backyard flocks in the US states of Idaho, Oregon, and Washington, with smaller outbreaks occurring in January, February, and March. Starting in April, the virus spread rapidly, resulting in the "most severe epizootic event in the history of the poultry industry" (Windhorst, 2016). More than 50 million layer poultry and turkeys were affected and had to be culled. The agricultural and poultry industry was severely impacted, especially in the concentrated outbreak centers in Iowa and Minnesota. The epidemic had lasting effects on the US egg market and international trade (Windhorst, 2016).

Two years after the USA, Germany similarly experienced the largest HPAI outbreak in its history. The 2016 and 2017 HPAI outbreak was the largest ever recorded outbreak of HPAI in Germany. The first officially recognized HPAI cases occurred in the state of Schleswig-Holstein in early November of 2016. The outbreak lasted until April of the next year, and for the first time in German history, all 16 states

[1] https://www.munichre.com/en/homepage/index.html

were affected by the virus. In total, more than 1,100 infected wild birds were identified and confirmed HPAI positive. Including birds from 15 zoos and animal parks, a total of more than 1.4 million birds were affected and had to be culled.

The poultry production value chain in both the USA and Germany is multi-faceted and complex. These kinds of large-scale HPAI outbreaks in highly developed value chains are well documented, allowing for an in-depth time-spatial analysis of their outbreak. This thesis focuses on economic and time-spatial analysis using the available data in both countries. The study depicts direct and indirect effects and will detail how the outbreaks developed over time from a local spatial dimension perspective. In a comparative analysis, the findings of the time-spatial analysis in both countries are evaluated.

This thesis also provides a qualitative analysis. In both the USA and Germany, experts from different professions, the commercial realm, and public/NGOs who either were affected directly through their business or were actively engaged in mitigation efforts during the time of the outbreaks were interviewed. Their assessments of the outbreaks allow for a qualitative analysis of the HPAI events, which is an essential second focus of this thesis. The results of the qualitative analysis are also compared to enable ideas for possible improvements in both countries.

1.2 Research design

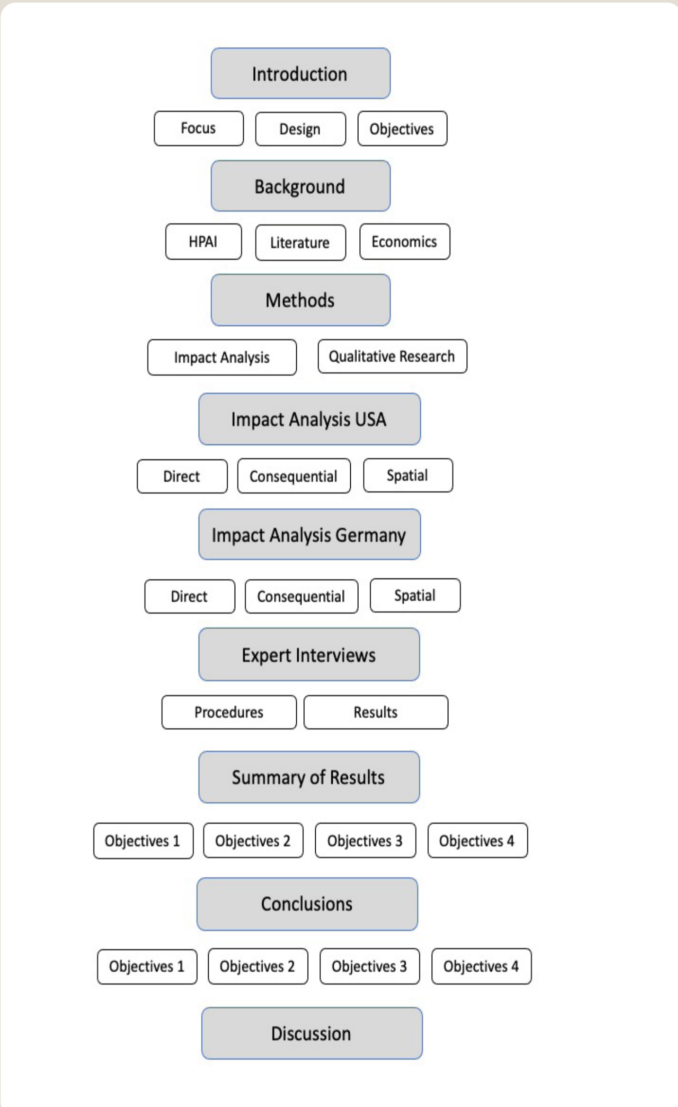
The structure of the research and its design are described in this chapter, clarifying all the research processes and the superordinate structure of the paper. The scientific approach to the outbreaks in the USA and Germany described above will be explained. Of note is that the research design is not to be mistaken for research methods, which are detailed in a subsequent chapter.

There are several forms of research designs, including experiments, correlation studies, field studies, evaluation studies, and case analysis. This thesis applies a field study. Mey and Mruck (2010, p. 230) define a field study as research that does not investigate within an artificially created environment, but in the regular natural environment of the subject instead. “Escapist external perspectives” and incorrect research methods (Mayring, 2016, p. 55) have the potential to distort conclusions and are therefore avoided in this thesis. The field study research design includes interviews with experts from the respective fields to ensure that all conclusions drawn from the research are based on highly accurate information and in relation to the daily operational issues and practical challenges in an outbreak scenario. Field research is a crucial element of this thesis. Figure 1 (p. 17) displays the research design which divides the thesis into ten chapters. The introductory chapter explains the focus, research design, and objectives of the thesis. The subsequent background chapter includes critical information on avian influenza and the current and past status of literature and research. The methods chapter depicts the methods used in this thesis to conclude the HPAI impact analysis for the USA and Germany. The chapter also explains in detail the methods used for the expert interviews.

The chapters on impact analysis in Germany and the USA analyze the outbreak situations in the USA in 2014 and 2015, and Germany in 2016 and 2017. These chapters provide an overview of the time-spatial development of viruses in both countries. Following the impact analysis, the thesis explains the exact procedures of the field research. These include the process of drafting an interview guideline and the choice of experts. In the results section, the thesis displays the aggregated findings of the expert interviews. The concluding implications and discussion chapters combine the outcomes of previous chapters such as market description, outbreak management, and impact analysis, with conclusions in the results chapter, which also includes propositions for improvements for both countries should future outbreaks occur.

Figure 1

Doctoral thesis research design
Source: Own elaboration applying information by Mey and Mruck (2010, p. 229)



1.3 Objectives

This paper has four key objectives that define the goals of the research and serve as contextual guidelines for subsequent chapters while focusing on the two significant outbreaks in the USA and Germany described above. The outbreak in question in the USA started in late 2014 and lasted until mid-2015. For simplification, the remainder of the research refers to this outbreak in the USA as the "2015 outbreak" or the "US outbreak". The outbreak in Germany started in late 2016 and lasted until mid-2017. This paper will refer to this outbreak as the "2017 outbreak" or the "German outbreak".

Objective 1
Develop a substantiated understanding of how HPAI was able to unfold on such a large scale in both Germany and the USA.

The poultry industry in both Germany and the USA is highly developed, modern, and very efficient. There are regional and international experts working in a variety of functions across the value chain in these countries. So how was a large-scale HPAI outbreak able to unfold in both countries? It is the objective of this paper to develop an answer to this question.

Objective 2
Comparison and analysis of spatiotemporal developments during HPAI outbreaks in the USA and Germany.

Large HPAI outbreaks are believed to follow a distinct pattern of proliferation. The virus progression in both the USA and Germany can be tracked in hindsight, and potentially offers additional insights that are important for the understanding of the economic impacts and mechanisms of HPAI outbreaks. Additionally, this type of analysis offers further insights into the epidemiologic development of the virus.

Objective 3
Comparison and analysis of economic impacts caused by HPAI outbreaks in the USA and Germany.

The economic impact analysis of the outbreaks in 2015 and 2017 are the core of this analysis. It is the goal of this paper to analyze the economic effects of the respective outbreaks in detail. The analysis will lead to conclusions regarding how future outbreaks must be approached within the context of economic impacts, and about how future outbreaks can be optimally handled.

Objective 4
Validate quantitative results and enhance understanding of outbreak effects on the international poultry industry through comprehensive expert interviews.

During the outbreaks, industry members, governmental institutions, and farmers were directly impacted by the avian virus. These first-hand experiences are valuable sources of information in the understanding of HPAI mechanisms. It is the goal of this paper to validate the results of the above-mentioned objectives using in-depth expert interviews. In addition to validating the results, the experts' experiences offer additional context and advanced insights into the problems, challenges, and accomplishments that were not visible via desk-based research. This paper aims to render this additional insight visible, and place it within the context of the respective findings.

2 Background AI

An analysis of the 2015 and 2017 HPAI outbreaks in the USA and Germany requires a thorough understanding of the virus. This includes a historic background, general HPAI characteristics, an epidemiological understanding, and an understanding of their zoonotic potential. This chapter explains these issues as a basis for the subsequent economic and spatiotemporal analysis.

2.1 The history of HPAI

HPAI as a virus has been present for many decades. In the early years of HPAI outbreaks, veterinary diagnostics were not as developed as they are today, meaning that veterinarians and stakeholders in poultry production did not fully understand the disease. This section highlights the veterinarian historic perspective of HPAI.

Perroncito (1878) was the first to describe a disease in poultry. In a detailed paper, he described a mild form of a disease that turned virulent with very high mortality rates over the course of time (Kaleta & Rulke, 2008). Before these findings in avian diseases, virulent human diseases with high mortality rates were recorded and written about as early as the fifth century BC. The veterinary sector as we know it today developed starting at the end of the 1700s (Morens & Taubenberger, 2010). The poultry industry was not organized until the end of the 1900s (Morens & Taubenberger, 2010), and only when poultry became economically more important and a significant part of daily diets and farm household income did research on it intensify (Rülke, 2007). Until 1955, HPAI was referred to as *typhus exudatious gallinarum,* during which time the disease was proven to be an influenza A virus. The term *classical fowl plague* established itself during this time (Lupiani & Reddy, 2009). During the First International Symposium on Avian Influenza 1981 in Beltsville, USA, the disease was newly termed *avian influenza,* or *highly pathogenic avian influenza,* and has been referred to this way since (Bankowski, 1981). Other names over time included fowl pest, peste aviare, *Geflügelpest,* Brunswick bird plague, Brunswick disease, fowl disease, fowl grippe or bird grippe (Swayne & Suarez, 2000). The Brunswick disease name originates from the incident at the 1901 Brunswick poultry show in Germany. Infected birds were found at the show, after which the authorities cancelled the event and sent participants home, effectively spreading the disease across all of Germany (Lupiani & Reddy, 2009).

Table 1 shows significant HPAI outbreaks in Germany since 1950. In 1979 there was a single HPAI outbreak in Germany that Alexander and Brown (2009) believe was caused by wild bird introduction. The 2003 HPAI outbreak in Germany was part of the massive Dutch HPAI H7N7 outbreak (DG Sante, 2003). In 2008 and 2009, a substantial LPAI outbreak occurred in Germany. While LPAI outbreaks were also frequent in the USA before 2014 (Morens et al., 2004) they are not mentioned in the tables below. The LPAI outbreak of 2008/2009 is however critical to mention because it made authorities finally aware of the destructive potential of HPAI and LPAI, and resulted in significant improvements to mitigation processes (LAVES, 2009).

Table 2 shows the significant outbreaks of HPAI in the USA since

Table 1

Major HPAI outbreaks in Germany since 1950
Source: (Alexander & Brown, 2009; LAVES, 2017; LAVES, 2009; TSK, 2017b; OIE, 2017)

Year of occurrence	Virus Subtype	Affected farms	Lost birds
1979	HPAI H7N7	2	680,000
2003	HPAI H7N7	1	419,000
2008/2009	LPAI*	33	616,000
2017	HPAI H5N8	122	1,402,016

*Low Pathogenic Avian Influenza

Table 2

Major HPAI outbreaks in the USA since 1950
Source: (Alexander & Brown, 2009; USDA, 2016b; USDA, 2016a; USDA, 2016c; USDA, 2017)

Year of occurrence	Virus Subtype	Depopulated farms	Lost birds
1983-84	H5N2	NA	17 million
2004	H5N2	1	NA
2014-2015	H5N8, H5N1, H5N2	231	50.1
2016	H7N8	9	414,000
2017	H7N9	14	253,000

1950. The HPAI H5N2 strain resulted in a significant outbreak in 1983 and 1984 in which authorities had more than 17 million birds culled. Following this occurrence, there was only one small outbreak in 2004 that did not result in any noticeable impact. So when the 2015 HPAI outbreak occurred, the authorities at the time were mostly new to this kind of situation. Table 2 describes two more outbreaks in 2016 and 2017 that were contained within days and did not lead to more substantial impacts.

2.2 HPAI characteristics

This section highlights the general characteristics of the HPAI virus. It includes insights on how virus testing is performed and how LPAI and HPAI are differentiated. The distinction between LPAI and HPAI is important because it has implications for subsequent reporting and mitigation activities.

HPAI virus, a cause of substantial worldwide economic losses in the poultry industry, is an influenza A virus. Influenza A viruses are ubiquitous to the planet and are widespread human and veterinary health pathogens (Suarez, 2016). Influenza viruses are part of the orthomyxoviridae family in which there are several more genera (Capua & Marangon, 2006). The International Committee on Viral Taxonomy has accepted influenza types A, B, C, and isavirus, thogotovirus and quaranfilvirus as members of the segmented negative-sense RNA virus family (Suarez, 2016). The influenza B and C viruses are human pathogens, whereas the type A viruses spread across a variety of avian and mammalian species (Suarez, 2016). Classification is based on two surface proteins within type A viruses: the hemagglutinin (HA) and the neuraminidase (NA). Today, 18 hemagglutinins (H1 to H18), and nine neuraminidases (N1 to N9) are officially recognized (CFSPH, 2015; Suarez, 2016). These subtypes do not appear evenly across bird and mammalian species. Whereas the occurrence of different subtypes is limited in mammals, there is a more extensive variety of subtypes in the Aves class, especially in the order of Anseriformes and Charadriiformes (Suarez, 2016). The officially recognized name of an influenza virus is defined through naming the type, the host, the place of first isolation, the strain number, the year of isolation, and the antigenic subtype (USDA, 2015c). The virus A/chicken/Hong Kong/y385/97(H5N1) is an influenza A-type virus in chickens that was first isolated in Hong Kong. The strain number is y385. The virus was isolated in 1997 and is in the subcategory H5N1.

The subtypes H5 and H7 are of particular interest for the poultry industry because HPAI and low pathogenic avian influenza (LPAI) outbreaks are caused only by H5 and H7 influenza type A viruses (FLI, 2017a; OIE, 2015). The German Friedrich-Löffler-Institut (FLI) is required by the OIE to define all H5 and H7 subtypes as notifiable avian influenza (NAI) which subsequently entails the necessity to officially report all cases to the OIE (FLI, 2017b; OIE, 2015). The OIE terrestrial animal health code requires reporting of poultry infections through H5 and H7 subtypes with high and low pathogenicity, including when these subtypes are confirmed outside of domestic poultry, for example in wild birds (OIE, 2015). Influenza A viruses H1-H4, H6, and H8-H18 do not require reporting (OIE, 2015).

For this paper, it is furthermore essential to define HPAI in the context of other global disease phenomena. Parallel to OIE definitions, FAO classifies HPAI as a significant transboundary animal disease (TAD) (Otte et al., 2004); it is defined as (FAO, 2016b, p. 3):

"Those that are of significant economic, trade and/or food security importance for a considerable number of countries; which can easily spread to other countries and reach epidemic proportions; and where control/management, in-cluding exclusion, requires cooperation between several countries."

Because the social and economic impact of a TAD has the potential to be dramatic for the public and private sector, its occurrence receives considerable attention (Otte et al., 2004). Mitigation measures are taken on individual, collective, and international levels to prevent further adverse effects of the disease (Otte et al., 2004). Other critical TAD include foot-and-mouth disease (FMD), *Rinderpest,* bovine spongiform encephalopathy (BSE), contagious bovine pleuropneumonia (CBPP), Rift Valley fever (RVF), *Peste des petits ruminants* (PPR), classical swine fever (CSF), African swine fever (ASF), and Newcastle disease (ND) (Otte et al., 2004).

There are no pathognomonic signs of influenza A viruses, meaning its identification requires laboratory testing (Spackman et al., 2008). Detection of influenza A viruses is achieved through the verification of virus or type-specific antibodies (Spackman et al., 2008). The significance of HPAI to the international community is considerable, which has led to international universalization of testing in HPAI suspect cases under the guidance of the OIE (Spackman et al., 2008; OIE, 2015).

Virus isolation (VI) is optimally conducted to confirm LPAI and or HPAI cases; its respective testing is laborious and time-consuming (OIE, 2015). Other tests include antigen capture immunoassays (ACIAs) or real-time reverse transcription polymerase chain reaction (rRT-PCR) tests. Samples here are obtained from either dead or living birds. Samples originating from deceased birds use intestinal content such as feces or cloacal or oropharyngeal swabs. Additionally, trachea, lung, air sac, intestine, spleen, kidney, brain, liver, and heart samples are processed separately or as a pool (OIE, 2015). For live birds, samples are taken through oropharyngeal and cloacal swabs (OIE, 2015).

Clinical signs of HPAI are ocular and nasal discharges, coughing, “snicking” and dyspnea, swelling of the sinuses and head, listlessness, reduced vocalization, reduction in feed and water intake, cyanosis of unfeathered skin, wattles and comb, incoordination, nervous signs, and diarrhea (CFSPH, 2015). Signs of influenza in laying hens include a significant reduction in eggs or a stark increase in poor quality eggs (CFSPH, 2015). Overall, morbidity and mortality increase significantly, with mortality rates up to 100% depending on the species and virus strain (Capua & Marangon, 2006; CFSPH, 2015).

LPAI generally manifests itself with noticeably milder clinical signs, if at all. Nonetheless, an LPAI infection can convey signs of an HPAI infection if other infections are present; if the flock is in a state of overall poor health; or if the flock is or has been exposed to strenuous environmental conditions (OIE, 2015). Influenza virus infections of high pathogenicity to date have always been linked to viruses of the H5 and H7 subtypes. Viruses of the subtype H1-H16 are ubiquitously present in wild birds, and if transferred to domestic poultry flocks can potentially cause mild LPAI infections (Capua & Marangon, 2006). Genomic studies have shown that to date, the emergence of an HPAI virus strain has always originated in low pathogenic strains (Capua & Marangon, 2006). This pathogenicity shift is the reason why LPAI virus strains of the H5 and H7 virus subtypes are treated with equal caution and commitment to mitigation. The mutation from low pathogenicity to high pathogenicity is not predictable and can happen in a manner of days, or after several months of circulating in the local bird population (Capua & Marangon, 2006). The pathogenicity shift is believed to happen primarily in domestic poultry flocks (CFSPH, 2015; Swayne, 2016). Although evidence of a mutation from LPAI to HPAI in wild birds has to date not been identified (USDA, 2015c), HPAI H5N strains have in fact occasionally been found in wild birds as well, hinting at the possibility that certain species can be carriers of HPAI strains without showing the respective symptoms (USDA, 2015c). An example of two cases in Chile unambiguously shows the pathogenicity shift from LPAI to HPAI. In May 2002, LPAI H7N3 was confirmed in a broiler operation. In June of the same year, HPAI H7N3 was confirmed in the same flock, leading to economic losses of nearly $31 million based on approximately two million birds lost (Lupiani & Reddy, 2009).

2.3 Infection and spread of HPAI

An understanding of how viral material travels across continents over long periods of time is essential when examining these issues. The two outbreaks analyzed in this paper were part of a larger international outbreak series. Counteracting or preventing future international spreads of the HPAI virus means understanding the respective mechanisms as well as possible. This section summarizes the current knowledge on this topic.

The dissemination of viral material peaks in autumn when large quantities of young birds gather in migratory staging locations (USDA, 2015c). These young birds are highly susceptible to influenza viruses because they have yet to develop the required immunity (USDA, 2015c). At the same time, the virus can survive considerably longer during cold seasons. Greene (2015) states that with the beginning of spring and increasing temperatures, HPAI tends to decline. It is possible to eliminate virus material around domestic operational areas. The OIE has published guidelines on how to destroy HPAI (OIE, 2018). Cooking and pasteurization for predetermined minimum time frames will eliminate the virus (OIE, 2018, p. 617). Additionally, there are several organic solvents and or chemical detergents that will inactivate it. Acidic cleaners with pHs of <=2 will also destroy HPAI. The virus can survive in surface waters up to 160 days depending on the temperature. If frozen, the virus survives indefinitely. Liquid poultry feces constitute a basis for the virus to survive for 30-35 days (USDA, 2015c). The virus can also survive as a byproduct of the poultry industry's processing activities. If heating procedures are not followed correctly, it will survive in these byproducts for several weeks. Byproducts include viscera, blood, feathers, feet, heads, neck, and poultry entrails that are for example used in pet food. This potential hazard has to be taken into account, especially for the international trade of these products (USDA, 2015c). Bird carcasses are also a host for virus material. At daytime temperatures, the virus will survive for several days in bird carcasses. If these are refrigerated, the virus will even survive a few weeks (USDA, 2015c). The USDA (2015c) recommends burying, incinerating, or composting for the disposal of dead birds.

HPAI infections in domestic poultry most likely originate in direct or indirect contact with infected wild birds that migrate inside of the same territory (Suarez, 2016). In Minnesota, USA, it was common during the 1980s and 90s to rear domestic turkey outside all year, including during the migratory wild duck season (Suarez, 2016, p. 12). Interaction and close contact between wild ducks and the domestic turkey were customary, as were regular outbreaks of influenza viruses of different subtypes. After the practice of outside rearing was changed to confined and sealed indoor rearing, outbreaks of influenza ceased (Suarez, 2016, p. 12).

The accurate analysis of where and when the index case of an outbreak occurs is challenging to conclude (Hinrichs, Sims, & McLeod, 2006). Several extensive studies were concluded in which the exact method of HPAI infection was analyzed. Brown (2017) concluded an extensive survey among member states of the European Union. APHIS (2015a) analyzed several transmission theories in a large study following the 2015 outbreak in the USA. Both studies were unable to point out the exact moment and mode of transmission that initially started an outbreak. Generally, the first case of an outbreak is not necessarily the index case, but merely the case that was first noticed (Hinrichs et al., 2006). A likely occurrence is that initial contact to domestic poultry occurs through direct contact with wild birds. The virus is then transferred to domestic flocks via contaminated saliva, nasal secretion, and feces (Beach et al., 2007; Brown et al., 2017). Along with direct contact, personnel, equipment, vehicles, feed, and bedding can also be responsible for the transfer of virus-contaminated material from wild birds to domestic flocks (FLI, Beach et al., 2007; Brown et al., 2017; 2016). Secondary infections within a large outbreak scenario are most likely caused by a human transfer of virus material on shoes, clothing, equipment, or vehicles (Beach et al., 2007; Brown et al., 2017). The transfer of already-infected domestic poultry to HPAI-free farms is another pro-bable cause of its spread (Brown et al., 2017). Lacking understanding of biosecurity at any level and unknowingly spreading HPAI in the poultry industry represents another way the virus disseminates (Swayne & Suarez, 2000). Industry representatives in the USA agreed on this conclusion in a Senate hearing following the 2015 HPAI outbreak in the USA (United States Senate Committee on Agriculture Nutrition and Forestry, 2015).

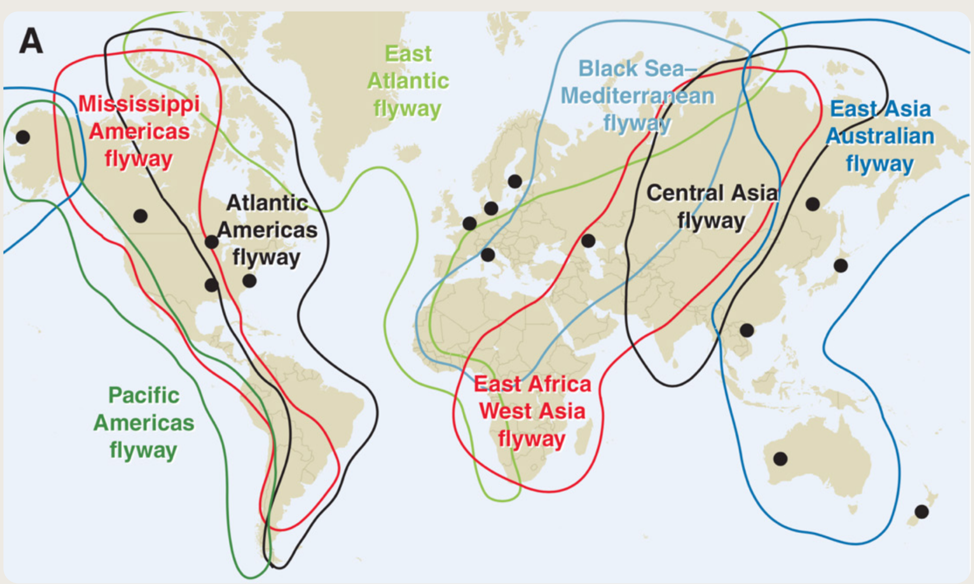
HPAI is not restricted to occasional local prevalence; it has progressed to full international dissemination on all continents (Flint et al., 2015). This international spread of the disease is attributed to the international flight routes of wildfowl that act as reservoirs and shed active virus material during their migratory north-to-south movements (Flint et al., 2015). Sampling of wild birds has increased over recent decades to improve the understanding of international wildfowl migration and how it serves as an HPAI reservoir. As part of the mitigation efforts during the 2015 HPAI outbreak in the USA, a total of 7,068 samples were taken, of which 65 were HPAI-positive (USDA, 2015b). An increased amount of samples and genomic sequencing has resulted in a better understanding of the international flight routes of wildfowl. This improved understanding helps assess the likelihood of new virus introductions (Snow et al., 2007).

Waterfowl migration in North America generally consists of north-south seasonal movements between breeding grounds and wintering areas. The distance between the habitats ranges from local movements to intercontinental transfers (Olsen et al., 2006). Olsen et al. (2006) analyzed international flight routes of wildfowl. Flyways are corridors in which many different avian species travel along similar north-south axes. In North America, these flyways are aligned with topographical features such as the Rocky Mountains or the Mississippi River (USDA, 2015d). There are at least three flyways in North America, which can be seen in Figure 2. Flint et al. (2015) quote Machalaba et al. (2015) who have pointed out AI hot spot areas in high altitudes in North America where birds from multiple fly routes breed together, creating "the potential for broad-scale dispersal of virus along an East-West gradient" as a result (Flint et al., 2015, p. 3). International bird migratory routes in Europe are made up of the Black Sea - Mediterranean flyway, the East Atlantic flyway, and partly the East Africa West Asia flyway. As can be seen in Figure 2, these flyways in Europe also overlap in areas, especially in Siberia in Russia. Here, an exchange of virus material between different flight routes is possible and highly likely (Flint et al., 2015). Olsen et al. (2006) point out that the flight routes shown are simplifications, and some bird populations can in fact behave differently.

Many avian species are susceptible to the 18 subtypes of influenza. In the class of Aves, Anseriformes, Charadriiformes, Procellariiformes, and Galliformes are susceptible to influenza viruses. Most relevant for the international poultry community is domestic poultry belonging to the family of Galliformes, notably chicken and turkey. Ducks, geese, and guinea fowl that are of economic importance around the globe (USDA, 2015c) can however also be affected by the virus. Influenza A viruses exist in highly complex networks among different bird species, while wild waterfowl are proven to be the main host and multipliers of influenza A viruses (Unger et al., 2008). The FLI states that it is plausible that generally all avian species

Figure 2

International flight routes of wildfowl
Source: Olsen et al. (2006)



are potentially susceptible to influenza A viruses, with a wide range of different clinical outcomes ranging from no symptoms at all, to a 100% mortality rate (FLI, 2017a). The H5N8 virus for example has shifted and changed through the interaction with other circulating LPAI viruses, thereby creating new viruses with new characteristics (Hall et al., 2015). The different strains of the virus have changing effects on the diversity of species. For instance, the H5N2 virus that was present in the 2014-2015 outbreak seemingly had a more severe effect on turkeys than on chickens (USDA, 2016d).

2.4 Cross-species infections and zoonotic potential

One of the major challenges of HPAI is its zoonotic potential. Earlier outbreaks have shown that some HPAI strains indeed have crossed the species barrier and caused human fatalities. The potential for cross-species infection has major economic implications, and is therefore important to consider in an economic analysis. This section summarizes the relevant information on this topic.

Influenza type A viruses are generally host-specific to humans, pigs, horses, and poultry (Suarez, 2016). The longer a virus circulates in a species, the more host-speci-fic this virus will become (Suarez, 2016). Although the likelihood of a cross-species infection decreases over time, cases have in fact shown that it still occurs (Suarez, 2016). Experience has also shown that human infections generally take place through very close contact to live or dead birds (Perdue & Swayne, 2005); the consumption of sufficiently cooked poultry products will not result in infections in humans (Carver & Krushinskie, 2006). Carver and Krushinskie (2006, p. 4) believe that "the farming practices and culinary customs unique to Asia" are the reason why the majority of all fatal human HPAI cases have so far occurred there. In humans, Avian influenza viruses manifest themselves with differing severity. Mild infections only involve mild conjunctivitis or minor respiratory diseases. More severe infections in humans include a high fever and cough (WHO, 2016). Symptoms such as diarrhea, vomiting, abdominal pain, bleeding from the nose and gums, chest pain, and further complications such as hypoxemia and multiple organ dysfunctions have been seen in patients as well (WHO, 2016). During the 2003 Dutch outbreak of an HPAI H7N7 strain, a 57-year-old veterinarian fell victim to acute respiratory distress syndrome that could be traced to the H7N7 virus (WHO, 2003). The WHO (2016) further notes that the fatality rate of influenza A viruses of the subtypes H5 and H7N9 is higher than standard human seasonal influenza infections. Capua and Marangon (2006) furthermore see increasing potential for pandemics arising through a new mutation that would create a permanent avian-human link. Blayney et al. (2006) agree with this assessment, warning of a human pandemic if an HPAI virus mutates and becomes transferable from human to human. HPAI subtypes H5N1 and H7N9 are known to cause severe infections in humans, while subtypes H7N7 and H9N2 have been found in humans with mild or subclinical symptoms in most cases (WHO, 2016). If an avian influenza virus has cross-species potential, especially if it has zoonotic potential, the economic impact of an outbreak is potentially more significant, especially in terms of international meat trade (Morgan & Prakash, 2006). Along with HPAI H5N1, this is also the case for BSE infections (Morgan & Prakash, 2006).

Blayney et al. (2006) define three factors that help determine the severity of a disease's outbreak. Along with imports and exports, cross-species pathogeny affects economies. With the possibility of a zoonotic development, a disease's outbreak is not limited solely to the poultry industry, but extends to the general public as well (Sugiura, 2013). Reports of a zoonotic disease often result in decreases in demand for poultry, with corresponding impacts to the industry. This relates directly to food scarcity effects, which are discussed in more detail below.

Liverani et al. (2013) see animal health and biosecurity as being under constant threat. As long as private businesses seek to improve their market status, there is an ongoing incentive to disinvest in security measures and “engage in risky practices” (Liverani et al., 2013, p. 874). Stakeholders have recognized this problem, and have started to regard global health issues as a combined effort to combat both human and animal diseases. Narrod et al. (2012) see the need for collaboration between human and veterinary medicine here, especially in developing countries. Lee and Brumme (2013, p. 1) state that a so-called “One Health” approach “calls upon the human, animal, and environmental health sectors to cross professional, disciplinary and institutional boundaries, and to work in a more integrated fashion”. The occurrence of zoonotic diseases makes One Health concepts mandatory, especially in light of the fact that outbreaks cause major economic shutdowns (Dhama et al., 2013). The interaction between domestic and migratory birds and their primary role in disease transmission between the two species has also been recognized by Dhama et al. (2013).

In sum, the possibility of cross-species human infections has elevated HPAI to a disease of primary international concern. Not only does HPAI cause significant damage to livestock populations; today it is a constant high-potential threat to humans. This two-fold threat causes significantly higher economic impacts upon outbreak compared with a non-zoonotic disease limited to livestock species.

The previous section discussing zoonotic viral potential is directly linked to the statements in this chapter. Food scarcity and spillover effects are a primary consequence of the zoonotic potential of HPAI.

The occurrence of a potentially zoonotic disease has received intense public attention. An aversion to purchasing poultry products in times of HPAI outbreaks has been noted in the past, leading to increased prices in other meat sectors such as pork or beef (Burgos & Burgos, 2007). Brown et al. (2007, p. 343) refer to this as “consumer shifts to substitute products”. However, Brown et al. (2007) also note that substitute products and industries can fall victim to a negative demand effect as well. These effects can be noted even in countries without an outbreak. “Media coverage of HPAI risks and foreign outbreaks can reduce poultry demand even prior to discovery of domestic cases [...]”(Beach et al., 2007). This has been observed in both developed and developing countries, with consumption decline ranging from 20 to 70 percent (Moore & Morgan, 2006). Paley (2008) describes this as a food scarcity effect, and shows that it is statistically significant even in subsequent years following a viral occurrence. In a study to show lasting effects, Allais and Nichèle (2007) used a Markov model to highlight changes in French meat and fish demand. The results showed that a first BSE crisis in 1996 disrupted demand for almost three years, while the following BSE crisis impacted demand for only four weeks. Beach et al. (2008) showed that a high amount of news coverage about bird flu could potentially be linked to decreasing demand for poultry products. Their study examined H5N1 migration from Asia to Europe from 2004 to 2006. Demand impacts here did not persist, and declined again after a period of five weeks.

Little is known about demand shocks and the perceived public appeal of vaccination strategies in disease situations. Bergevoet et al. (2007) completed a study on the perception of different vaccination strategies during CSF outbreaks which included a consumer questionnaire. Their results show that products of animal origin with a link to vaccination were regarded as positive concerning animal welfare, and negative when it came to quality and taste. Longworth et al. (2012) state that the actual public acceptance of vaccination campaigns is unknown due to lacking empirical evidence on this specific topic.

In addition to demand shocks that affect the poultry industry, other non-related sectors such as tourism can be affected. This is referred to as “spillover effects” by Bergevoet and van Asseldonk (2013). Especially during the time of an ongoing outbreak, “tourism and other services in a member state may be confronted with reduced incomes” (Bergevoet & van Asseldonk, 2013).

These findings show that economies are in fact influenced by potential zoonotic infection and the considerable disruption of demand that sometimes results from it. HPAI thoroughly raises concern among consumers, which is amplified by news coverage of the topic. Along with the poultry industry itself, other non-related industries such as tourism can be affected as well.

3 Background Literature

This research is part of the scientific field of agricultural geography. This chapter illustrates its historic development and how agricultural geography should be perceived today. In addition, it explains the concept of human-animal studies, a subcategory of agricultural geography. Because a large part of this research is also an economic analysis, a respective examination of the work in the scientific field of animal disease economics is provided as well.

3.1 The science of agricultural geography

Before and during the 18th century, geography was not yet a scientific discipline by itself, but instead seen as an intermediary discipline. An issue in the scientific field of geography always was that several other disciplines encompass critical information for use in geographic analysis. Hartshorne (1958) of the University of Wisconsin specified this problem in his essay "The Concept of Geography as a Science of Space, from Kant and Humboldt to Hettner" in 1958. He noted that, independently of each other, Kant and Humboldt were the first to specifically point out that geography should be considered an independent and distinct institution of modern science. Hartshorne (1958) pointed at the introductory course in geography given by Kant in Königsberg during the late eighteenth century in which Kant noted the difference between the science of history and geography. Hartshorne (1958, p. 100) cited Alexander von Humboldt with the following: "Thus zoological history, the history of plants, and the history of rocks, which tell only the past state of the earth, are to be clearly distinguished from geography".

The German geographer Hettner further remarked in his 1905 essay *Das Wesen und die Methoden der Geographie* that the scientific community must be sure to apply the concept of labor division. This would ensure orientation in the wide variety of new scientific fields (Hettner, 1905), and for him was the reason why geography must be an independent field of future study. While the establishment of geography as a scientific field began during this time, the development towards more distinct subcategories of geography, especially agricultural geography, started later. In Germany, crucial contributions to a better understanding of agricultural geography were made by Johann Heinrich von Thünen, Albrecht Thaer, and most importantly Thies Hinrich Engelbrecht (Sick, 1983). Engelbrecht today is considered one of the first and most critical agricultural geographers of his time. He lived in Sioux City, Iowa in the USA for several years to improve his understanding of spatial processes, which is believed to have influenced him significantly (Waibel, 1935). In his work, Engelbrecht structured the world based on agricultural statistical data and was able to work out a total of 76 detailed agricultural maps of the world between 1882 and 1890 (Waibel, 1935). In the Anglo-American scientific community, Baker (1923) completed comparable work with a distinct focus on maps of North America.

Erich Otremba further shaped the scientific understanding of agricultural geography in Germany. In his 1960 book *Allgemeine Agrar- und Industriegeographie* he described agricultural geography as an integral part of economic geography (Otremba, 1960), demanding a "synthetic view" of the whole economy in a spatial system, within which agricultural geography and industrial geography cannot be separated (Otremba, 1960). Today, agricultural geography is accepted as part of economic geography within the broader field of general geography (Klohn & Voth, 2010; Ruppert, 1984). In his pioneering book, Otremba (1960, p. 21) further supported the notion that both industrial and agricultural systems build upon each other.

Furthermore, these two categories coexist symbiotically. The main difference between agricultural and industrial systems in the eyes of Otremba was the fact that in agricultural systems, natural circumstances such as climate, soil, and weather significantly influence the outcome of the system. Industrial spaces on the other hand are mostly influenced by economic, i.e. human-influenced regularities (Otremba, 1960, p. 21). Both systems nonetheless follow commercially-driven and market-based ideas and respectively shape the spaces in which they exist (Otremba, 1960, p. 21).

Andreae (1977) built on the work of Otremba, describing in greater detail the relationship between agricultural geography and neighboring disciplines. He referred to this as *Grenzwissenschaft* (Andreae, 1977), meaning that agricultural geography is situated on the border of many more scientific fields. Disciplines such as economic geography, agricultural economics, animal and plant geography, climatology, sociology, ethnology, culture geography, and several others from this perspective are an integral part of an agricultural geographic study. This multitude of disciplines is also the reason why no book is fully able to cover every aspect within this scientific field (Andreae, 1977). Despite this multitude of disciplines with sometimes differing research objectives, agricultural geography never stood in opposition or competition to its neighboring disciplines, but in a complementary position instead (Borcherdt, 1996). Whatmore (1993) extends this finding further, adding that agricultural geography even added value and depth to the understanding of neighboring disciplines.

From a more general perspective, Ruppert (1984) stated that agricultural geography is a typical example of anthropogenic scientific geography. The spatially sectored human interaction and utilization of the landscape always was an essential element of agricultural geography (Ruppert, 1984). Starting in the 1970s, social geography influenced agricultural geography and directed attention towards the effects of specific social groups on the spatial agricultural system (Klohn & Voth, 2010). Klohn and Voth (2010) names Morgan and Munton (1971) as representatives of these so-called "behavioral approaches". More modern takes on agricultural geography consider the agri-food chain, which takes into account local agricultural supply chains as they are impacted by globalized markets and trade (Klohn & Voth, 2010).

3.2 Agricultural geography: A definition

Over time, many different definitions of agricultural geography were developed by geographers. Hettner (1905) stated in 1905 that geography is a chorological science of the earth's surface. According to him, geography considers the earth's surface in terms of its spatial differences (Hettner, 1905, p. 10). Agricultural geography as a subcategory of geography was defined by Sick (1983) among others as a spatial science. Here the research objective is the analysis of the earth's surface created and changed through agricultural land use. In 1984, Bowler stated that agricultural geographers try to "classify space by identifying agricultural regions" (Bowler, 1984, p. 256). Following Bowler (1984), the methods for this classification became more and more sophisticated over time. More recently, Urbanik (2012) has defined agricultural geography as a science that analyzes why things are the way they are, where they are. This formerly narrow definition was later expanded upon to include a broader range of topics. Klohn and Voth (2010) and Borcherdt (1996) for instance clarify that agricultural geography must also include an economic and spatial analysis.

The most comprehensive definition for agricultural geography was given by Windhorst (Windhorst, 1989, p. 147):

"Agricultural geography is the scientific field of structure, function and spatial prevalence and organization of agricultural production and the processing of animal and non-animal agricultural products. Agricultural science thrives on understanding economic activities in their change over time, to understand processes of regionalization and thrives to describe spatial models that derive of the before mentioned activities."

This definition by Windhorst is open to new research topics in the field of agricultural geography. Modern agricultural geography should also make connections with non-agricultural topics (Borcherdt, 1996). Borcherdt (1996) names climate change, global disease phenomena, and changing consumer preferences as new factors that influence agricultural spatial and economic spaces. Klohn and Voth (2010) adds the structural change in agricultural communities, globalization, agricultural policy impacts, and increasing environmental problems in areas with high animal husbandry density to the list of pressing topics in agricultural geography. These new topics are also covered in the definition by Windhorst.

3.3 Human-animal studies

The field of human-animal studies has developed independently from agricultural geography. It can be understood as a sub-category of animal geography. Although the topic of animal studies became relevant as early as 1939 (Philo & Wilbert, 2004), early studies limited the significance of animals to their economic value (Yarwood & Evans, 2000). Today the relationship between humans and animals in a rural spatial environment is more critical (Yarwood & Evans, 2000). Urbanik (2012) states that humans have a significant effect on the environment and on animals within this environment as well. This means that an agricultural geographic analysis must always include an analysis of the human-animal relationship (Urbanik, 2012). Philo and Wilbert (2004, p. 2) quote Cockburn (1996) and Cole and Ronning (1974) who go so far as to state that the relation between animals and humans is so close that animals are "undoubtedly constitutive of human societies in all sorts of ways". Animals are sources of food, clothing, and are furthermore "materials which sustain our human existence" (Philo & Wilbert, 2004, p. 3). Philo and Wilbert's remarks are complemented by three key points by Urbanik (2012) that point out additional truisms about the human-animal relation: "First, the boundary between human and animals is not consistent. [...] Second, animals are much more than background to human lives only to be acknowledged intermittently. [...] Third, who and where you are as a human in the world shapes the type of interaction you will have with different species."

The context of geography and animal studies is more concisely defined by Yarwood and Evans (2000) through their analysis of animal breeds across the globe. There is a definite "association between breeds, place, and culture" (Yarwood & Evans, 2000, p. 100). Every time human migration has happened, animals have migrated along and were correspondingly adapted to new surroundings and demands. The analysis of this past co-development is an integral part of human-animal studies (Yarwood & Evans, 2000).

3.4 Animal disease economics

This chapter describes the method used to define economic impacts of animal diseases. There are several categories of impacts that will affect various stakeholders to differing degrees of severity at different times of an outbreak. A detailed pre-definition of these categories is vitally important to enable comparability and understanding of the analysis approach. This chapter is divided into three parts. The first section discusses general theory of disease impacts. The second section discusses the definition of economic impacts, while the third describes the impact definition approach used for this study.

The principles of animal disease economics are rooted in basic economics. This chapter highlights the interrelationships between basic economic principles and disease management economics. Economic goals are defined by each economic individual or organization who formulate aspects such as performance, financial, organizational, social, and ecological goals (Thommen & Achleitner, 2006). This is equally true for economic organizations and individuals in farming and its related secondary industries. Farm economics, although a subcategory of business economics, deals with the same issues as in conventional business economics. This includes for example optimal resource allocation, opportunity costs, diminishing marginal returns, and the concept of externalities (Nellis & Parker, 2006).

During disease outbreaks, these principles come under pressure and change for the duration of the outbreak, in some cases even for prolonged periods after it is over. Otte et al. (2004) have described the most important and basic disease effects on farm economics. Table 3 (p. 30) provides an across-the-board overview of these effects, which include impacts on production, prices and markets, trade, food security and nutrition, health and environment, and financial aspects. Beach et al. (2007, p. 471) generally agree with this list and

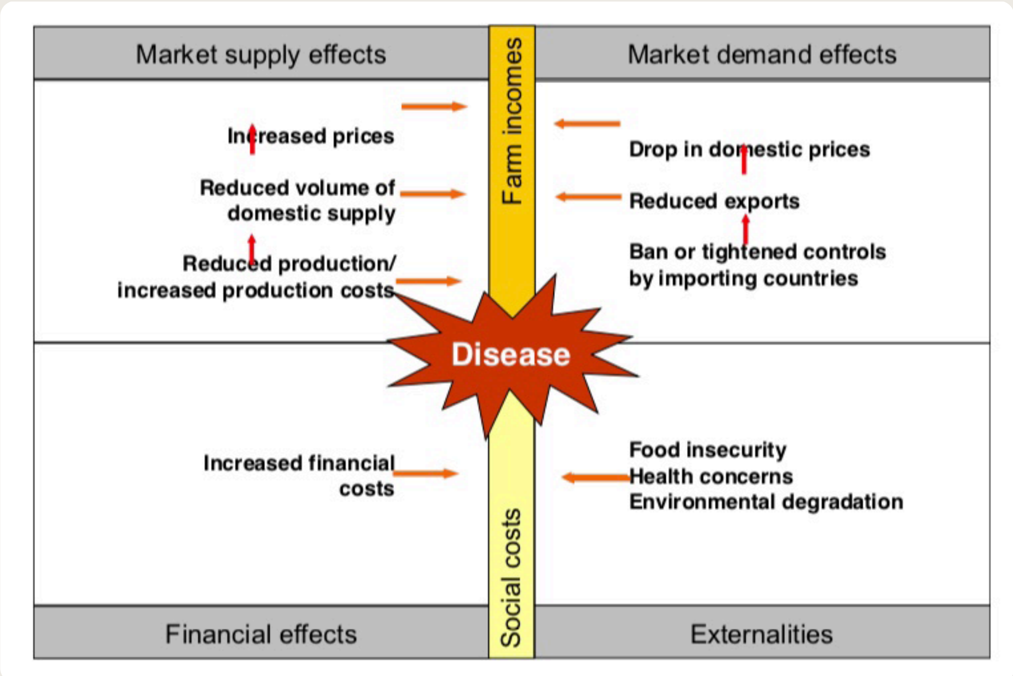
Table 3

Disease effects on farm economics
Source: Own adaptation with information of Otte et al. (2004)

Aspect	Impact of disease	Result
Production	Loss of or reduced production efficiency	Reduction in farm income
Price and market effects	Variations in the price for farming commodities depending on relative market elasticities	Variations in wages for farms and their employees
Trade	Import/export restraints	Loss of sales/markets in foreign markets
Food security and nutrition	Loss of important food supply (in developing countries)	Civil unrest and famines in developing countries
Health and environment	Transmission of disease from animals to humans (if zoonotic)	Avoidance behavior, human casualties
Financial	New budgetary expenditures for control measures and reimbursements	Permanently increased budgets for inspections, monitoring, and prevention

Figure 3

Disease effects on market supply and demand, financial effects and externalities
Source: Otte et al. (2004)



state that "infectious animal diseases represent a major threat to agriculture and can impose significant social and economic costs".

Figure 3 builds on Table 3 and further elaborates upon how a disease outbreak has implications for basic economics. Figure 3 by Otte et al. (2004) is a schematic overview of the disease effects on market supply, market demand, financial aspects, and externalities. Market supply effects of a disease outbreak include increased prices, a reduced volume of domestic supply, reduced production, and increased production costs. Market demand effects include drops in domestic prices, reduced exports, and bans or tightened controls by importing countries. Financial effects comprise financial costs. Externalities include food insecurity, health concerns, and environmental degradation.

An animal disease outbreak which only affects parts of the farming/animal husbandry sector can falsely be believed as being of only minor significance because only the farming sector is affected. Beach et al. (2007) clarify that disease outbreaks can nevertheless represent a significant threat to the overall economy. The global HPAI phenomenon of the H5N1 strain that spread across Asia, Europe, and Africa caused significant losses to the general economy in countries on almost every continent. The follow-up investments by private and public sectors to prevent and control future outbreaks were massive (Beach et al., 2007). Economics thinking therefore makes it very rational to work to prevent animal disease outbreaks instead of merely waiting for disease effects to lesson by themselves (Otte et al., 2004).

Economists have defined the economic man (Nellis & Parker, 2006) which represents a fundamental principle of economic behavior in a market environment. The description of the economic man was broadened later, with scientists adding irrational behavior based on emotions to the concept. People and organizations affected by animal disease outbreaks presumably make rational decisions as extensively as possible to avoid economic disadvantages. At the same time however, these same people and organizations experience strong emotions such as panic and shock. Beach et al. (2007) emphasize that for this particular reason, the behavior and emotional patterns of market participants are equally important to consider. Upton (2009) emphasizes that in order to understand economic decision making in an outbreak situation, it is vital to consider the affected people on all levels of the value chain. This makes it the duty of the field of economics to forecast the rational and irrational behavior of market participants, and make provisions in policy accordingly. Doing this allows animal disease economics to guide market participants who are affected by the disease, as well as the policymakers who are engaged in disease management (Upton, 2009). Upton (2009) further makes plain that in the context of animal health and production economics in farming, the main principle is not money, but instead rational choices/decisions in the allocation of scarce resources for the achievement of competing goals.

In the context of agricultural geography, authors point to the importance of agri-statistical data. Gregory (2014) states that geographers must present valid data with a sufficient quantitative basis, mainly when geographers cooperate with other disciplines. Bowler (1984) approves of this statement, while at the same time indicating that land use and agricultural census data often do not fulfill quality and reliability standards. Klohn and Voth (2010) adds that, frequently, data privacy concerns, comparability, or a lack of data in general hamper a geographer's work. Rushton et al. (1999) see valid data as a critical component of meaningful economic assessments.

Basic theoretical concepts are explained in this section. First, a microeconomic perspective is taken on the impact of a disease, followed by an exploration of a macroeconomic perspective. There are also additional aspects that are worth special consideration in the context of impact analysis, i.e. the importance of the international poultry trade, the spatial dimension of an outbreak, the zoonotic potential of a disease, and food scarcity and spillover effects.

3.4.1 Microeconomic perspective

This section focuses on the microeconomic perspective of a disease outbreak. It shows which theoretical processes take place on production levels, using a figure to break down the processes.

Figure 4

The effect of disease on livestock production
Source: Bennett (2003)

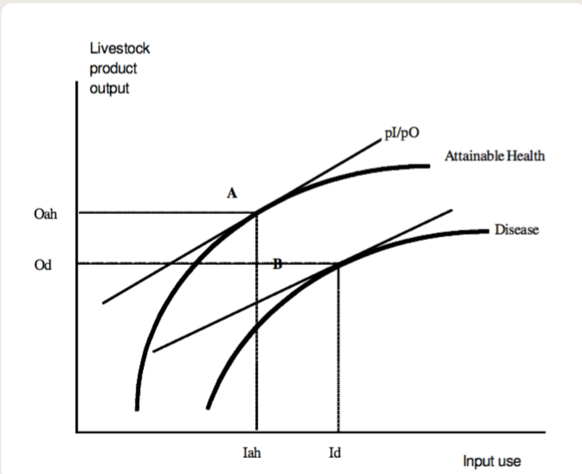


Figure 5

Impact of a disease in a closed economy
Source: Upton (2006)

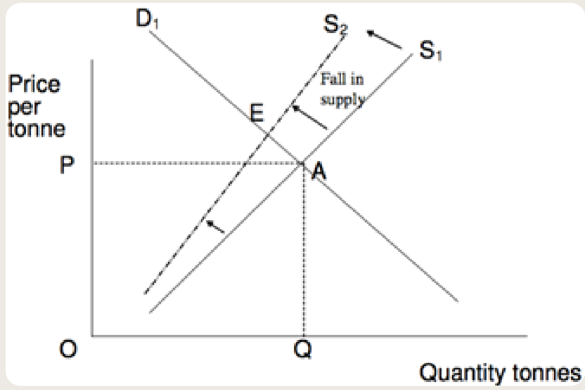


Figure 4 shows livestock production output on the y-axis, and the x-axis under the constraint of input use. The attainable health curve depicts production under disease-free circumstances. The term “attainable health” constitutes how in realistic circumstances, even if there is no active disease pending, there are always factors that prohibit flocks from performing optimally. Based on experiences with previous flocks, it’s possible to define a production curve with attainable production parameters under normal constraints. Point A depicts the optimal equilibrium between the use of inputs and respective livestock product output. In the case of an HPAI disease outbreak, the amount of input increases while at the same time livestock product output decreases. In a realistic situation, these two effects do not necessarily become proportionally effective. Depending on the situation and the immediate reaction to a disease, it is conceivable that the input use does not change at all, while livestock product output drops. Either way, a new curve must be drawn for a disease situation, described as the disease curve in figure 4. The new equilibrium here between input use and livestock product output (B) is below the former equilibrium (A).

Here it’s seen that the microeconomic effect of a disease outbreak manifests itself in decreased livestock product outputs or increased input use. If details are available, these numbers can be calculated in monetary terms for each farm. This is a strictly theoretical approach, as in a realistic situation there are several additional effects that must be considered. On some farms, production will halt completely to allow thorough mitigation measures, whereas other production facilities that are not affected directly will continue to produce at regular output levels. The latter will experience impacts based on e.g. movement restrictions or failing markets.

3.4.2 Macroeconomic perspective

While the previous section detailed the effects on the farm level, this section summarizes HPAI outbreak effects from a macroeconomic perspective. Market impacts are modelled under the assumption of closed and open markets. Figure 5 shows the impacts of a disease in a closed economy.

The quantity of available goods in tons is represented on the x-axis, while the respective price per ton is shown on the y-axis. The demand line D1 shows the development of demand in relation to quantity and price. The supply line S1 displays

Figure 6

Impact of disease in a closed economy
Source: Upton (2006)

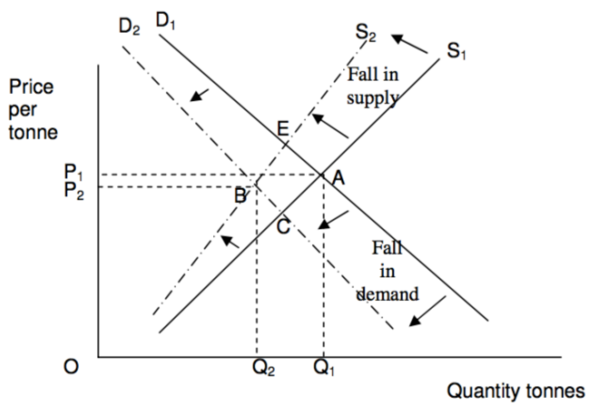


Table 4

Summary of overall market impacts of HPAI
Source: Upton (2006, p. 8)

Country status	**Market impacts**				
	Production	Consumption	External trade	Price	Preventive controls
AI outbreaks No trade	Losses from mortalities and culling. Later restocking & recovery	Food safety fears cause a decline. Demand may recover later if HPAI controlled.	None	Lower if fall in demand exceeds fall in supply: Rises if fall in supply exceeds fall in demand	May be intensified in view of outbreak
AI outbreaks Net importer	Ditto	Ditto	Imports adjusted to meet change in excess demand	Domestic price remains stable	Ditto Greater need to protect borders
AI outbreaks Net exporter	Ditto	Ditto	Export markets closed: trade bans	Domestic price likely to fall with exports lost	Ditto Limited by need to be 'disease free
Disease free Net importer	May respond to decline in demand	Ditto Effect may be smaller without outbreaks	Imports adjusted to meet change in excess demand	Domestic price remains stable	Need to protect borders
Disease free Net exporter	Response to changing world prices.	Ditto	Exports may expand as others face export bans.	Domestic price influenced by	Ditto Limited by need to be 'disease free

development of supply under the same constraints. Intersection point A displays market equilibrium where the supply and demand curve meet, constituting the current price and quantity level in a no-disease situation. When HPAI occurs, it will result in loss of birds, hence the decrease in supply. Supply curve S2, supply under the constraint of a disease outbreak, depicts this effect. Point E represents the new equilibrium price and quantity under the assumption that demand remains unchanged. This offers the conclusion that a disease outbreak theoretically results in higher prices. Under realistic circumstances, however, this barely is the case. If at the same time the demand decreases due to evasive behavior, price change will be negative. Figure 6 (p. 33) displays this two-fold effect.

If both supply and demand decrease become effective at the same time, the new market equilibrium price is the new intersection point B. It can be seen that both effects counteract each other. Depending on which effect exerts stronger influence, price and quantity are higher or lower respectively. Kamina Johnson (2017, p. 5) states that "the interaction between demand shocks and supply shocks drive the price results in each quarter". Prior to an outbreak, predictions about price and or quantity change are not possible due to this uncertainty in several different areas (Upton, 2006).

The above-mentioned principles are basic macroeconomic assumptions regarding a closed market. The poultry markets in the USA and Germany are on the contrary open markets and compete on international markets as well. So the interaction with international demand and supply settings necessitate further differentiation. Upton (2006) explains that increased imports generally can be used to replace declining domestic supply, and decreased imports can be used to account for a lower domestic demand. When domestic demand declines during HPAI outbreaks, the natural alternative is to shift more products to the export sector. This however is not possible in the majority of cases because the export sector is often equally affected. Once HPAI has been confirmed by official institutions, import bans are enacted until the country has regained disease-free status (USDA, 2015b). The effects of an absence of export markets as a fall-back solution for an internal supply surplus and the suspension of all regular exports reinforce each other and result in a greater supply surplus, thus causing price drops for domestic producers. These price effects are especially destructive in countries that are heavily dependent on export markets (Van Asseldonk et al., 2005), e.g. the USA and Germany. In these countries, price effects of disease outbreaks are expected to exceed the direct losses (Van Asseldonk et al., 2005). In summary, (Morgan & Prakash, 2006, p. 519) state that diseases like HPAI provide "unprecedented challenges" for market participants and increase the complexity of the overall market.

Table 4 (p. 33) summarizes the impacts of HPAI outbreaks. The columns show how the effects differ in the areas of production, consumption, external trade, and price development. The rows point to the respective effects under the different circumstances of trade, no-trade, and disease status.

These are theoretical approaches to disease outbreaks. The reality of an outbreak is more complex. The respective impacts are as multi-faceted as the industry itself. Burgos and Burgos (2007) state that markets are influenced by internal and external forces, some of which can be controlled, while others cannot. They further state that the zoonosis HPAI is uncontrollable and unpredictable, making this fact significant in its analysis. Moore and Morgan (2006) add that although HPAI almost always surfaces as a local phenomenon, it has far-reaching consequences for international trade flows and the development of the poultry industry. A multi-continent global disease phenomenon like HPAI is not sufficiently handled by welfare mechanisms and basic economic principles alone. The multitude of affected countries, industries, and institutions, along with factors such as irrational behavior make additional steps such as qualitative analysis necessary.

3.5 The status quo of animal disease economics

The drastic economic impacts of animal diseases have strained the efforts of authorities, with the subject of animal disease economics as part of agricultural economics growing in importance over time as a result. This section describes the work of essential economists over the last decades and the application of disease economics today.

In his book *The Economics of Animal Health and Production*, Jonathan Rushton states that the subject of disease economics is relatively new in comparison with other economic subjects (Rushton, 2009). In the 1960s and 70s, governments began investing in fighting diseases such as infertility or parasitism that had high economic impacts, and that regularly occurred (Rushton, 2009). Governments developed an interest in understanding the costs of these disease eradication campaigns, which led to the development of animal health economics as a recognized field of research on par with animal disease epidemiology (Randolph et al., 2003). The economic analysis was intended to economically justify the increasing costs of efforts for disease eradication (Rushton, 2007).

Although there was a considerable amount of prior data available on animal health economics, a detailed analysis of it was not pursued until the 1960s (Rushton, 2009). Rushton (2007) describes how animal health economics developed from quantitative veterinary epidemiology. Its goal was "supporting veterinary decision making" on two levels: societal disease control programs and farm-level herd health management (Randolph et al., 2003). According to Randolph et al. (2003), the research on decision making on the societal level aims at showing the value of veterinary services, as well as at delivering an economic justification of national efforts to eradicate a disease. These objectives are achieved through the application of benefit-cost analysis, through economic surplus models, and macro-economic analysis of market and trade impacts. Randolph et al. (2003) further describes the methods of farm level decision making which was achieved through partial budgeting exercises, multi-year dynamic programing, and gross-margin and decision analysis. Two additional levels of analysis were added at later stages in the development of animal disease economics: the socio-economic behavior of actors affected during an animal disease outbreak, and the political and institutional environments (Randolph et al., 2003).

When animal health economics began to emerge in the late 1960s, universities and scientists started shaping its modern understanding. First, there was Peter Ellis and his team at the University of Reading in the United Kingdom who did extensive research on topics such as cost-benefit analysis. Richard Bennet at the same university later added additional perspectives on the topic of disease economics with a focus on UK-associated diseases. In close cooperation with (among others) Peter Ellis and Alt Dijhuizen, Jonathan Rushton has significantly contributed to the development of animal health economics. He currently works at the University of Liverpool's Institute of Infection and Global Health. Tim Carpenter and his team at the University of California in Davis added to the topic with a multitude of analytical tools. John McInerney and several team members work in animal health economics at the University of Exeter in the United Kingdom and are today credited with having introduced theoretical economics to the field of animal disease economics. Richard Bennet (mentioned above) has supported this new approach.

In the city of Wageningen in the Netherlands, Alt Dijkhuizen and fellow scientists performed a comprehensive range of research on animal disease economics at the University of Wageningen. With a focus on disease events that are relevant for Dutch markets, he applied a multitude of tools including risk analysis. Helmut Saatkamp at the University of Wageningen also contributed significantly at the University of Wageningen, with he and his team developing a comprehensive and consistent framework for animal disease impact analysis (that is partly incorporated in this thesis as well, see Longworth et al. (2014a, 2014b); Saatkamp et al. (2014)). Clem Tisdell added further understanding and research depth to the topic at the University of Queensland, advancing the work of

McInerney and his group (Tisdell et al., 1999). Tom Randolf is credited by Rushton (2007) as having introduced more complex models of analysis to the range of disease economics research which has, among other things, led to the introduction of computerized general equilibrium models to animal disease economics.

Philip L. Paarlberg is also important to mention, who has been outstandingly prolific in the subject of animal disease economics. He works at the University of Purdue's College of Agriculture where he teaches in the area of agricultural economics. Together with Ann Hillberg Seitzinger, who has worked as an Agricultural Economist at the USDA's Veterinary Services, they have published several influential papers on the economic impacts of animal diseases (see Paarlberg (2013); Paarlberg et al. (2007); Paarlberg et al. (2008); Seitzinger and Paarlberg (2016)).

Epidemiologic research complements this economic thinking. It has remained dominant throughout its development (Randolph et al., 2003), with many epidemiologists considering animal economics as mere additions to cost-benefit models (Rushton, 2007). Because there is an increasing amount of different HPAI virus strains present today, with the amount of countries affected by HPAI outbreaks on the rise, ongoing epidemiologic analysis of HPAI is crucial for increasing the effectiveness of mitigation efforts.

Although the epidemiology of HPAI is not the main objective of this thesis, some of its research and the scientists performing it ought to be mentioned. All economic analysis is based on an epidemiologic understanding of HPAI, which deems epidemiological research critical. The following research institutes and scientists have made considerable contributions to the understanding of HPAI, improving its understanding within an economic context as well.

There are a multitude of laboratories on the planet conducting comprehensive research on the epidemiology of HPAI. The most influential are described below. In the USA, the National Veterinary Service Laboratory (NVSL) is the leading institute conducting systematic and comprehensive research on the epidemiology of HPAI. It is the designated OIE reference laboratory for HPAI in the USA, as well as the FAO reference center for animal influenza (APHIS, 2015b). The NVSL is located in Ames, Iowa, and Plum Island, New York (NVSL, 2019). As part of the NVSL, Dr. Mia Kim Torchetti heads the avian viruses section, advancing research on HPAI, especially in the field of the role of migratory wild birds and the spread of avian influenza (see for example Lycett et al. (2016)). The most influential researcher in the field of HPAI is David E. Swayne, who has significantly contributed to the understanding of HPAI. He currently leads the exotic and emerging avian viral disease research unit at the Southeast Poultry Research Center which is part of the United States Department of Agriculture in Athens, Georgia. The books *Avian Influenza* (Swayne, 2009) and its second edition *Animal Influenza* (Swayne, 2016) were edited by David Swayne and have become international standard references for all major fields concerning avian and mammalian influenza.

In Europe, Stefano Marangon is divisional director of epidemiological surveillance and the department of epidemiology at the Istituto Zooprofilattico Sperimentale delle Venezie (IZVSe) in Padua, Italy (IZVSe, 2019b). The institute is an OIE, FAO, EU and national reference laboratory for HPAI and ND (IZVSe, 2018; IZVSe, 2019a). Stefano Marangon's work is leading the way in research on vaccinations in HPAI outbreak scenarios (see for example Capua and Marangon (2000, 2003, 2007a, 2007b)).

Additionally, research into the socio-economic and psychological impacts of animal disease outbreaks has been conducted. Otte et al. (2004) assessed the socio-economic impacts of transboundary animal disease in general. Further work on socio-economic impacts has been done by Katsuaki concerning BSE in Japan. Tadelle et al. (2003) researched the socio-economic function of chicken in Ethiopia. Geerlings et al. (2007) produced an FAO paper on the socio-economic impact of HPAI on households in Egypt, as did Rich and Wanyoike (2010) on the socio-economic impacts of Rift Valley fever outbreaks in Kenya.

The topic of psychosocial impacts has been researched as well. Mort et al. (2008) looked more closely at human trauma arising from virus outbreaks, publishing a paper on the psychosocial implications of the 2001 UK foot-and-mouth disease disaster, while Fasina et al. (2010) analyzed the psychosocial effects of HPAI H5N1 in Nigeria. Elbers et al. (2010) analyzed the possibilities to improve early detection for avian influenza outbreaks.

3.5.1 Spatial analysis in animal disease economics

This section focuses on the spatial dimension of animal disease economics. It shows how the spatial structure of a region can have an influence on the economic impact of an HPAI outbreak.

The importance of the spatial dimension on impact analysis was shown by among others Stegeman et al. (2004), who applied an ex-post analysis of the 2003 HPAI outbreak in the Netherlands. This study evaluated the effectiveness of the control mechanisms applied using quantification of between-flock transmission characteristics. The first outbreak occurred in the Gelderse Vallei, which has one of the highest poultry densities in the Netherlands. Stegeman et al. (2004) suggest that it would have been more effective to prevent HPAI from spreading to other poultry-dense areas, instead of preventing the spread within an area. They suggest that in a poultry-dense area such as the Gelderse Vallei, it was not possible to prevent the ongoing spread in the first place because reproduction rates of the virus were too high. This shows the particular challenges occurring in areas with a high poultry density.

Figure 7

Map showing the risk of HPAI incursion in domestic poultry; Source: Snow et al. (2007)

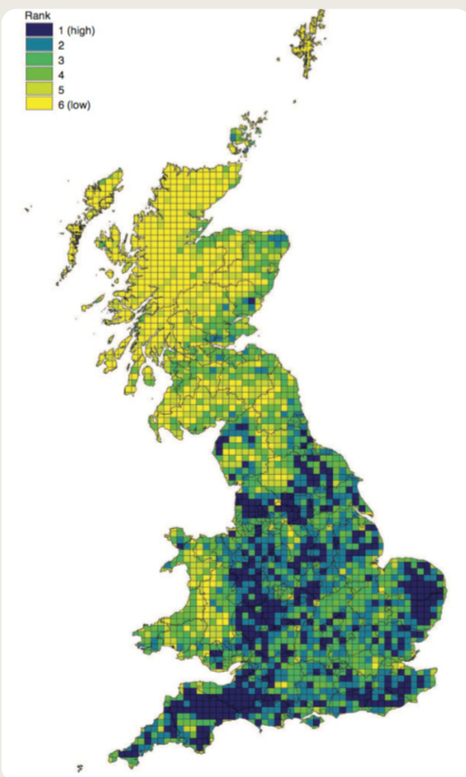
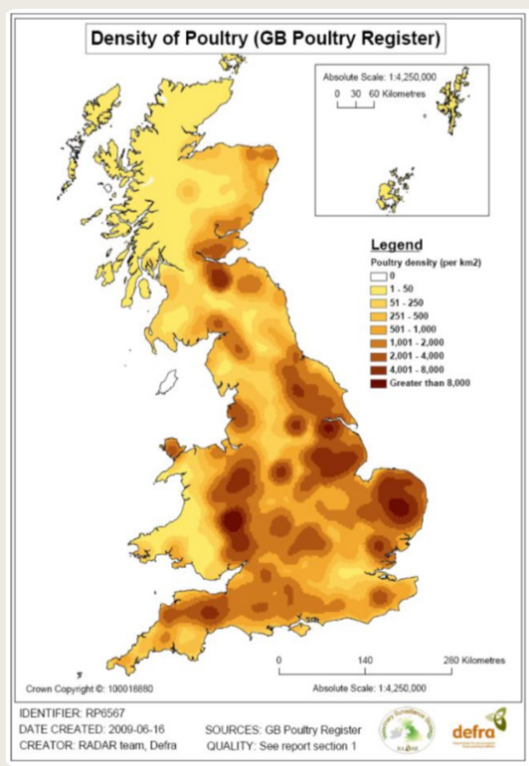


Figure 8

Density of poultry production throughout Great Britain 2009; Source: AFIT (2009)



Grabkowsky (2010) added to the research on challenges regarding the spatial prevalence of poultry, conducting a risk assessment study of HPAI infections on regional and supra-regional areas. It was the objective of this study to point out the main risk factors for an HPAI infection. Regional poultry density is a key driving factor in terms of HPAI infection risks. Using Delphi methodology, Grabkowsky (2010) conducted expert interviews and elaborated on the relative importance of poultry density in HPAI risk assessment. In the study, the experts state that along with the total amount of commercial poultry in an area, the area's amount of free range poultry significantly increases the risk of HPAI infection. Grabkowsky (2010, p. 85) also cites Snow et al. (2007), who determined the relation between poultry density in an area and HPAI infection risk. In the study, experts concluded that the risk of HPAI infection increases non-linearly as the natural log of the number of birds in the area. Additionally, free-range holdings constitute a higher risk in comparison to other forms of poultry holdings. The risk map in figure 7 (p. 37) was developed for the United Kingdom based upon these assumptions. Figure 8 (p. 37) shows a map of poultry density in the UK. Upon comparison, it's seen that areas with a high density of poultry husbandry are correlated to higher risks of HPAI infections. Once a single livestock location is infected, the chances of cross-infection with premises in direct proximity are significantly higher.

Geenen et al. (2007) added research on the contact structures of the Dutch broiler and layer farms within an HPAI outbreak perspective to these findings. The analysis of the contact structures showed that in addition to airborne spread, private contacts, direct sale of farm products, and employees potentially increase the spread of HPAI within the area. At the same time, professional contacts to/from a farm such as veterinarians who travel long distances between different farms are most likely responsible for spread to new high density areas. Specifically, in the 2003 HPAI outbreak in the Netherlands, the joint use of vehicles, technical equipment, and employees was presumed as increasing the rate of infection in the high density area of Gelderse Vallei (Geenen et al., 2007).

These findings show that outbreaks in high density areas have higher potential economic impacts. The proximity of other poultry facilities, and as a consequence the increasing risk of infections, clearly illustrates the significance of a spatial dimension in the analysis of these impacts.

4 Qualitative Research Methods

This chapter defines the methodology of the research. The economic impact assessment requires quantitative data that in turn allows for quantitative analysis. As introduced in chapter 1, this research also includes a field study in parts that include expert interviews, which are typical for qualitative research (Mey & Mruck, 2010, p. 231). This chapter describes both quantitative and qualitative research and defines the respective methods, also showing how the qualitative information benefits the quantitative research. The qualitative research is extensively defined to ensure comparability and avoid arbitrariness. Additionally, some thought is given to the distinction between an ex-ante and ex-post perspective.

4.1 Ex-ante vs. ex-post analysis

Ex-ante analysis of disease impacts works to predict the severity of future outbreaks under defined circumstances. The results of ex-ante analysis studies generally vary significantly. This is related to the differing pre-defined circumstances that rely on past observations and on data from previous outbreaks. In other words, the assumptions made for future outbreaks will always be hypothetical. According to Burgos and Burgos (2007, p. 1006) "The unfathomable nature of random events tells us that the past cannot predict the future, but useful lessons can be drawn from it". Reliable predictions of future outbreak scenarios are challenging and imprecise at best. For policymakers, an ex-ante analysis is promising in terms of future planning, while keeping in mind that the significant variance in its results has to be taken into account.

Ex-post analysis strives to recreate past outbreaks and describe the impacts of the events. Because the analysis is based on past outbreaks, it achieves its detailed impact breakdown in hindsight. Available data is here used to understand the impacts a past outbreak has had; predictions of future developments are generally not the primary goal. In addition, policymakers use ex-post analysis to understand the severity of a past animal disease and the importance of control measures.

4.2 Quantitative and qualitative research

Statistical and geographical data is used in this thesis to describe two major HPAI outbreaks in developed countries with a highly developed agricultural industry and well-funded public sector. This means that statistical data is widely available, allowing for a detailed quantitative analysis within a defined framework.

To validate the quantitative results, experts from the different industries in both countries were consulted for expert interviews, which belong to the field of qualitative research. Mayring (2016, p. 19) constitutes that quantitative and qualitative research complement each other. If qualitative verification is neglected, distorted results may occur (Mayring, 2016, p. 19). Although generic economic data provided by quantitative analysis leads to conclusions about changes in welfare or prices, it is not able to "incorporate structural change such as any rationalization of an industry arising from a disease event" (OECD, 2013, p. 54). This indicates that there is sound value in expert knowledge and experience, and ultimately in combining quantitative and qualitative data.

Qualitative research is relatively new, especially in the field of geography. Several qualitative research methods have been developed in recent years (Mayring, 2016, p. 65). Kruker and Rauh (2005, p. 19) note that qualitative research has commonly been applied in geography since the 1980s, and has unintentionally been used ever since. Geographical research has in fact always been based on the locals' knowledge of their particular geographical location. Mey and Mruck (2010, p. 226) summarize the works of Denzin and Lincoln (2005) and (Ross, 1996) who explained the history of qualitative research further. Qualitative research had a period of significance most notably from the 1970s until the 1990s. This on the other hand provoked sharp criticism regarding its viability. Qualitative research was depicted as arbitrary, and helped lead to the so-called "science wars" (Ross, 1996). Scientists as a result developed a mixed methodology in which qualitative and quantitative data could be combined provided that the process was accurately standardized (Mey & Mruck, 2010, p. 227).

Qualitative research is suitable for both gaining an overview of the topic and for validating results (Kruker & Rauh, 2005, p. 65). It is the goal of this thesis to incorporate both functions into it. Using any form of qualitative research demands pro-per attention by the author. Mayring (2016) says that today, the key challenge is defining the method of qualitative research as precisely as possible. The exact definition and description of the applied qualitative research enables readers and follow-up researchers to later reproduce its results. The procedures of the qualitative research applied have to be comprehensive to the audience and follow strict guidelines and structures (Mayring, 2016, p. 65). This allows subjective information gained through expert interviews to be objectified, which in turn permits the application of the results in combination with quantitative data. Mattissek, Pfaffenbach, and Reuber (2013, p. 35) note that qualitative research design and the results thereof have to be replicable and accountable. And in practice, the results of qualitative research in previous years could in some cases not

Table 5

List of supporting institutions for research
Source: Author

Germany
Animal Disease Notification System* (ADNS)
Niedersächsisches Landesamt für Verbraucherschutz und Lebensmittelsicherheit (LAVES)
Tierseuchenkasse Niedersachsen (TSK Niedersachsen)
Gesellschaft für Seuchenvorsorge (GESEVO)
Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz (ML)
Bundesministerium für Ernährung und Landwirtschaft (BMEL)
Niedersächsische Geflügelwirtschaft Landesverband e.V. (NGW)
Landkreis Cloppenburg
USA
Animal and Plant Health Inspection Service (APHIS)
United States Department of Agriculture (USDA)
Minnesota Poultry Testing Laboratory (MPTL)
Iowa Department of Agriculture and Land Stewardship
Iowa Poultry Association (IPA)
Center for Food Security and Public Health (CFSPH)
National Veterinary Service Laboratory (NVSL)
The Food Industry Center, University of Minnesota
Minnesota Department of Agriculture
International
Office International des Epizooties OIE (World Organisation for Animal Health)

*The European ADNS is operated by the European Commission be compared to other qualitative research, as methods and their application differed greatly (Mayring, 2016, p. 15).

4.3 Desk research

Gathering empirical data for quantitative analysis along with sources of background information was performed via desk research for this study. The literature review and the methodology's definition were also done using desk research. The library at the University of Vechta and its adjacent international digital databases, the literature database of the WING Institute, as well as other publicly available literature databases provided information to complete the literature review. Table 5 (p. 40) shows the governmental and non-governmental institutions that provided support during the research. These contributed data, content-related information, or general guidance on the thesis' topic.

4.4 Field research: Expert interviews

The field research within this thesis was conducted in Germany and the USA regarding the HPAI outbreak. Professionals from all parts of the poultry value chain, from governmental institutions, non-governmental organizations (NGOs), and associations were contacted. A total of 21 interviews were conducted in the USA and 15 in Germany. Gathering qualitative information using interviews is a well-accepted method (Mey and Mruck (2010)), and differing methods of interviews are available.

Interviews are used to understand arguments, reasoning, and background implications of problems (Mey & Mruck, 2010, p. 432). "Opinions, arguments and personal experience are the main focus" (Kruker & Rauh, 2005, p. 62). Different interview formats have been defined and applied. Examples among others include narrative, narrative biographic, ethnographic, focused, subject-centered, person-centered, problem-centered, semi-structured, confrontational, and expert interviews (Mey & Mruck, 2010, p. 424 ff.). The central objectives of the thesis focus on the analysis of two HPAI outbreaks, hence the topics for the interviews were pre-defined, helping to identify problem-centered interviews as the choice approach for the field research. All conversations during the interviews were guided towards the topic of the HPAI outbreaks and the professional experience of the experts. Furthermore, the interviewer could actively structure the conversation and validate his/her understanding by checking back with the interviewee (Mey & Mruck, 2010, p. 425 ff.)

Mey and Mruck (2010) define an expert by making a distinction between common and specialized knowledge. Common knowledge is available to everybody, whereas specialized knowledge can only be acquired by professional experience in the area in question. The choice of experts is defined more closely in chapter 4.4.4.

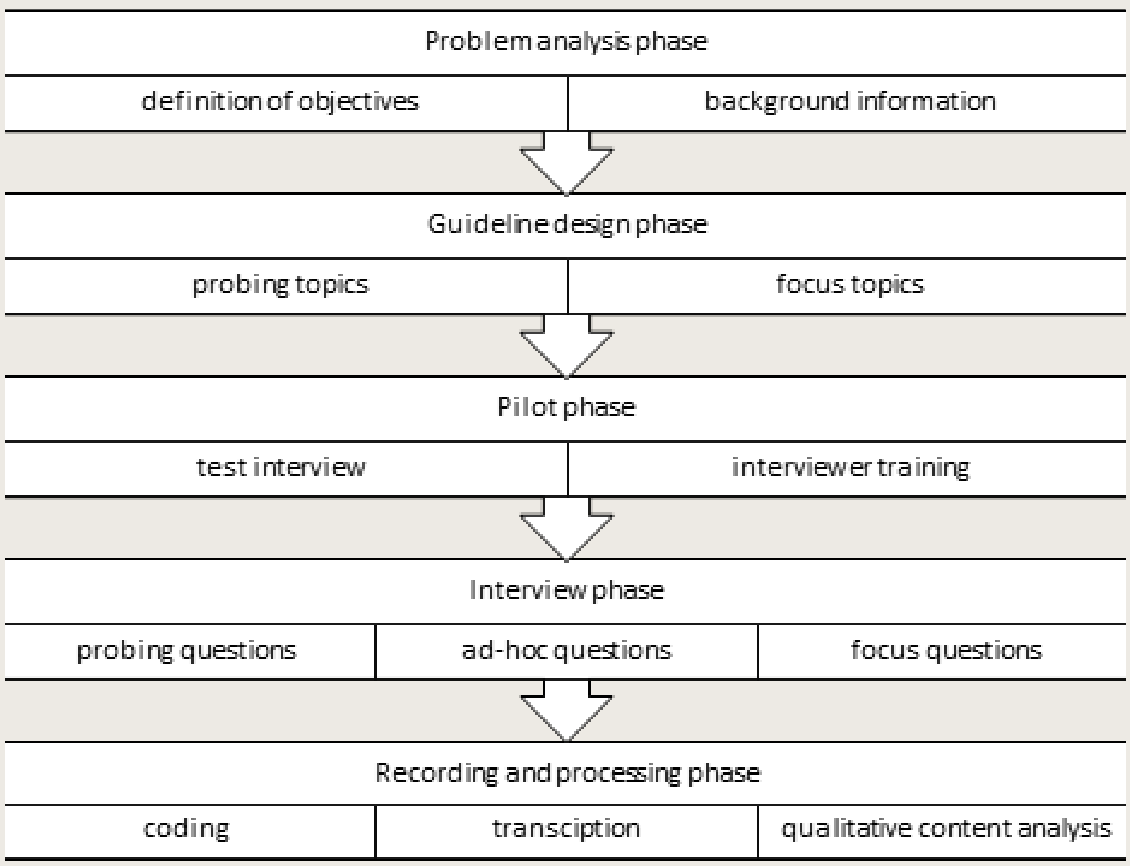
The degree of structuring during the interview is equally essential. A high degree of structuring, such as that found in standardized questionnaires, results in standardized, almost quantitative data. This is in opposition to the objective of this thesis which aims to gather in-depth background information. Low levels of structuring, as in a narrative interview, bear the risk of unrelated and off-topic responses with no benefit to the research goals. This makes semi-structured interviews optimally suited for the objective of the thesis. They combine "control over the topics of the interview" and avoidance of a "fixed range of responses" (Given, 2008, p. 810). The control of the conversation by the researcher enables extensive comparisons between the statements and expert opinions. Semi-structured interviews use predominantly open-ended questions (Given, 2008, p. 810). Mey and Mruck (2010, p. 425 ff.) describe questions in expert interviews more closely, stating that in narrative interviews they are regarded as a disturbance because they interrupt the natural flow of the conversation. An interview guideline is a basic necessity for a semi-structured interview with open-ended questions. It prepares predefined topics and pre-formulated questions to guide the conversation during the interview (Mayring, 2016). Chapter 4.4.2 highlights the use of an interview guideline in the thesis more closely.

4.4.1 Procedures

Figure 9 describes the interview procedures in detail. As conceptualized by Mayring (2016, p. 72), the overview shows critical steps in conducting problem-centered interviews. The problem analysis phase incorporates the definition of objectives and the gathering of background information. This allows the interviewer to pose focused and topic-related questions, thereby clarifying the overall direction of discussion. Based on these preparations, the guideline for the interviews is then created during the guideline design phase. The interview guideline is used during the interview itself to provide orientation during the conversation. It displays the focus topics and key points to discuss. Additionally, the guideline features probing questions which are used to gain a general overview of the interviewee and his or her role in the industry. The pilot phase is used to test the interview guideline in a comparable interview situation. This situation trains the interviewer and can reveal weak or unclear questions. The actual interview features focus along with probing questions, while additionally making use of ad-hoc questions that are used to ensure that the interviewer has understood the new content correctly, which is then processed following the actual interviews. This includes transcription, coding, and identification of key messages.

Figure 9

Procedures in expert interviews
Source: Author’s interpretation using information by Mayring (2016, p. 72)



4.4.2 Guideline design

Mey and Mruck (2010, p. 430) name several tasks that are fulfilled by guidelines. In the pretext of the original field research, the creation of the guideline helps the researcher to understand the topic, organize his or her work and processes, and discuss the relevant topics beforehand. Prior to and during the interview itself, the interviewer can use the guideline to remind him-/herself of focal topics and key questions. At the end of the interview, the guideline can be used as a checklist to ensure that all major topics have been discussed.
Guideline questions can broadly be divided into three different kinds (Mayring, 2016, p. 71). Probing questions are used to open the conversation, get comfortable with the conversation, and discuss the general topic. The objective is to work out the importance of the topic for the interviewee and their role in the poultry industry. Most importantly, probing questions also serve as an icebreaker and familiarize the two persons involved.

Focus questions approach the core topics. Their objective is to discuss critical issues and explore details. The interviewer uses the conversational character of the interview to obtain details and cover the subject again if answers are not deemed sufficient. These questions are ad-hoc and not specifically planned in the interview guideline; the interviewer determines the amount of ad-hoc questions used.

4.4.3 Context

The location and context of the interview have a significant influence on its outcome. Interviews outside of the professional environment of the interviewee can potentially produce distorted results. The respondent is detached from professional constraints and is forced to take the position of an external stakeholder (Mayring, 2016, p. 55). This is contrary to the objective of the thesis, which primarily requires the views and opinions coming from the professional roles of the interviewees. Kruker and Rauh (2005, p. 65) also see benefits in face-to-face interviews and note that the workplace of an interviewee can be an additional incentive for sharing workplace-related information.
Whether the interview is carried out with single interviewees or with a group has an impact on the outcome as well (Kruker & Rauh, 2005, p. 63). In a group setting, interviewees might refrain from sharing information. When a competitor, an NGO, or crucial government institution member is also part of the group, this has a significant impact on the outcome of the interview. There are also perceptible group effects such as the dominance of extroverted group participants who will influence the course of conversation significantly (Given, 2008). This is contrary to the objectives of the thesis that aim for differences in opinions between different stakeholders, which is why single person interviews were chosen. In a face-to-face interview situation, an interviewee will not weigh their answers, and is free to point out their subjective ideas. During the conversation the respondent can develop conceptions of a causal relation without restricting their answers for e.g. political reasons (Mayring, 2016, p. 69). The interviewer can furthermore encourage the interviewee to speak openly by creating a relaxed and exceptionally trust-based atmosphere (Kruker & Rauh, 2005, p. 63).

4.4.4 Experts

A comprehensive list of experts were chosen for this thesis. Kruker and Rauh (2005, p. 54) recommend structuring experts into groups prior to conducting the interviews. Based on the expert's role in the industry, level of experience, or degree to which the person was affected by the HPAI outbreak, a categorization of the experts can be applied. A private entrepreneur for instance is expected to show different attitudes and preferences than a member of the public sector. Only experts of the field were part of the interviews, so naturally, every interview participant answered according to their experiential context. With this in mind, an experiential context goes along with personal or professional interests in the topic, which meant every answer is laden with intention and bias (Kruker & Rauh, 2005, p. 63). According to Kruker and Rauh (2005); this has to be taken into account during the analysis.

The choice of experts is generally made before the actual interviews, as well as during the ongoing process (Kruker & Rauh, 2005, p. 54). If new experts are added during the process, this is clearly explained. During the first interviews, it becomes clear to the interviewer which areas need to be explored further, and might create the need to add more experts to the panel. The experts of first choice may even want to suggest additional experts from their professional field. With the methods of grounded theory as developed by Glaser et al. (1968), this process of adding experts at a later stage of the research is imminent. Glaser et al. (1968) point out that additional experts should be added provided that no new information is to be expected from another expert. Adding new experts occurs only when the research is fully saturated to a degree where no further input can be expected. Following Glaser et al. (1968), the choice of experts is entirely arbitrary as long as new results on the particular topics are to be expected. This is the theoretical sampling process. Wiedemann (1991) points out that if theoretical sampling is applied, the criteria and reasoning for adding a new expert must be explained. Mattissek et al. (2013, p. 152) recommend that experts with a decidedly high discrepancy in opinion should be chosen intentionally, ensuring a broad range of opinions and preventing uni-directional analysis of a problem.

4.4.5 Recording and transcription

All interviews are audio recorded "to capture material for data analysis and reporting" (Given, 2008, p. 41). Video footage is useful if facial expressions and gestures are of relevance for the analysis. Although the objectives of the thesis also point at qualitative impacts, this thesis is neither of social science nor psychological character in which a secondary meaning beyond the actual wording might be of relevance. The recording during the interviews therefore was limited to audio. Given (2008, p. 41) stresses that audio recording is not mandatory in "projects that involve a small amount of data or simple applied goals." The objectives of this thesis do in fact necessitate a high number of experts, with a significant amount of detail regarding the processes of analysis; this is why all interviews in this study were audio recorded. Exemptions here can be made in case the recording device inhibits a free and open conversation, or if the interviewee does not feel comfortable being recorded. If recording is not preferable, a detailed protocol of the conversation written during and after the interview is mandatory, ensuring that important details are not lost, along with proper capture and storage of the data gathered.

Independent of using an audio recording or not, a written protocol of the conversation is produced by the author that allows the interviewer to check all content by confirming it with the interviewee during the interview. It is expected that this rechecking engages both participants in a more concentrated conversation. It also ensures that the interviewer has understood and interpreted everything correctly (Kruker & Rauh, 2005, p. 76). As part of the written protocol, additional impressions of the interview are noted by the author. Mey and Mruck (2010, p. 432) suggest that writing down feelings, first impressions, and an initial evaluation of the quality of the conversation is helpful for the analysis.

A transcript of all the recordings is produced upon completion of the interviews. "Transcription is the process whereby recordings of research conversations [...] are turned into textual material (transcripts), which then become the primary data for subsequent analysis" (Given, 2008, p. 884). There are different forms of transcripts with differing levels of detail. Given (2008, p. 884) defines how a direct transcript features "verbal content (e.g., words, word fragments, filled pauses such as *um* and *er*), prosodic information (e.g., rhythm, intonation, pitch, volume), paralinguistic information (e.g., laughter, audible breaths, sighs), extralinguistic information (e.g., gestures, fidgeting, gaze), pauses, and various contextual cues." He further notes that it is impossible to transcribe all the details and nuances of a lively conversation.
However, a transcript with a high level of detail is achieved only if the meaning of the words is secondary

to the way they were spoken (Mattissek et al., 2013, p. 156). Mattissek et al. (2013, p. 156) clarify that only those details should be transcribed which are later needed in the analysis process. Secondary information derived from paralinguistic, extralinguistic, prosodic, and contextual cues are not relevant for this thesis. Although its objective is to gather qualitative data about the HPAI outbreaks, the thesis does not strive to produce personal analyses or comparable studies of the experts. As a result, the verbal content transcribed in a simplified form is sufficient. The transcript features simple literal statements on each of the relevant topics. Where desirable, some content is used as a quote in the analysis.

Since the study will make use of simplified transcripts, it is important to mention that the preparation and editing of the transcript is a form of first interpretation. Although all claims were rechecked with the interviewee, all transcripts are “selective constructions by the interviewer” (Mattissek et al., 2013, p. 153). Given (2008, p. 883) supports this and notes that “transcriptionists are engaged in interpretive and constructive acts”.

4.5 Qualitative content analysis

The new content undergoes further analysis following the completion of transcription. For this thesis, qualitative content analysis (QCA) is applied to the transcribed material of the expert interviews. Given (2008, p. 120) defines QCA as follows: “Content analysis is the intellectual process of categorizing qualitative textual data into clusters of similar entities, or conceptual categories, to identify consistent patterns and relationships between variables or themes.” Given (2008, p. 120) further states that QCA is used to “reduce data”. QCA furthermore gives meaning to the reduced context.

Interview transcripts are one of the main QCA areas of application. There are of course further areas of QCA application, but procedures are different with every one of them. There is no single valid form of QCA (Schreier, 2014). The key task is to define the individual steps of interpretation beforehand so that the process is repeatable and “intersubjectively testable” by others (Mayring, 2014, p. 53). This makes an exact description of the procedures critical. Only then can QCA make a valid scientific contribution. Mayring (2000) details three advantages of QCA: step-by-step rules of analysis, founded and revised categories for analysis, and application of the criteria of reliability and validity.

There are three different general forms of QCA that result in different procedures of analysis (Mey & Mruck, 2010, p. 602). A summary reduces all of the text to develop key messages. Inductive category formation is an example of this kind of technique. There are also explication methods that try to clarify unclear text passages by including the adjacent context of the text. And structuralizing methods use pre-defined deductive categories for analysis. Each of these methods are adapted to the objective of a study and the available data (see also Mayring & Brunner 2009).
For this thesis, inductive category formation is applied. Summarizing the results of the interviews into categories to render key messages among all participants supports its objective of finding similarities and critical differences in opinions among the experts.

Mattissek et al. (2013, p. 110) stress that all analysis using qualitative methods is a second-degree interpretation. When answering, experts automatically interpret and construct, most often unconscious of their answers and the topic. This means that the analysis cannot represent absolute truth, but instead helps to understand the critical issues within their particular context instead (Mattissek et al., 2013, p. 118).

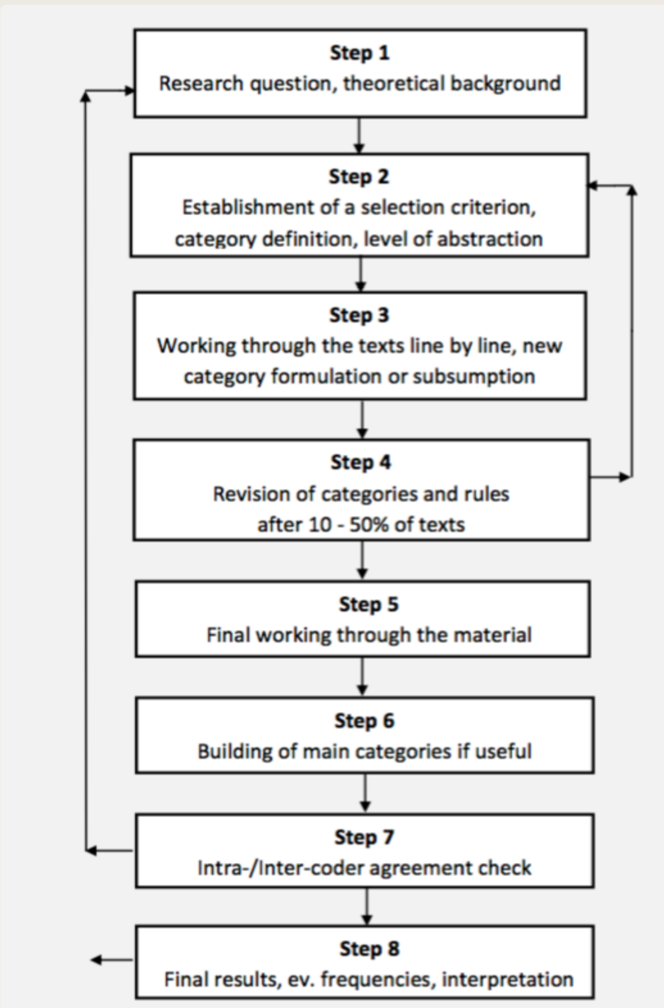
4.6 Inductive category formation

Figure 10 shows the process of inductive category formation as depicted by Mayring (2014), and to which this thesis will adhere. The revision of categories and rules following an examination of ten to fifty percent of the texts is a key element of the process. The procedure of inductive category formation is a circular process, where there is constant feedback about the core element of the category's definition (Mey & Mruck, 2010, p. 602 ff.). Here, the criteria for the categories are always based on both the perceptions of the newly analyzed data and the theoretical background. The quality of the research results will hence develop further with an increasing amount of data or interviews (Mayring, 2000).

At this point, the close relation to grounded theory as developed by Corbin and Strauss becomes visible (Corbin & Strauss, 1990; Glaser et al., 1968). The basic principle of grounded theory contains a constant revision of previous findings during the research process.

Figure 10

Process of inductive category formation
Source: Mayring (2014)



4.7 Quality assessment

For all qualitative research, an assessment of the validity of the results is mandatory. Although objectivity is the goal of any research, absolute objectivity can never be achieved, especially within qualitative research approaches (Kruker & Rauh, 2005, p. 32). Nonetheless, efforts can be made to avoid subjectivity as much as possible. These should focus on limiting the influence of the researcher during the research process (Kruker & Rauh, 2005, p. 32). A researcher can influence results via a selective choice of experts and by applying biased research criteria, and in some cases even perform the wrong interpretation (Kruker & Rauh, 2005, p. 32).

Standardization is applied whenever possible to limit the influence of the author's subjectivity. This thesis improves upon objectivity through standardization in the research process. Openness is a positive trait for the interview situation but must not be applied during analysis.
The analysis has to follow concise procedures, and methods have to be replicable (Mey & Mruck, 2010). The guidelines for all interviews are standardized and each conversation is approached the same way. Further, there are standardized processes in interview recording, transcription, and their subsequent analysis that prohibit arbitrariness during the research process (Mey & Mruck, 2010).
In addition to standardization, representativity is achieved through the choice of experts. Choosing experts of similar professional backgrounds produces similar results, limiting the range of opinions. Experts with presumably differing opinions add higher overall value to the study because the scope of opinions on the topics is significantly larger (Kruker & Rauh, 2005, p. 34).

4.8 Planning

Table 6 shows the planning of the expert interviews. They were planned according to the structure that was described in chapter 4.4.1.

Table 6

Planning and execution of interviews
Source: Author

Organizational Unit	Task	When
Problem Analysis Phase	Information Gathering	2017
	Problem Description	CALENDAR WEEK 8
	Empirical Development	CALENDAR WEEK 8
	Definition of Task and Objectives	CALENDAR WEEK 8
Guideline Design Phase	First Draft Guideline Design	CALENDAR WEEK 14
	First Draft Focus/Test Questions	CALENDAR WEEK 14
	First Draft Checklist for Guidelines	CALENDAR WEEK 15
	Final Draft Guideline Design	CALENDAR WEEK 19
Pilot Phase	Preparing Test Interview	CALENDAR WEEK 20
	Conducting Test Interview	CALENDAR WEEK 21
	Test Interview Evaluation	CALENDAR WEEK 21
	Update Interview Guideline Design	CALENDAR WEEK 22
Conducting Phase	Conducting Interviews in the USA	CALENDAR WEEK 22-CALENDAR WEEK 26
Processing Phase	Transcription	July / August 2018
	Coding	
	Qualitative Content Analysis, Inductive Category Formation	

5 Methods Economic Impact Analysis

An examination of economic impacts requires impact analysis to be clearly defined. The following gives an overview of efforts that have been made so far to clearly define economic impacts. First, the importance of a coherent framework is described followed by the fundamental principles of impact definition. After that, the difference between direct, indirect, as well as the definition of sub-categories are clarified.

5.1 Fundamental principles

A first definition of fundamental principles was elaborated upon by Häsler et al. (2013) who generally define economic impact as the "required remedial actions at the use of scarce resources that would be unnecessary in the absence of disease". The opportunity costs of these actions must be regarded as the economic cost of a disease. This is a definition in the broadest sense. McInerney et al. (1992), who were among the first to demand clear definitions, described economic costs (C) as both losses (L) and expenditures (E) combined, thus creating the following formula with a clear difference between costs and losses.

$$C=L+E$$

Costs are related to expenditures that would not occur in the absence of animal disease. Losses are defined as input forgone due to the presence of the disease. Hence the total economic cost of a disease is made up of losses forgone and expenditures. Expenditures are then separated again into treatment and prevention expenditures. This distinction is important because some prevention expenditures are actually standard operating procedures, and do not represent economic costs (McInerney et al., 1992). McInerney et al. (1992) further remark that the perspective of the costs must be further defined because there are private, public, and social costs to consider.

Accordingly, the formula was restated in more detail by Bennett (2003):

$$C=(L+R) + T + P$$

Bennett (2003) defines C as "direct disease costs". L describes the "value of the loss in expected output due to the presence of a disease". R represents an "increase in expenditures on non-veterinary resources due to disease", meaning for example feed or farm labor. T sums up the costs that arise when treating the disease. P represents the costs of preventing the disease.

The definitions as mentioned above do not feature a distinction between direct and indirect costs. Rushton et al. (1999) developed the work of McInerney further and detailed animal disease impacts including indirect effects. A major part of any impact definition is this clear distinction between direct and indirect losses. The following case exemplifies the importance of a delineation between the direct and indirect impacts of animal disease.

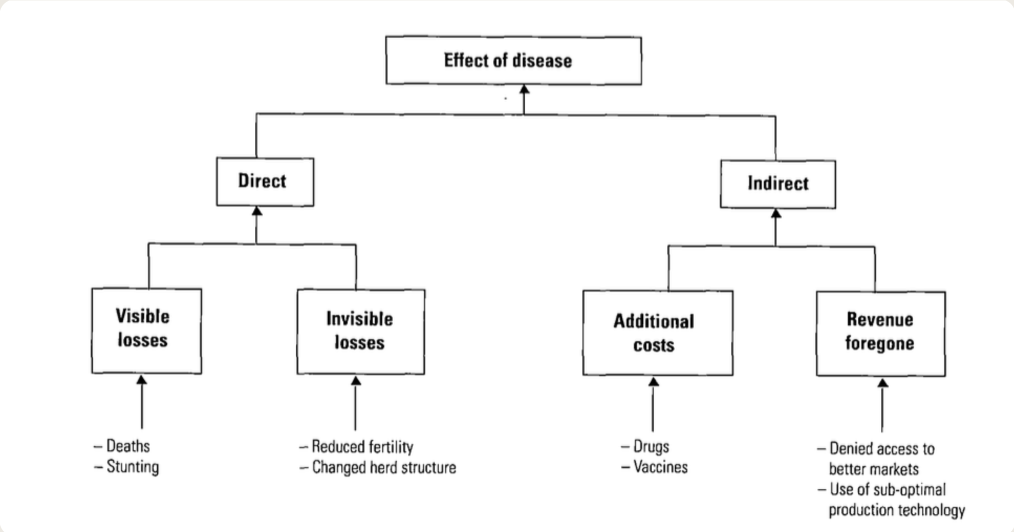
In northern Alberta in Canada, a single BSE-infected cow was found in May 2003 (Global News CA, 2015). During this time, Canada heavily depended on beef exports, with 12 percent of all live animals and 50 percent of total beef production destined for export markets (Morgan & Prakash, 2006). The United States immediately closed its border to live and processed beef imports after the Alberta BSE incident. Forty other countries followed. Only after two years and estimated economic impacts of US$ 4 billion did trade resume to pre-crisis levels.

This exemplifies the dramatic effect of the indirect impacts of animal diseases. In the case mentioned above, the direct loss of a single BSE-infected cow was minimal, whereas indirect losses lasted for two years and cost billions. This shows that the inclusion of indirect costs is imperative for disease analysis. Several attempts have been made to classify direct and indirect costs. Rushton et al. (1999) assigned indirect forms of economic impact to the subgroups "visible", "invisible", "additional costs", and "revenue foregone". Figure 11 (p. 50) displays the distinction between the categories.

Additionally, Van Asseldonk et al. (2005) state that other parts of the agricultural supply chain besides farms have to be considered, meaning breeding organizations, feed mills, slaughterhouses, and related processing and transportation industries. Bergevoet and van Assel-

Figure 11

Effects of disease on a livestock system
Source: Rushton et al. (1999, p. 317)



donk (2013) name these additional impacts ripple effects because "the effects from outbreaks are felt upstream and downstream along the livestock value chain, from breeding, feed production, input supply, slaughter, and processing, to final sale and consumption". The "high degree of vertical linkages" Morgan and Prakash (2006, p. 524) in the poultry industry as well as the horizontal ties amplify ripple effects in cases of outbreaks. Brown et al. (2007) agree, and state that impacts to the poultry sector are widely accepted, whereas losses in other sectors outside primary poultry production tend to be neglected.

5.2 Coherent framework of analysis

Defining the economic impact of animal disease is complex. Knight-Jones and Rushton (2013) state that its research cannot be based on examinations of individual cases, but on population analysis instead. The researchers note that "to consider this as a function of losses in diseased individuals and the number affected is an over-simplification; for livestock diseases [...] the full impact of a disease is far more complex" (Knight-Jones & Rushton, 2013, p. 2). Häsler et al. (2013) generally state that "quantifying certain loss values" is scientifically challenging, as there are also intangible loss values. So far, there has not been conformity on which aspects must be part of an impact analysis of animal diseases. Paarlberg (2013) demands "a greater consensus" in attributes such as epidemiological input, export loss, recovery, and consumer response. A commonly acknowledged tool that combines both epidemiological and economic data remains lacking. At the same time, it is evident that the method of defining impacts influences the results significantly. Because of this, there are many papers on the topic without a coherent definition of impact analysis. In the aftermath of disease outbreaks, stakeholder groups, politicians, and researchers produce statements concerning their monetary severity. These statements cannot however be compared because their methods are not coherent. As a consequence, Saatkamp et al. (2014) demand a consistent framework to describe the various components of the economic impact of highly contagious livestock diseases.

The "starting tableau for economic analysis of HCLD" by Saatkamp et al. (2014) attempts to incorporate all the relevant aspects mentioned above. HCLD is the abbreviation for highly contagious livestock disease, the term used by Saatkamp et al. (2014). Saatkamp et al. incorporate several levels of differentiation such as economic stakeholder, type of cost, and moment of occurrence during the time of the outbreak. The following paragraphs give an overview of these levels; the total economic impact is produced by

Table 7

Starting tableau for economic analysis
Source: Saatkamp et al. (2014).

Table 1. Starting tableau for economic analysis of HCLD (x: costs likely to occur; a: other costs that could be appropriate for certain situations)

	DC				DCC				ICC				AC			
Economic level/stakeholder	Organisation	Destruction animals	Cleansing and disinfection	Other	Idle production factors	Welfare slaughter	Reduced net cash flow	Other	Change in producer surplus	Change in consumer surplus	Macroeconomic impact	Other	Change in producer surplus	Change in consumer surplus	Macroeconomic impact	Other
Farmers																
Affected		x	x	a	x		x	a					x			a
Non-affected inside MRZ		x		a	x	x	x	a					x			a
Non-affected outside MRZ									x			a	x			a
Providers of services					x			a	x			a	x			a
Depending on animal products					x		x	a	x			a	x			a
Final consumers										x		a		x		a
Non-livestock economic sectors					x		x	a				a				a
National government	x	x	x	a		x		a			x	a			x	a
Supra- national government	x	x	x	a		x		a				a				a

Table 8

Classification of economic impacts according to moment of occurrence
Source: Own design with adaptations of Longworth et al. (2014a, p. 200)

Category	Direct costs (DC)	Direct consequential costs (DCC)	Indirect consequential costs (ICC)	Aftermath costs (AC)
Origin	virus control	prevention of virus spread	market disruption during outbreak	market disruption after outbreak
Epi. factors	number of affected farms	size and duration of out-break, spatial structure of outbreak region	duration of outbreaks, type of control strategy	/
Economic factors	spatial situation of first outbreak	production structure in movement restriction zones, livestock sub-structure	response trade partners, market structure	response trade partners, market structure
Occurrence	beginning of and during the outbreak	during the outbreak	during/after the out-break	after regaining di-sease-free status

adding the impacts on all individual levels.

Table 7 (p. 51) shows the starting tableau for economic analysis that is used as a guideline in this study. An enlarged version of table 7 is enclosed in the Annex in chapter 12.7.

The framework by Saatkamp et al. (2014) for economic analysis in table 7 (p. 51) uses two major factors for analysis along which the categorization is aligned. The first factor is the type of affected stakeholder. This describes in more detail exactly which stakeholder is affected. The second factor of analysis is the time of occurrence during the outbreak, describing in more detail the exact time of the impacts. The following section describes the latter in greater detail.

5.3 Categorization

5.3.1 Time referenced categorization

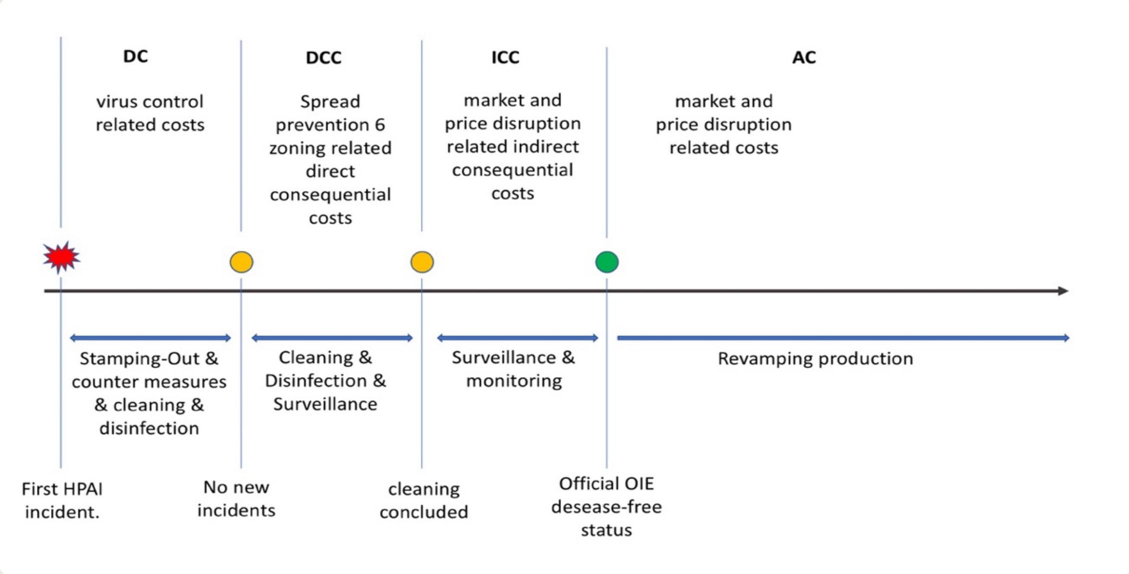
According to the categorization of Saatkamp et al. (2014), an important level of categorization concerns the moment of occurrence. While the outbreak unfolds, different types of costs occur for different kinds of stakeholder. Defining the exact moment of occurrence is crucial for a clear and concise analysis of the outbreaks costs.

Table 8 (p. 51) displays four major categories of impacts and their moment of occurrence, along with the origin of the cost and epidemiological and economic factors.

Table 8 shows that DCs are comprised of virus control costs that are influenced by the number of affected farmers and the spatial situation of the first outbreak. They occur at the beginning of and during the outbreak. DCCs are correlated with the prevention of the virus' spread. The size and duration of the outbreak, the spatial structure of the outbreak region, the structure of agricultural production, and the livestock sub-structure influence DCCs. DCCs occur during the outbreak. ICCs describe market disruptions during the outbreak. The type of control strategy, the duration of the outbreak, the response of trade partners, and the market structure influence ICCs. They occur during and after the outbreak. Aftermath costs describe the market disruptions after official OIE disease-free status is regained. Figure 12 displays the timeline of costs during an HPAI outbreak and

Figure 12

Timeline of costs during an HPAI outbreak
Source: Own adaptation with data from Saatkamp et al. (2014)



gives an overview of the concepts as depicted above.

Following the categorizations above, the summary for the total economic impact of an HPAI outbreak is as follows: Total economic impact (TEI) = Direct costs (DC) + direct consequential costs (DCC) + indirect consequential costs (ICC) + aftermath costs (AC).

This study focuses on two of the four categorizations. DC and DCC of the outbreaks in the USA and Germany were analysed in detail. ICC and AC were not analysed as part of this research. The analysis of ICC and AC requires extensive additional data and different forms of analysis. In additione, there are many open and unclear variables in analysing ICC and AC. Costs of ICC and AC are strongly interlinked respectively were accounted for already as part of the DC and DCC analysis. A distinct elaboration of these aspects and a concise analysis of ICC and AC would have extended the scope of the research.

5.3.2 Stakeholder categorization

The second level of categorization involves the different levels of affected economic stakeholders. The following table displays an overview of economic stakeholders who are affected during an outbreak according to Saatkamp et al. (2014). This is a complete list that also includes non-direct stakeholders.

Table 9 shows all stakeholders who are potentially affected by an

Table 9

List of economic stakeholder affected by HPAI outbreaks
Source: Own design, adapted from Saatkamp et al. (2014, p. 430)

Economic stakeholder		Description
Farmers	Affected	Virus affected farmers
	Non-affected	Farmers inside an MRZ*
	Non-affected	Farmers inside the OZ**
	Non-affected	Farmers outside the MRZ/OZ
	Backyard	Hobbyist backyard farmer
Providers of service		Animal transport
		Feed industry
		Veterinarian services
		Cleaning and disinfection services
		Processing industry
		Pest control services
Food industry		Industries depending on egg or poultry meat-related products for further processing for food products
		Retail industry
		Catering and food services industry
Final consumers		Final consumer domestic
		Final consumer international
Non-livestock economic sectors		Tourism
		Construction
		General transport
National government		Federal and state government institutions
Supra-national government		EU, UN

*Movement Restriction Zone **Observation Zone outbreak. Farmers are differentiated into five sub-categories. These are dependent on whether the farmer was affected or not, and on whether the farmers were impacted by MRZs or OZs. One additional sub-category is backyard farmers.

5.3.3 Cost categorization

The framework for impact analysis necessitates the use of two different sets of values for results. The difference is significant and mentioned in all successive analyses. Table 10 shows an overview of the different categories of costs and types of values. Further, there is a more detailed specification of what precisely the four different categories encompass.

Table 10

Definition of costs
Source: Author with adaptations of Saatkamp et al. (2014, p. 430)

Type of costs	Type of value	Sub-type	Description
DC	Monetary	Organization	Administration of MRZ/OZ including surveillance and observation
	Monetary	Destruction of animals	Value of destroyed animals
	Monetary	Cleansing and disinfection	Cleaning and disinfection of facilities that have been impacted by HPAI outbreaks
	Monetary	Other	
DCC	Monetary	Idle production factors	After cleaning and disinfection has been concluded, production facilities are left idle for a pre-defined time
	Monetary	Welfare slaughter	If farmers are in movement restriction zones, welfare slaughter might become necessary because livestock cannot be sold conventionally
	Monetary	Reduced net cash flow	When in movement restriction or observation zones, this is related to a reduced net flow because business can be procured normally
	Monetary	Other	
ICC	Economic	Change in producer surplus	Welfare gains or losses for producers
	Economic	Change in consumer surplus	Welfare gains or losses for consumers
	Economic	Macroeconomic impact	Consumer surplus + producer surplus + taxpayer gains
	Economic	Other	
AC	Economic	Change in producer surplus	Welfare gains or losses for producers
	Economic	Change in consumer surplus	Welfare gains or losses for consumers
	Economic	Macroeconomic impact	Consumer surplus + producer surplus + taxpayer gains
	Economic	Other	

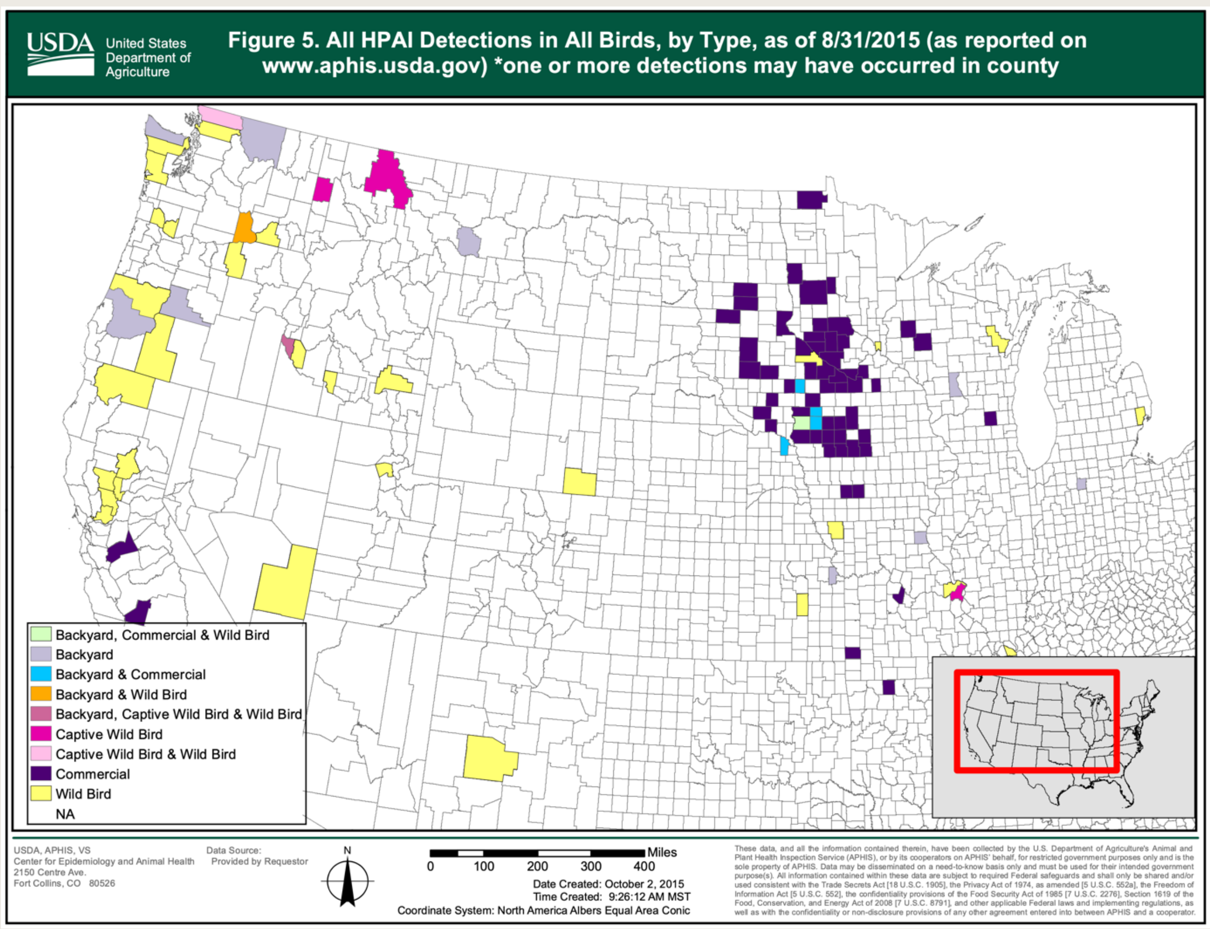
6 AI Impacts US Outbreak 2015

This chapter describes the time-spatial development and economic impacts of the 2014-2015 HPAI outbreak in the USA. It begins with an overview of the outbreak, followed by an in-depth time-spatial analysis. There are also several areas of interest presented that help to understand its complexity. The chapter concludes with the calculation of direct costs (DC) and direct consequential costs (DCC). These are performed according to the framework of analysis as defined by Saatkamp et al. (2014).

The 2015 HPAI outbreak was the largest animal disease event ever to be recorded in the history of the United States (USDA, 2016a). First findings of HPAI were recorded in the Pacific Northwest in December 2014 along the Pacific Flyway. These were the first cases arising following ten years without any incidents (USDA, 2016a). The first domestic poultry was officially recognized as infected with H5N8 in mid-December 2014 in Oregon in a backyard flock with 106 animals. The second detection of H5N2, 140 animals in a backyard poultry rearing barn, was made in the neighboring state of Washington at the end of December 2014. Around the same time, nineteen separate findings of HPAI-infected wildfowl were made in the Pacific Northwest in the states of Oregon, Washington, and Idaho (USDA, 2015b). A variety of wildfowl were infected with both H5N8 and H5N2 such as mallards, pintails, widgeons, gadwalls, falcons, hawks, and geese (USDA, 2015b). In January 2015 the first commercial turkey production plant was officially confirmed as H5N8-positive in Stanislaus county

Figure 13

All HPAI detections in all birds by type
Source: USDA (2016a)



in the state of California, affecting 134,344 turkeys (USDA, 2016b). From there, the outbreak extended eastward across the Mississippi Flyway (Greene, 2015). On March 5th, 2015, the first H5N2 outbreak was detected in Pope county in Minnesota, affecting 26,305 turkeys. Two further outbreaks in commercial operations in the area followed shortly afterwards on the 26th and 28th of March in Lac qui Parle and Stearns counties. Both Minnesota and Iowa have areas with exceptionally high densities of commercial poultry farms (Huang et al., 2016), which provided the potential for further spread of the outbreak. By June 16th, the day of the last official confirmed outbreak, the states of Minnesota and Iowa had been heavily impacted with mostly H5N2 infections in both commercial turkey and laying-hen operations. A total of 211 commercial flocks were affected and accounted for up to 50,400,000 euthanized birds, of which 7.4 million were turkeys, and 43 million were layer chickens or layer pullets.

6.1 Spatial analyses USA

This section provides an overview of the spatial development of the nationwide 2015 HPAI outbreak in the USA. The majority of the individual outbreaks occurred in an area with high-density poultry production. A multitude of other states were also affected with HPAI outbreaks in domestic poultry. An understanding of the outbreak's spatial development is an important part of the economic analysis which is conducted in subsequent chapters.

Figure 14

Number of HPAI detections in all birds, by county, as of 8/31/2015
Source: USDA (2015a)

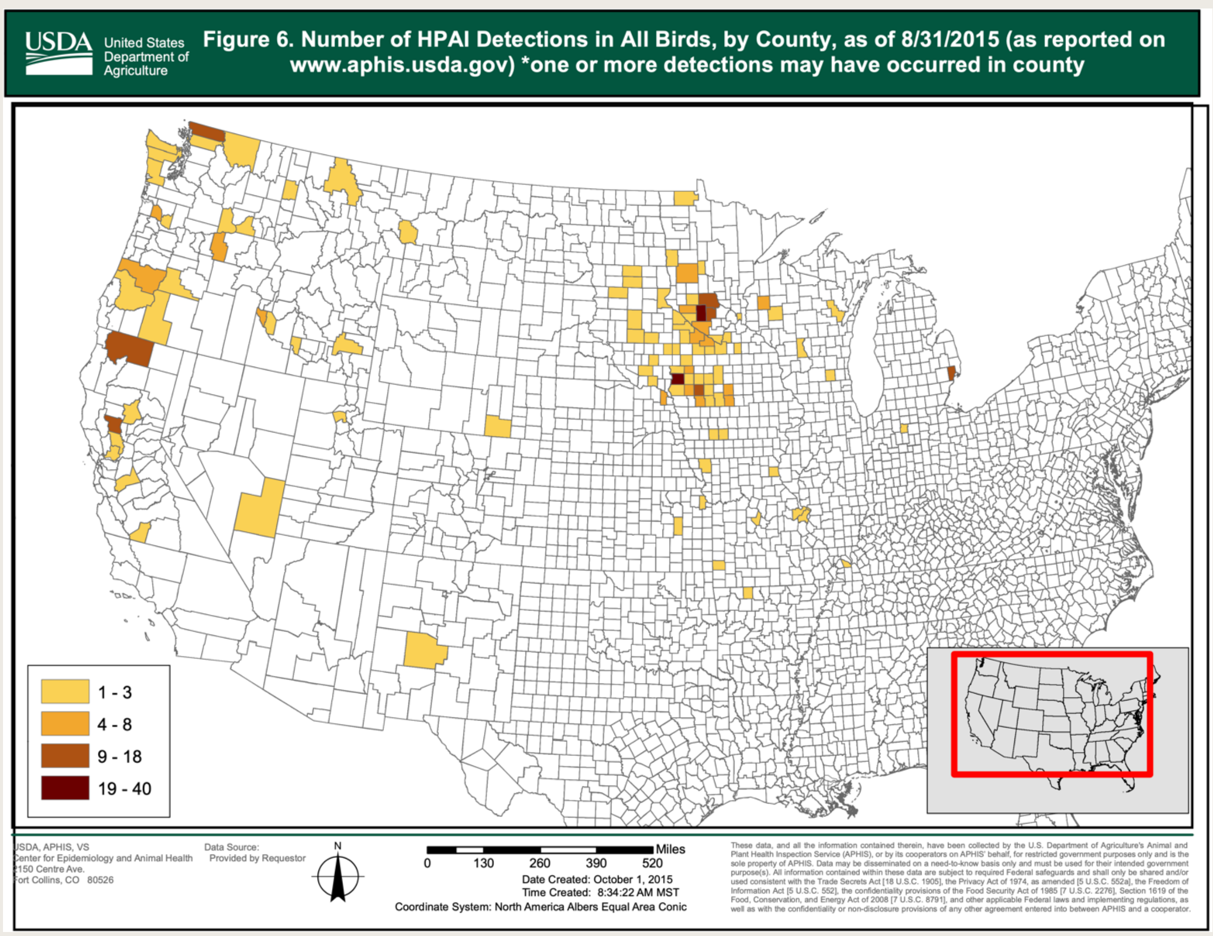


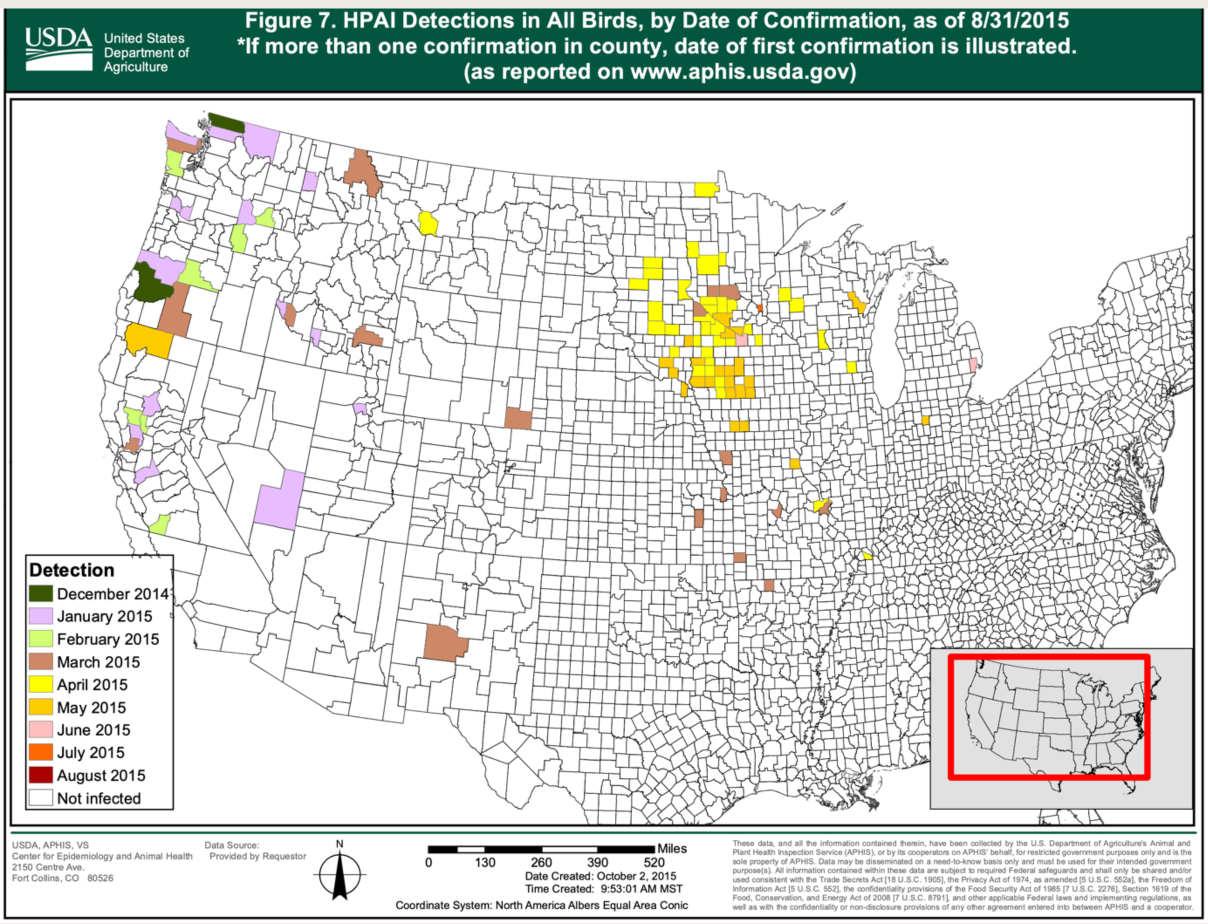
Figure 13 (p. 55) displays all HPAI detections in the United States from December 2014 to August 2015, differentiated by bird type and county of infection. Figure 13 shows that states on the east coast were not affected at all, while the west coast states and the upper midwest were heavily impacted by outbreaks. Figure 13 additionally shows the type of detection. While outbreaks along west coast states were predominantly backyard, wild bird, and captive wild bird infections, the region around the twin state area of Minnesota and Iowa was dominated by commercial HPAI infections.

Figure 14 (p. 56) displays the frequency of HPAI detections on a similar map with county-level differentiation. Some counties had a noticeable accumulation of cases. In Washington and California, there were three counties with more than nine detections. In the twin state region of Minnesota and Iowa, there were also three counties with more than nine HPAI outbreaks and two counties with more than nineteen infections.

Figure 15 shows the same map of the USA with county differentiation. Figure 15 illustrates the time-spatial progression of the virus from the first detections in west coast states towards the midwestern states. In December 2014, January 2015, and February 2015, states on the west coast were primarily affected by HPAI outbreaks. In March 2015, the virus extended substantially into the east, including the crucial states

Figure 15

HPAI detections in all birds by date of confirmation
Source: USDA (2015a)



of Minnesota and Iowa. Figure 15 (p. 57) shows that April and May 2015 were the primary months with commercial detections in these high-density areas.

6.2 Spatial analysis upper midwest

The following spatial analysis focuses on the upper midwest with the states of Minnesota, Iowa, Nebraska, South Dakota, and North Dakota, where the majority of HPAI outbreaks occurred.

Figure 16 shows the section of the US map used for this detailed analysis.

The analysis of the focus area is further divided into six different time periods. Each of these encompasses two weeks that are precisely defined in table 11. Because precise coordinates of the outbreaks are not available due to privacy protection laws, the smallest spatial unit of analysis is the county level. The specific dates used for the analysis are the NVSL confirmation dates as provided by the USDA (2016b).

The figures below display the progression of the virus outbreaks within these six periods. Figure 17 (p. 59) gives a spatial overview of the first detections of HPAI in March 2015 in Minnesota in period 1. Pope County had the first officially recognized HPAI incident in the focus area. It included a second affected area that was classified as a dangerous contact facility. Some sources mention that these

Figure 16

Focus on the hotspot area around Minnesota and Iowa during the outbreak, Source: Author

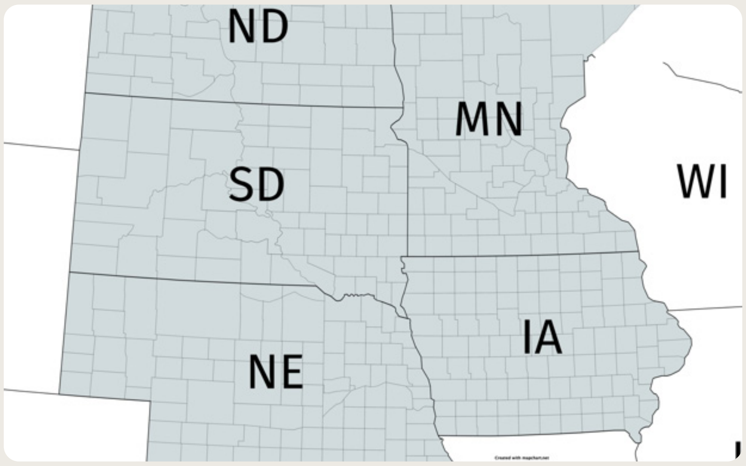


Table 11

Description of time periods for focus area analysis
Source: Author

Period	From – until (2015)
Period 1	16th March to 29th March
Period 2	30th March to 12th April
Period 3	13th April to 26th April
Period 4	27th April to 10th May
Period 5	11th May to 25th May
Period 6	25th May to 7th June

initial incidents had already happened some days earlier at the end of February (MNDNR, 2015), while official confirmation was registered on March 5th. A second outbreak occurred in the county of Lac qui Parle 21 days later in the proximity of the first outbreak. Pope and Lac qui Parle Counties can be considered as the first epicenters of numerous subsequent outbreaks.

Figure 18 displays the progression of the virus around the first epicenter in period 2. The virus spread south and west, affecting 14 additional counties in Minnesota, North Dakota, and South Dakota. The end of period 2 made it obvious that an epidemic was unfolding. Comparing the number of outbreaks in period 1 and period 2, it is striking to see the increasing speed of the virus' progression. New outbreaks are marked in dark red, whereas older outbreaks are marked in a lighter red. This way it becomes visisble where new outbreaks occurred during the process. The following figures apply the same coloring routine.

Figure 19 (p. 60) displays the virus' progression in period 3. While the virus continued affecting commercial operations around the initial epicenter in Pope in Minnesota, a tendency towards more southern areas became evident. Eventually, the first three counties in the north of Iowa were affected in period 3. This is especially relevant because this area has a considerable amount of poultry operations with exceptionally large layer flocks well above one million birds. The potential for negative economic impacts increased greatly with the arrival of the virus at these large layer complexes in the south of the first epicenter.

Figure 17

Virus progression in the focus area in Period 1
Epicenter I
Source: Own adaptation with data from USDA (2016b)

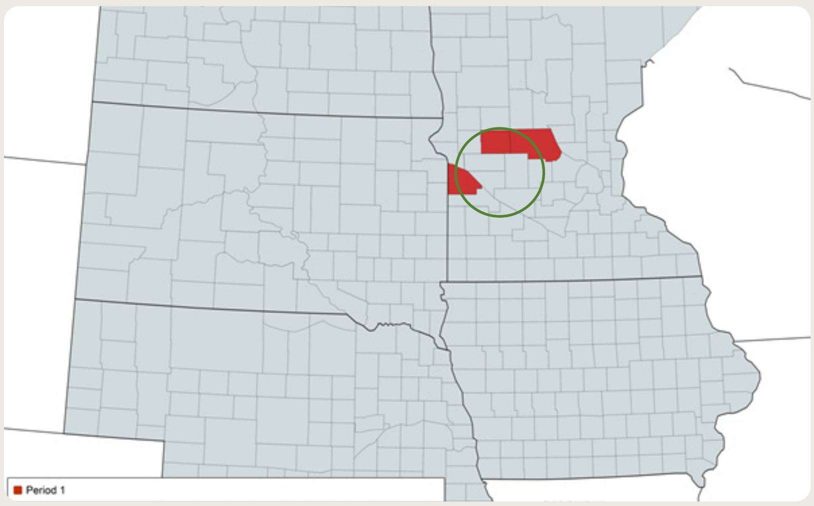


Figure 18

Virus progression in the focus area in Period 2
Epicenter I
Source: Own adaptation with data from USDA (2016b)

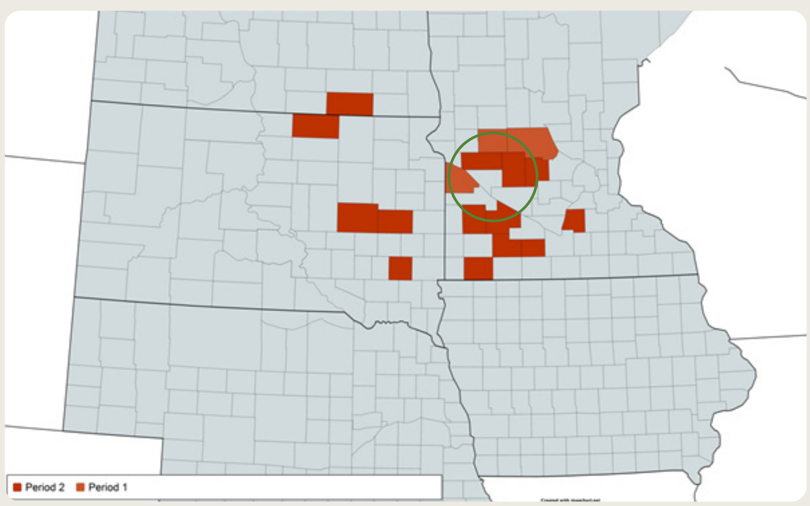


Figure 20 shows the development of the virus' progression in period 4. Although there were still new outbreak cases around the first epicenter, the virus consolidated in the south, spreading quickly with new incidents in a total of 10 counties. Taking into account the agglomeration of new outbreaks in the northwest of Iowa, it became clear that by period 4, a new epicenter had developed south of the former epicenter. The new epicenter is marked in figure 20. Some of the affected operations around the new epicenter were very large, having above two million birds per operation, and with the numbers of birds depopulated or to be depopulated dramatically increasing.

Chapter 6.3 showes that the majority of outbreaks in Minnesota happened in turkey operations, while Iowan outbreaks were mostly in the layer sector. Further, chapter 6.3 highlights that the number of affected farms was high in Minnesota in comparison with Iowa, and the number of birds depopulated per farm was relatively low in Minnesota, and relatively high in Iowa. Taking into additional consideration the spatial differences between the first and the second epicenter, it shows that the HPAI outbreak in the upper midwest was actually comprised of two outbreaks. The outbreaks in Minnesota around Epicenter I constituted the first turkey sector outbreak. In period 4, HPAI progressed south and resulted in a second layer sector outbreak around the second epicenter. The coloring shows that although a new epicenter developes there are still new outbreaks around the first epicenter.

Figure 19

Virus progression in the focus area in Period 3
Epicenter I
Source: Own adaptation with data from USDA (2016b)

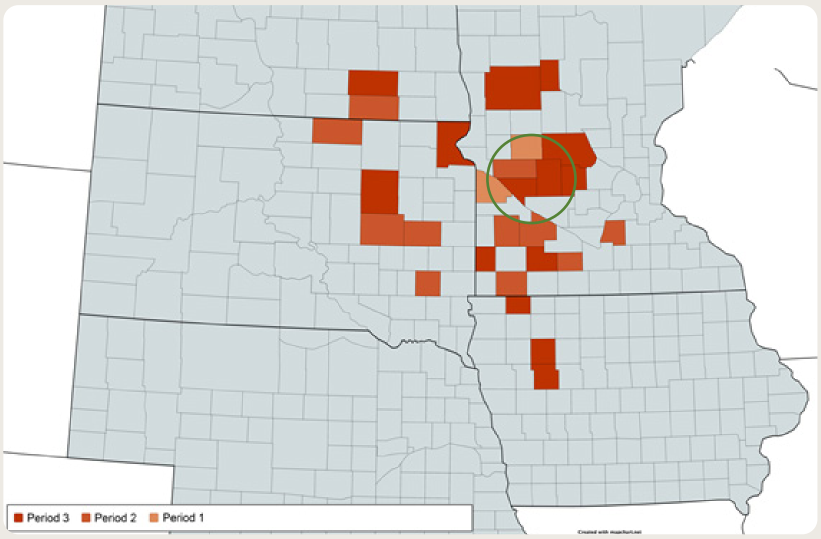
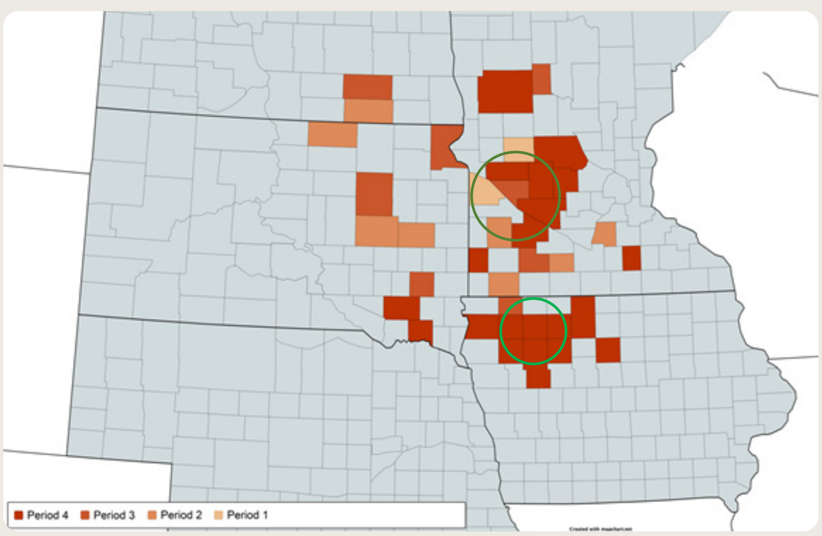


Figure 20

Virus progression in the focus area in Period 4
Epicenter I   Epicenter II
Source: Own adaptation with data from USDA (2016b)



The virus progression around both epicenters in periods 5 and 6 is displayed in figure 21. HPAI outbreaks progressed around the two main epicenters in southern Minnesota, west of the twin city area of Minneapolis-St. Paul, and in the northwest of Iowa northwest of Des Moines. At the end of period 6 in the beginning of June 2015, a decline in new incidents was noticeable in both Minnesota and Iowa. During the first week of period 6, there were still 18 new incidents, while in the second week of period 6 there were only two new incidents.

Figure 22 is a conclusive overview of all incidents from period 1 to period 6 in the focus area. It is visible that the virus developed during the period in two major epicenters, with some breakaway incidents. Epicenter I constituted a turkey-focused outbreak in many premises with low flock numbers. Epicenter II constituted a layer-focused outbreak with very large bird quantities at relatively few premises. It can be seen that Minnesota and Iowa are states with the highest amount of affected counties.

6.3 Quantities, operations, and states

This section provides an overview of the amount of lost birds in each state. It also highlights the amount of operations affected in these states. For a better understanding of the outbreaks mechanisms, the age and size structure of affected operations are described as well. In a sub-section that concludes this part, the chronology of events during the outbreak is explained.

Figure 21

Virus progression in the focus area in Periods 5 and 6
Epicenter I ◯ Epicenter II ◯
Source: Own adaptation with data from USDA (2016b)

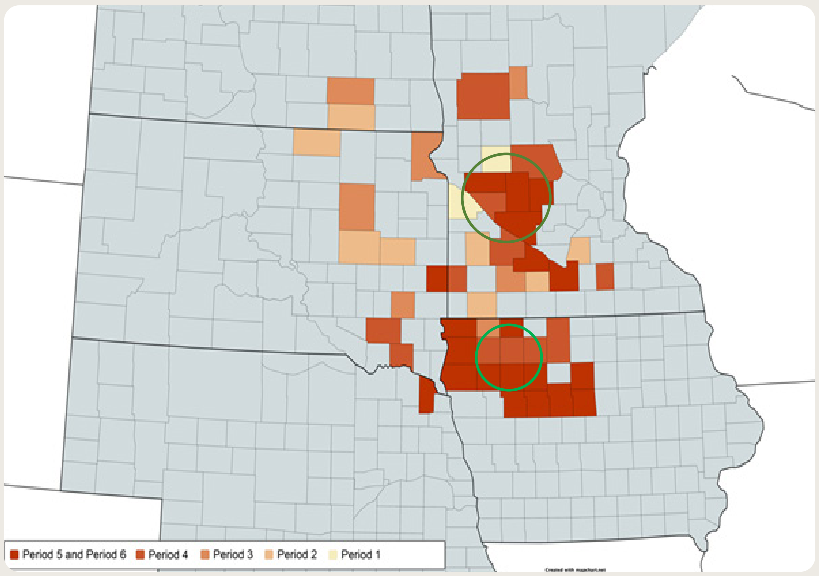


Figure 22

Incidents per county in the focus area
Source: Own adaptation with data from USDA (2016b)

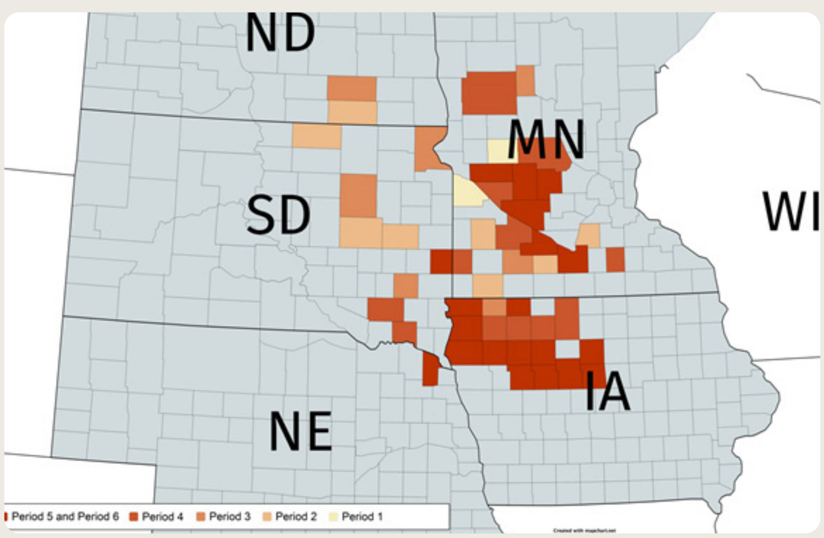


Figure 23 shows the distribution of losses in the layer sector. It can be seen that the majority of operations were premises with hens in their active lay period. Close to 36 million, 86 percent of all depopulated layers, were hens in active lay. The remaining 14 percent were pullets not old enough to have started laying. In addition, there was one parent stock operation with 45,455 breeder birds that also had to be depopulated.

Figure 24 displays the impacts on turkey stocks in the USA. It is evident from figure 24 that heavy male turkeys were affected most, with more than four million lost birds, which represents 51 percent of the total amount of affected turkeys. Hens and light male turkeys were affected marginally less, with approximately 3.5 million lost birds. At turkey breeder operations, farms having around 604,141 birds, representing seven percent of all affected turkeys, had to be depopulated.

Figure 23

Affected layer stocks in the 2014-2015 HPAI outbreak in the USA
Source: USDA (2016b)

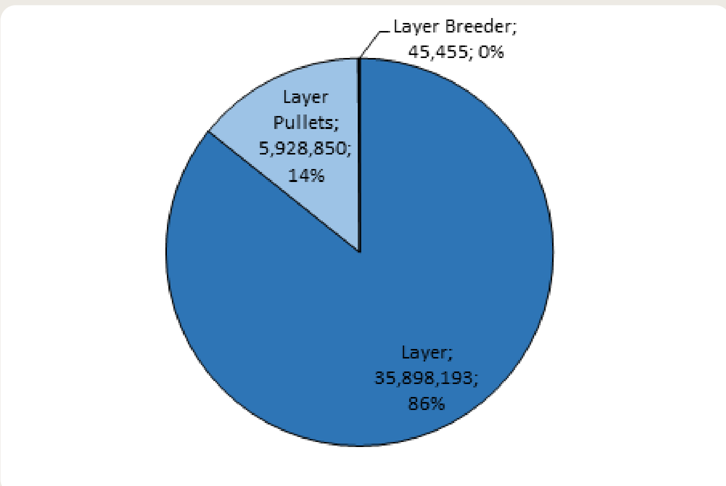
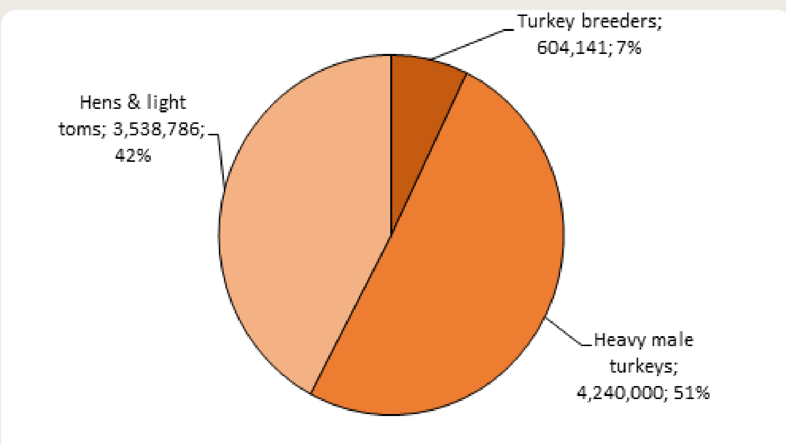


Figure 24

Affected turkey stocks in the 2014-2015 HPAI outbreak in the USA
Source: USDA (2016b)



Although the main concern of this thesis is the analysis of impacts to turkey and layer operations, other types of operations were affected as well. Figure 25 (p. 63) provides an overview of them. One commercial broiler operation, one game bird rearing operation, as well as several backyard operations were affected by the outbreak. The affected broiler operation required the culling of 112,857 birds. There were a total of 20 affected backyard operations, two of which were dedicated duck farms (USDA, 2016b). Combined, the backyard operations accounted for 6,622 birds (USDA, 2016b), while the game bird operation accounted for the loss of 3,004 birds. Compared to the above-mentioned losses in the turkey and layer sectors, the amount of birds euthanized in these other sectors was minimal, making them negligible for the subsequent economic analysis.

Table 12 (p. 63) gives an overview of the different states and to what degree they were affected by the HPAI outbreak. The table lists the number of affected premises for each state. The game bird operation is listed as a backyard operation. Every state with at least one official-

Figure 25

Affected broiler, duck, and backyard flocks in the USA outbreak
Source: USDA (2016b)

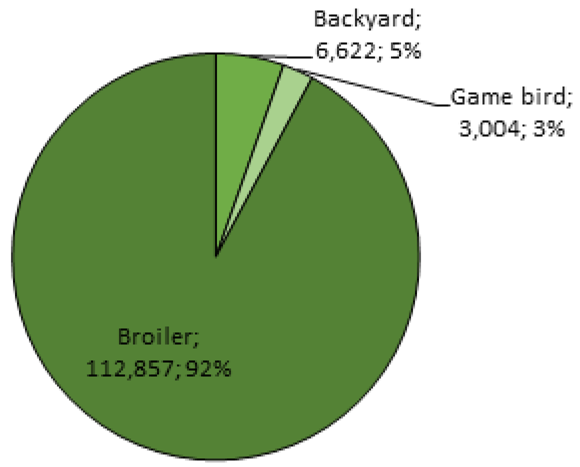


Table 12

Summary of all affected premises by state
Source: USDA (2016a)

State	Total Commercial H5-Positive HPAI Premises	Species (Commercial Premises)			Total Backyard H5-Positive HPAI Premises	Total by State
		Turkey	Chicken-Layer	Other		
Minnesota	109	104	5	0	1	110
Iowa	71	35	36	0	6	77
South Dakota	10	9	1	0	0	10
Wisconsin	9	6	3	0	1	10
Nebraska	5	0	5	0	1	6
California	2	1	0	1	0	2
Missouri	2	2	0	0	1	3
North Dakota	2	2	0	0	0	2
Arkansas	1	1	0	0	0	1
Kansas	0	0	0	0	1	1
Washington	0	0	0	0	5	5
Oregon	0	0	0	0	2	2
Montana	0	0	0	0	1	1
Idaho	0	0	0	0	1	1
Indiana	0	0	0	0	1	1
Total	211	160	50	1	21	232

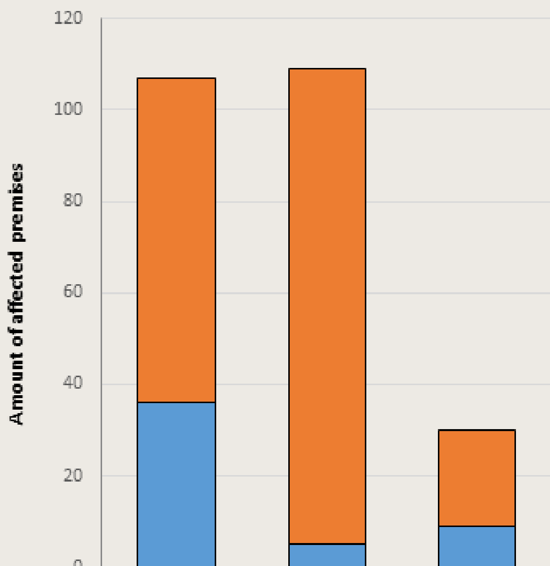
ly recognized HPAI case is itemized below.

Table 12 (p. 63) shows that infections were limited to only a few states, with Minnesota and Iowa accounting for the vast majority of outbreaks. The states of Kansas, Washington, Oregon, Montana, Idaho, and Indiana only had outbreaks in backyard operations. Arkansas, North Dakota, Missouri, California, and Nebraska were affected in total with five outbreaks or less each.

Figure 26 is a graphical representation of this observation. It shows that both Iowa and Minnesota each had more than three times the number of outbreaks in comparison to all other states in the USA

Figure 26

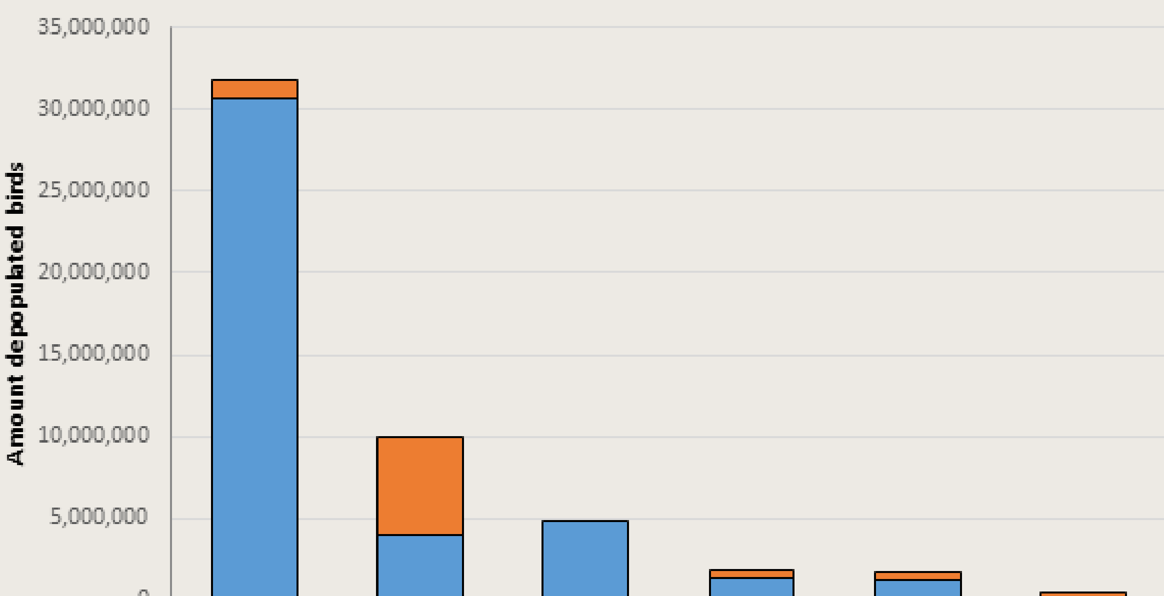
Quantity of HPAI-affected turkey and layer operations in different states
Source: USDA (2016b)



	IA	MN	Other
Turkey	71	104	21
Layer	36	5	9

Figure 27

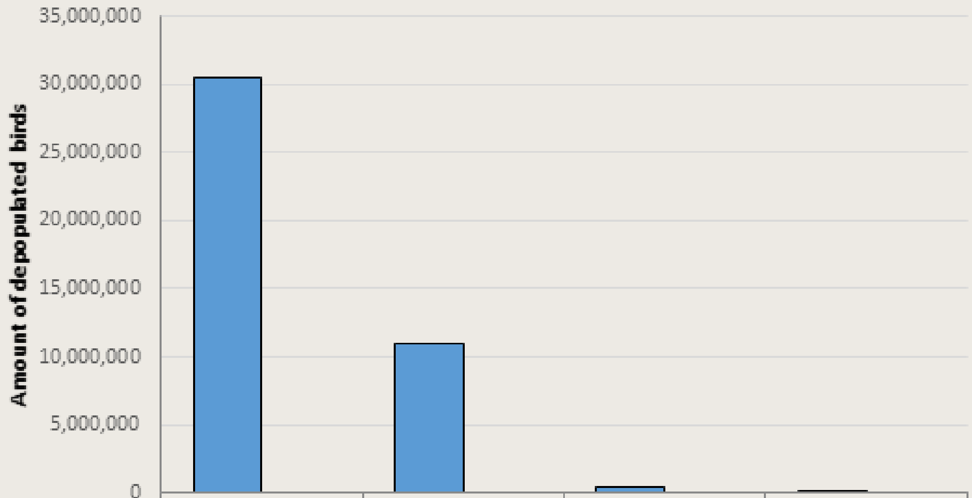
Amount of depopulated birds per state during the 2014-2015 outbreak
Source: USDA (2016a)



	IA	MN	NE	WI	SD	Other
Turkey	1,146,586	5,890,653	0	561,380	525,286	330,538
Layer	30,644,855	4,036,191	4,837,185	1,348,285	1,195,108	112,857

Figure 28

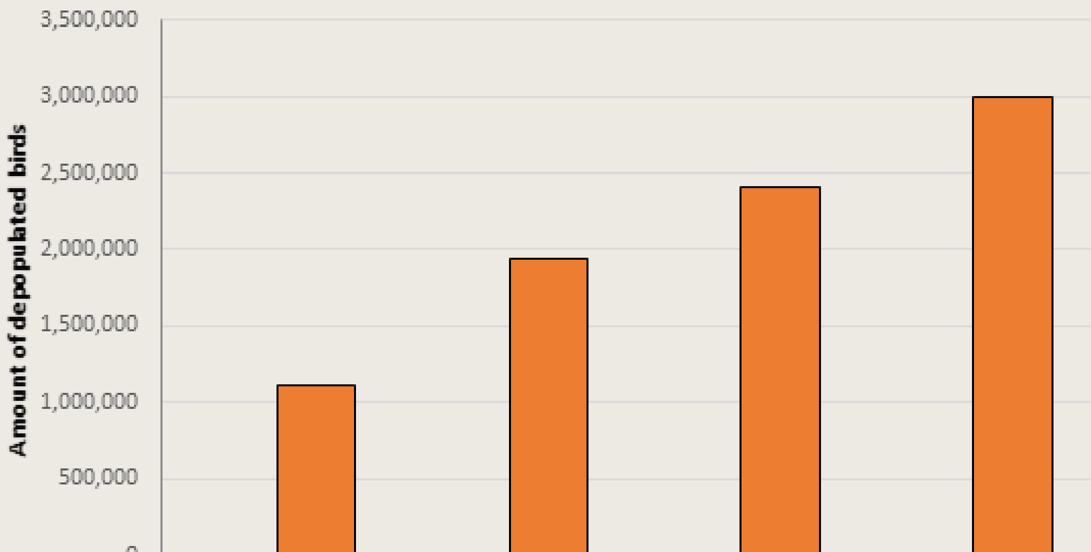
Farm sizes of affected layer operations
Source: USDA (2016a)



	>1 Mill	1Mill - 100 K	100 K - 50K	50K - 0
Layer	30,577,687	11,007,112	430,434	49,359
# Farms	14	29	5	2

Figure 29

Farm sizes of affected turkey operations
Source: USDA (2016a)



	>1 Mill	1Mill - 100 K	100 K - 50K	50K - 0
# Farms	1	11	36	110
Turkey	1,113,926	1,938,091	2,410,090	2,992,336

combined. Minnesota, with 104 affected turkey premises and five layer premises, witnessed the most HPAI infections.

Figure 27 (p. 64) shows the number of depopulated birds per state. It can be seen that the number of confirmed cases in total did not correlate with the total number of euthanized birds. Iowa culled approximately 32 million birds as part of countermeasures against HPAI. 95 percent of the culled birds in Iowa were layer chickens. In comparison, Minnesota depopulated one-third of Iowa's amount, with approximately six million turkeys and four million layer birds culled. All other states outside the two-state region depopulated 1.4 million turkeys and 7.5 million layer birds.

The following paragraph categorizes the affected poultry operations according to size to better analyze the discrepancy in farm sizes and bird numbers. Figure 28 (p. 65) allocates depopulated animals and their respective farms into four categories. Large operations with flock sizes above one million birds were categorized as such. Three more categories describe farms with a flock size between 1,000,000 and 100,000 birds; 100,000 and 50,000; and less than 50,000 birds. Figure 28 shows the affected layer operations grouped accordingly, while figure 29 carries out the same grouping for the turkey sector.

It can be seen that in the layer industry, a few operations were the site of the vast majority of euthanized birds. 14 operations were responsible for approximately 30.5 million depopulated birds, which represents 60 percent of the total amount. Figure 29 (p. 65) on the other hand shows that the majority of euthanized birds in the turkey sector were in the category having flock sizes of 50,000 or fewer birds. This makes the amount of affected operations the highest in this category with more than half.

These observations show that the average farm size of affected layer operations was significantly higher in comparison to affected turkey operations.

Table 13 compares the average farm size of turkey and layer operations that were affected by HPAI. The affected layer operations on average were more than 15 times larger than turkey operations. This again emphasizes the observations of figure 27 (p. 64), figure 28 (p. 65) and figure 29 (p. 65).

6.3.1 Chronology of impacts

A closer analysis of the chronology of events enables a better understanding of the outbreak. Figure 30 (p. 67) shows HPAI incidents per week in the USA from December 2014 until June 2015. The first HPAI outbreak cases were confirmed in December 2014. During the following months, new HPAI confirmations occurred sporadically until the virus progression reached the twin state area of Minnesota and Iowa. In this high-density poultry area, HPAI incidents increased dramatically starting in March 2015. The outbreak reached its climax in calendar week (CW) 19 of 2015, the beginning of May, with 38 HPAI incidents in one week. Until CW 23, the end of May, virus progression remained at a comparably high level. By this point, the majority of all recorded cases had been overcome. The virus progression in figure 30 strongly resembles a Gaussian bell curve, meaning that the majority of cases were within a comparably short time frame. Although the outbreak lasted more than half a year, it is now apparent that most of the

Table 13

Average farm sizes of affected layer and turkey operations
Source: Own interpretation with data from USDA (2016a)

layer operations*	turkey operations**
826,950	53,056.5

* includes layers of all ages, pullets, and breeders

** includes heavy male turkeys, light male turkeys, hens, and breeders cases occurred within of only one month.

The developments of the poultry market during the height of the outbreak are analyzed in the following paragraphs to put their disease impacts in a chronological perspective. Because the layer and turkey sector were predominantly affected, the following analysis is limited to these two species.

6.4 Impact on poultry production in the USA

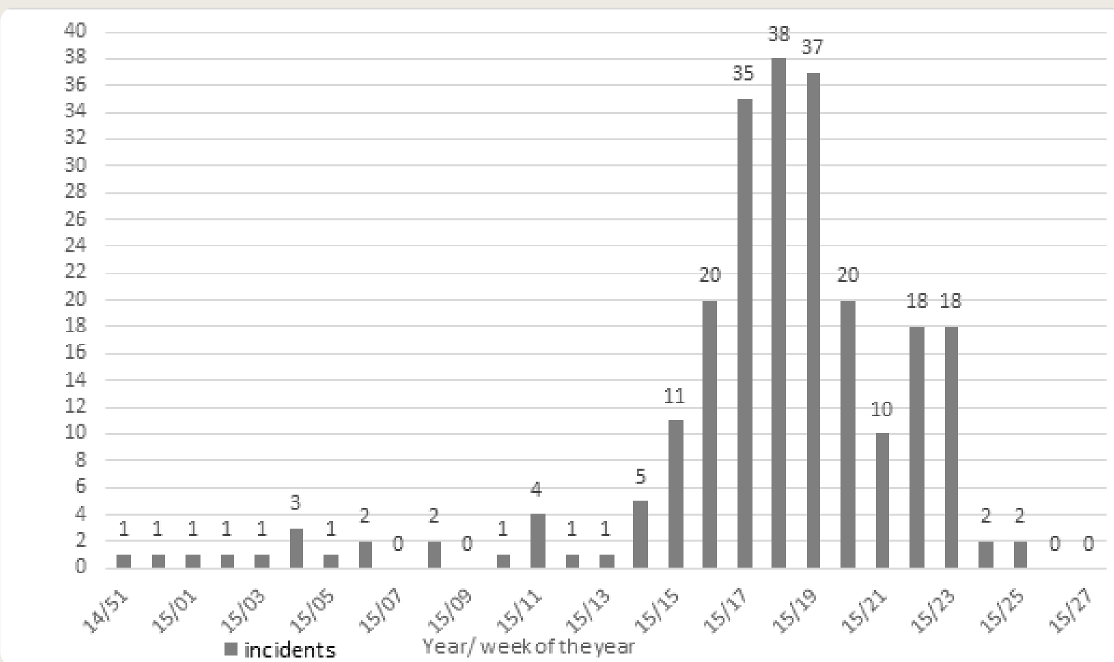
The US turkey industry is subject to a recurring cycle that is influenced by season, cultural events, and legal holidays. This cycle is visible in production curves every year. This analysis of the 2015 HPAI outbreak shows the visible effect it had on poultry production in the USA. Both layer and turkey operations were affected; the development of production and the respective prices are examined in the following, which begins with a general look at the outbreak's magnitude.

The impact of the 2015 outbreak is more closely described in table 14 (p. 68), which depicts the approximate percentage of US poultry affected by the 2015 HPAI outbreak. It is obvious that the size of the outbreak was a substantial event with implications for the entire US poultry industry. The calculations in table 14 (p. 68) were made by the Center for Epidemiology and Animal Health (CEAH), and represent a snapshot of the outbreak situation towards the end of the 2015 outbreak. The CEAH calculated the loss in production capacity of US layers at approximately ten percent of total US inventory. For pullet layer chicken, the loss was approximately six percent according to the CEAH. The turkey sector was affected with an impact of 3.16 percent.

These numbers and calculations show the significant impact of the 2015 HPAI outbreak. The USDA's final report concluded that the "[...] outbreak was the largest HPAI outbreak ever recorded in the United States and arguably the most significant animal health event in US history" (USDA, 2016a).

Figure 30

Total incidence of HPAI in the United States by week*
Source: USDA (2016c)



* Includes captive wild, commercial, and wild birds

Figure 31 displays the amount of young turkeys slaughtered per head per month from 2013 until 2016 in the state of Minnesota. Because the majority of HPAI incidents occurred there, the data of figure 31 is specifically focused on Minnesota turkey production. The line in figure 31 mirrors developments characteristic of standard seasonal behavior. In the beginning of 2015, the year of the HPAI outbreak, an expected seasonal reduction can be noticed. Under normal circumstances, the reduced amount is expected to increase during the course of the summer. Yet with the beginning of May, the effects of the HPAI outbreak fully unfolded, sharply dropping production numbers. Production levels only returned back to pre-outbreak expectations (see the four-year trend line) one year later in April 2016. Based on these observations, it can be stated that the impact of the HPAI outbreak on turkey production in Minnesota was significant.

For a comparison, figure 32 (p. 69) displays the same data for the entire USA. A drop in the numbers of turkeys slaughtered is apparent during the time of the outbreak, although this amount was not as obvious as it was for Minnesota.

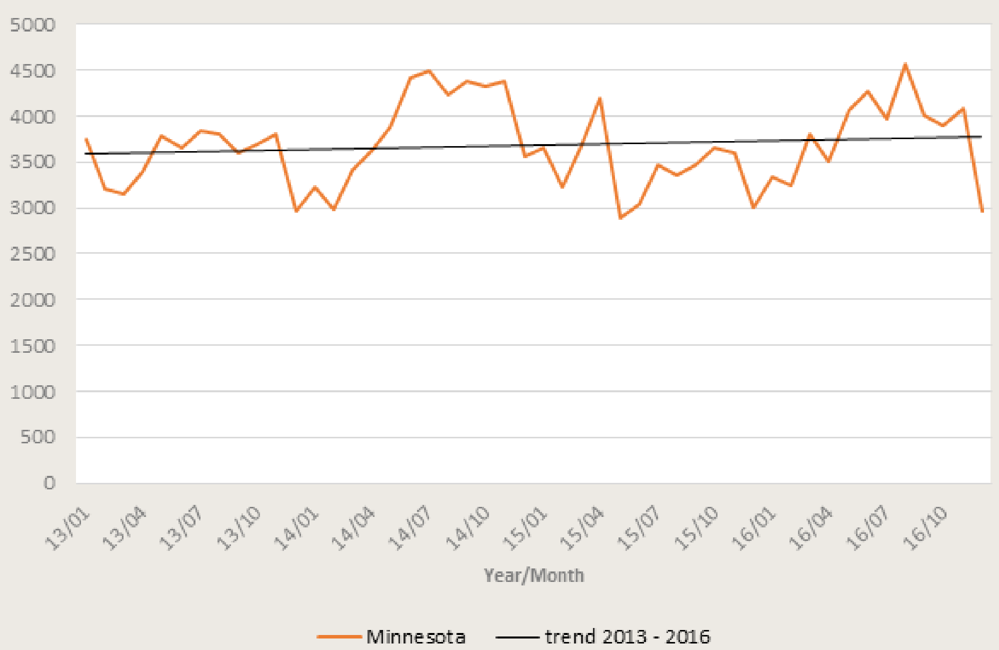
Table 14

Approximate percentage of US poultry affected by outbreak
Source: USDA (2016a)

Flock Type	Percent Losses
Layer Chickens	10.01% avg. US inventory
Pullet Chickens	6.33% avg. US inventory
Broiler Chickens	<0.01% avg. US inventory
Turkeys	3.16% annual production; 7.46% avg. US inventory

Figure 31

Slaughter of young turkeys in Minnesota per month 2013 - 2016
Source: USDA (2016a)



Further, the drop does not come across as an extraordinary event in comparison to conventional production volatilities during the time of the analysis. On the contrary, figure 32 contains some highs and lows in production that are significantly more striking. Table 14 (p. 68) showed that turkey production in the USA was impacted to a degree of less than four percent. Figure 32 and the findings of this chapter support an assumption of a relatively low impact of the HPAI event on the entire US turkey production.

The following paragraphs repeat the analysis over time for the layer sector. Figure 33 displays the aver-

Figure 32

Turkey slaughter per month in the United States 2013 - 2016
Source: USDA (2016a)

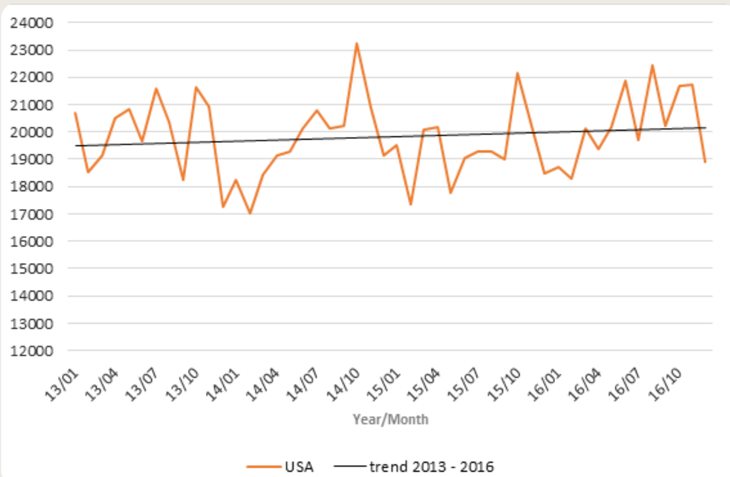
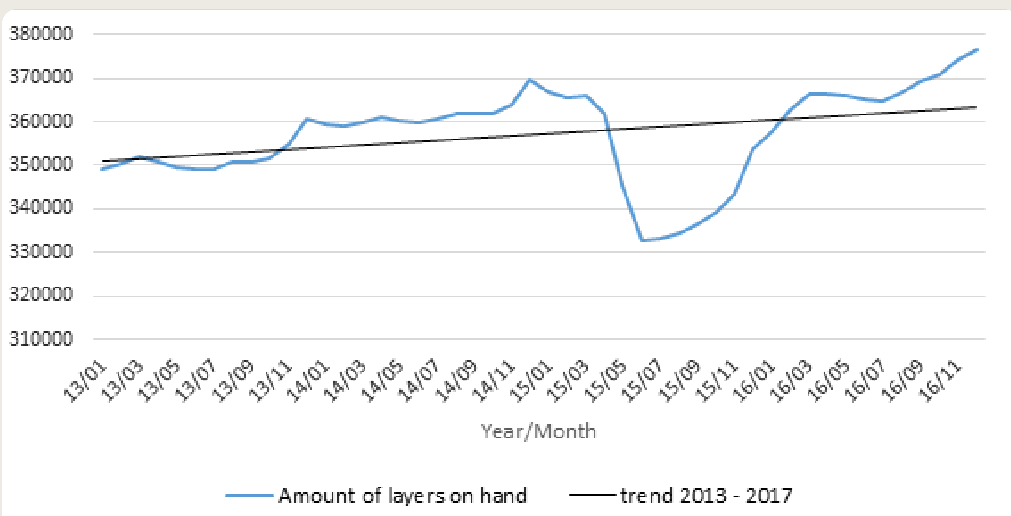


Figure 33

Average number of all layers on hand from 2013 – 2017
Source: USDA (2016a)



age number of layers at hand from 2013 until 2016. Table 14 (p. 68) above described the impact on the US layer industry as slightly more than 10 percent. Figure 33 (p. 69) shows that between April 2015 and April 2016 there was a significant drop in comparison with the 2013–2017 trend line. A decrease in layers starting at the moment of the first outbreaks is clearly visible. Figure 33 supports the notion that the 2015 HPAI outbreaks had a noticeable impact on the layer sector in the USA.

Figure 34 shows the total egg production in the USA in the same time span. Similar to turkey production, the layer industry in the USA is strongly influenced by seasonal patterns, which is visible in figure 34. Following the end of the year, there is generally a noticeable drop in production that is overcome in a matter of two months. Figure 34 shows that this seasonal pattern was interrupted starting in March 2015. US egg production fell significantly during the entirety of 2015. Only in the beginning of April 2016 pre-outbreak production numbers were regained.

In conclusion, the impact of the HPAI outbreak on production was significantly more noticeable in the US layer sector than in the turkey sector. This however does not suggest that the outbreak was not of importance for the turkey industry. The HPAI outbreak still was in fact the single most significant disease event in its history.

6.5 Direct costs (DC)

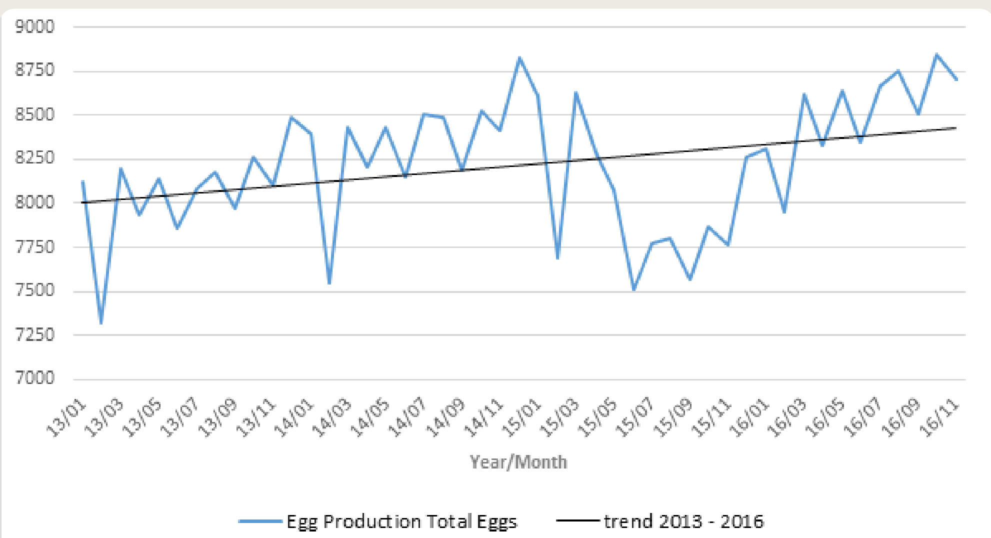
Chapter 5.2 depicted the framework for economic impact analysis as defined by Saatkamp et al. (2014). The following sections will map out the economic impacts in the USA according to the categorization by Saatkamp et al. (2014).

6.5.1 Farmers

HPAI mitigation efforts have an immediate effect on every farmer, even though the costs that arise with mitigation procedures are absorbed by governmental institutions. The process is organized in a

Figure 34

Total egg production in the United States by month 2013 - 2016
Source: USDA (2016a)



way that starting from the moment of official confirmation, governmental institutions provide for and organize all further steps (USDA, 2012). Government officials confirm a plan of action with the farmer and then proceed with euthanasia as well as cleaning and disinfection. During the time of the first countermeasures, the farmer's role is limited to peripherally supporting mitigation activities. Flock loss is compensated through indemnity payments for all birds destroyed. This means that bird losses are also paid for by governmental institutions. In cases where the farmer is actively engaged in these mitigation activities, he/she is compensated for them at predefined fixed rates. The costs for first mitigation measures are paid by governmental institutions. The subsequent chapter describes these in more detail.

6.5.2 National government and supra-national government

Consistent with the categorization by Saatkamp et al. (2014), governmental institutions and supra-national governmental institutions each represent a separate stakeholder group. Even though they are categorized as separate groups, they are combined in this chapter. Governmental institutions are the leading agents authorized to act in the instance of HPAI outbreaks.

6.5.2.1 Organizational costs

Organizational costs represent a significant part of total DC paid by governments. This paragraph is a description of the organizational efforts by the US government during the 2015 HPAI outbreak.
In December 2014 after the first HPAI case was officially confirmed, a so-called incident coordination group (ICG) was established. Later during the outbreak in April 2015, which was a month with exceptionally high rates of new HPAI incidents, the ICG was scaled up considerably due to the increasing scope and challenges of the outbreak. In June 2015, a so-called multiagency coordination group (MAC) to "coordinate resources across the agency" was additionally established (USDA, 2016d). These were coordinative instruments for the overall organization and management of the outbreaks.

Between the first outbreak in December 2014 and the last outbreak in June 2015, so-called national incident management teams (NIMTs) of the veterinary services of APHIS were engaged with organizing and supervising countermeasures across the different outbreak areas. Due to the scale of these, a new and additional NIMT was set up later during the outbreak. In addition, a national animal health emergency response corps (NAHERC) was appointed to support mitigation efforts, which included additional personnel who were trained in Ames, Iowa prior to their deployment.

In total, there were 1,220 deployments by 773 individuals, some of whom were deployed several times (USDA, 2016a). Two hundred temporary employees were also hired for the outbreak. An additional 300 personnel were deployed to ICGs for support purposes, for example in Ft. Collins, Colorado, where a national permitting unit was established (USDA, 2016d). Contractors supported the operations at all times (USDA, 2016d), and were used in different functions. ICGs used contractors to support coordination activities and were supported by full-time logistics management specialists and dispatchers (USDA, 2016d). The majority of contractors were used for depopulation, cleaning, and disinfection.

Additionally, security services, credentialing assistance, equipment rentals, and materials were provided by external contractors. Since composting was the primary choice for waste and carcass management, it required a large amount of personnel. Composting was executed by small and medium-sized enterprises (SMEs). At the height of disposal activities, 51 SMEs were deployed in the field (USDA, 2016d). Over the course of the outbreak, a total of 90 external individuals or organizations were contracted to support countermeasure efforts (USDA, 2016a). In peak periods, a total of 3,400 personnel, of which 3,000 were support contractors, 250 APHIS personnel, and 180 state responders, were engaged in mitigation activities.

Figure 35 shows the amount of APHIS personnel deployed in the different states. The figures show that Iowa and Minnesota were responsible for 89 percent of all deployments. This stands to reason considering the distribution of HPAI incidents across the states in the upper midwestern region.

Figure 36 shows the allocation of personnel along the timeline of the outbreak. In CW 27 of 2015 there was a peak in the number of personnel deployed. Preceding the peak, there was a steady build-up of personnel from CW 21 onwards.

Figure 35

Total number of APHIS personnel deployed to the states of incident
Source: USDA (2016a)

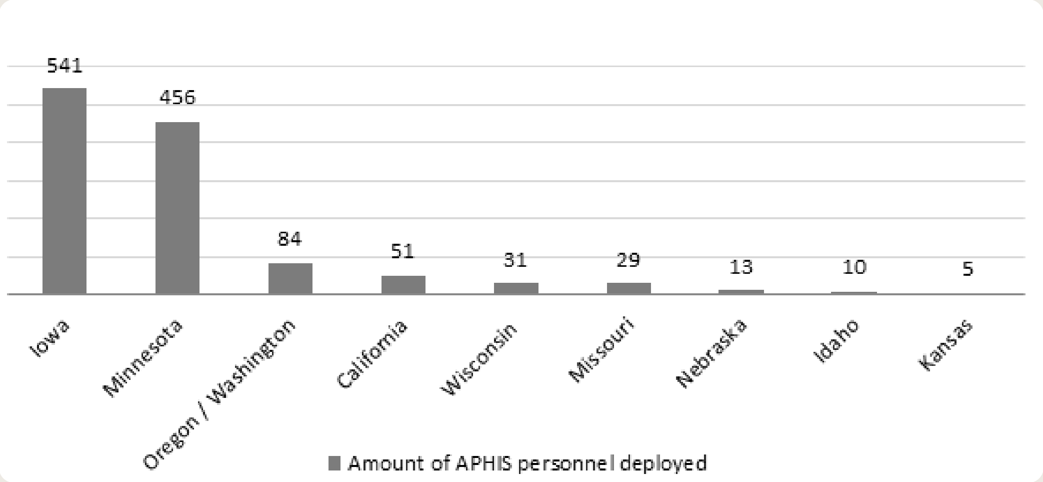
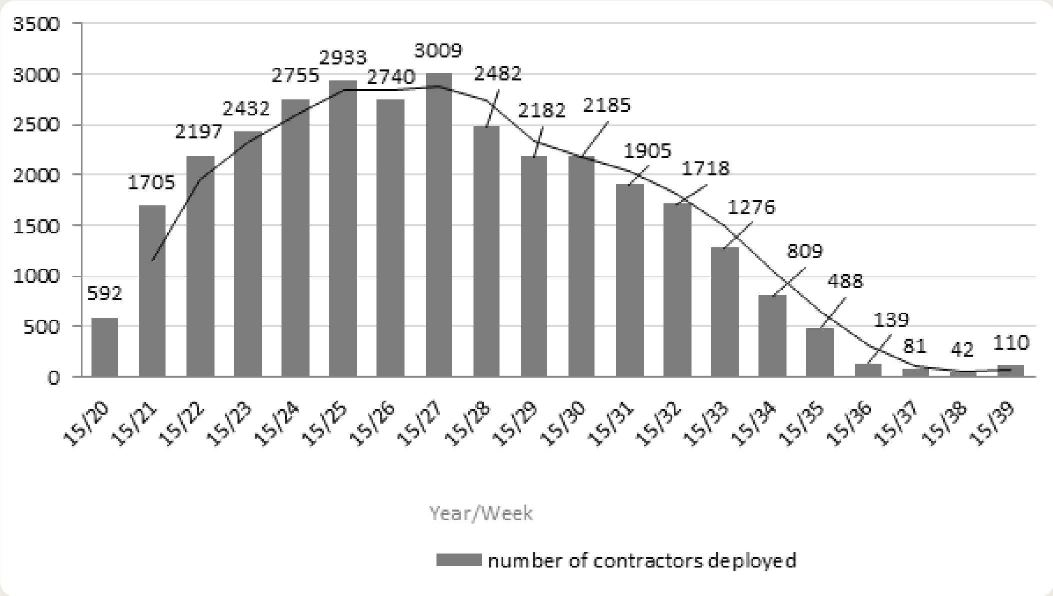


Figure 36

Number of contractors deployed during the outbreak
Source: USDA (2016a)



After CW 27, the use of personnel decreased steadily.

Figure 30 (p. 67) above describes the number of new incidents per week. Comparing figure 30 and figure 36 (p. 72), it is evident that there was a time-related shift between the occurrence of new incidents and use of personnel. While the number of new HPAI incidents was highest in CW 19, the use of personnel was highest in CW 27 of 2015. There are likely two reasons for this. First, depopulation activities do not require as much personnel as composting, cleaning, and disinfection. Cleaning activities commence only after depopulation is completed, so it is plausible that the need for personnel was higher later in the process of managing the outbreaks. Second, the southern epicenter where large layer operations were affected by HPAI developed later in the outbreak. These large operations required considerably more personnel for cleaning activities. Here it's seen that relatively few incidents resulted in the deployment of extensive personnel.

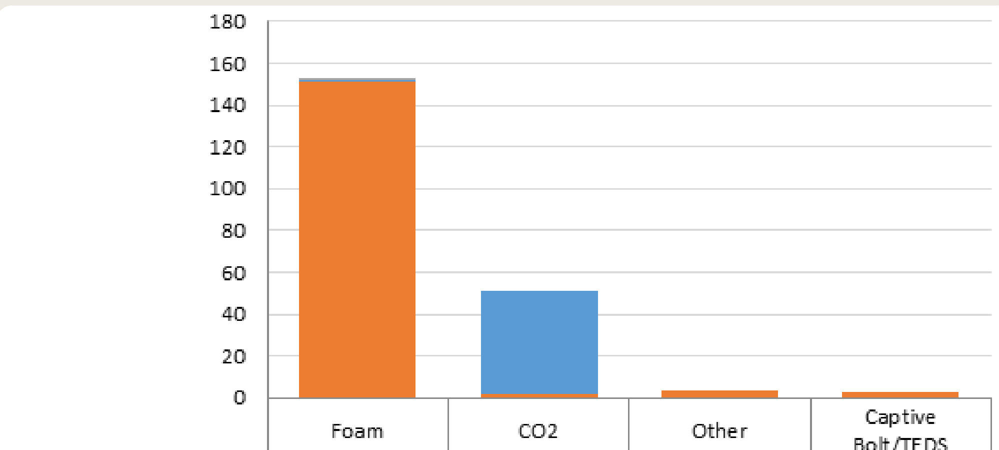
6.5.2.2 Depopulation, cleaning, and disinfection

Figure 37 shows depopulation methods by flock type. It is noticeable that foam was the method of choice for depopulation of turkey flocks, whereas CO_2 was primarily used for layer stocks. The apparent difference is likely based on differences in rearing systems. Turkey in the USA are floor-raised, for which foaming is most effective. Layer operations, especially large operations, apply high rise cage systems for production, which makes the use of CO_2 as a depopulation method necessary. As a consequence, foaming was applied only once in layer operations, whereas it was used 151 times in turkey operations. Depopulation of layer flocks was completed using CO_2 in 49 incidents, whereas only two turkey operations were depopulated using CO_2. Captive bolt and other methods were used on four and three turkey operations respectively, and not a single time for chicken or mixed poultry.

The disposal of carcass and material waste is a "key component of a successful response to a FAD outbreak" (USDA, 2016d). Simultaneous use of composting, burial, incineration, landfill, rendering, digesters, as well as a combination of methods were applied for the disposal of carcasses and infected ma-

Figure 37

Depopulation method by flock type for commercial premises
Source: USDA (2016d)



	Foam	CO2	Other	Captive Bolt/TEDS
Mixed Poultry / Other	1	0	0	0
Chicken	1	49	0	0
Turkey	151	2	4	3

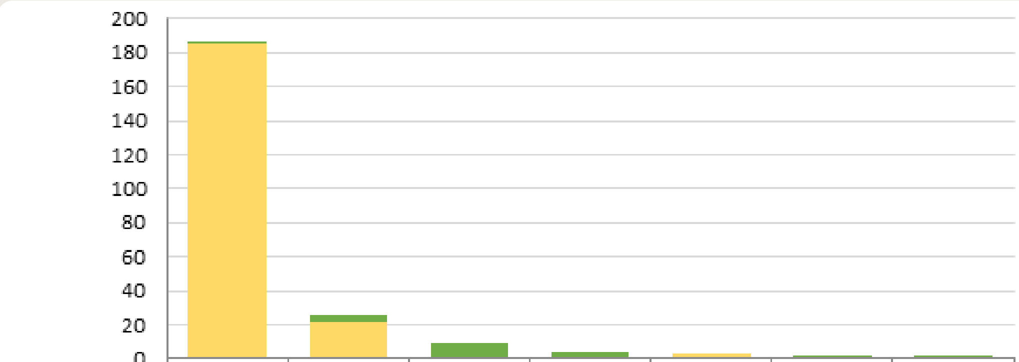
*Other: Combination of methods or other methods such as cervical dislocation terial. Figure 38 shows the primary disposal methods during the 2014-2015 outbreak. Composting was the method of choice for the majority of all incidents. In nearly all commercial flocks, burial or composting was applied. Alternative methods such as incineration, landfill, rendering, or digesters were used only in backyard operations.

For cleaning and disinfection, the APHIS lists wet disinfectant, heat treatment, extended fallow, and a combination of these methods.

Figure 39 displays the disinfection methods used for all premises. Wet disinfectant was used in 179 commercial premises and nine backyard operations, making it the primary disinfection method. Heat treatment was applied in 26

Figure 38

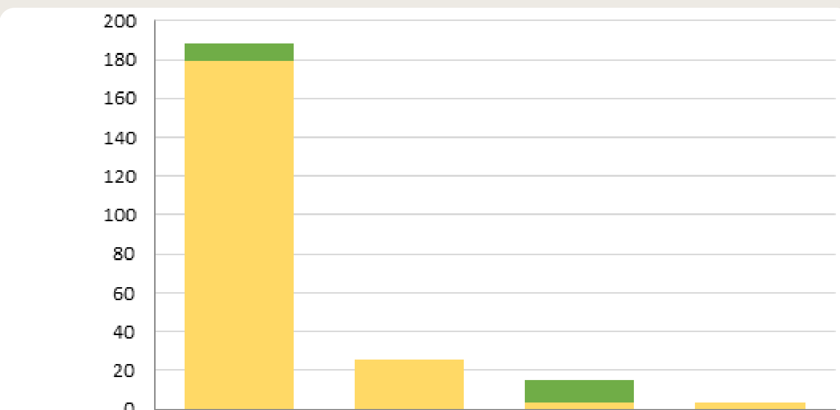
Primary carcass disposal methods
Source: USDA (2016d)



	Composting	Burial	Incineration	Landfill	Multiple	Rendering	Digester
Backyard	1	5	8	3	0	2	2
Commercial	185	21	1	1	3	0	0

Figure 39

Disinfection method used for all premises
Source: USDA (2016d)



	Wet disinfectant	Heat Treatment	Extended Fallow	Combination of Methods
Backyard	9	0	12	0
Commercial	179	26	3	3

commercial premises, and not at all in backyard operations. Extended fallow was used 12 and three times for backyard and commercial premises respectively. A combination of methods was used three times in commercial operations. The APHIS decided on a case-by-case basis which method was optimal; this was based on the availability of material, personnel, farm type, and local circumstances (USDA, 2016d). Similar to the procedures of disposal activities, the most important element in cleaning and disinfection was the possibility of “rapid contracting to obtain additional personnel for the response efforts” (USDA, 2016d).

6.5.2.3 Costs for mitigation activities

This chapter gives an overview of the available data about the allocation of costs to different response activities. Variables such as farm type, farm size, depopulation method, and deposal method each had a different impact on the overall costs (APHIS, 2016). In its final report, the APHIS declared the total “virus elimination costs” and “response activity costs” (USDA, 2016d). Both terms refer to the same activities of disposal, cleaning, and disinfection.

As can be seen in table 15, response activity costs were significantly higher with commercial layer farms. It was seen earlier in chapter 6.3 that layer operations on average, but especially in the focus area of the outbreak, were significantly larger, helping to explain the higher average costs for layer operations. In addition, the layer operation farm type is typically a multi-layer cage system that is considerably more difficult to empty, clean, and disinfect. Turkey operations on the other hand are typically constructed as floor-raising premises that allow for faster execution of response activities.

It is also useful to look at the response activity costs in terms of regional differences. While table 15 shows that the type of operation influences the cost structure, table 16 makes clear that there were also regional differences. Johnson et al. (2016) state that besides the differences in operation type, the area of the outbreak in Minnesota offered a higher availability of equipment and labor. In Iowa on the other hand, “limited availability of labor and other inputs drove up logistics costs and became constraining for responders working to depopulate quickly after disease detection” (Johnson et al., 2016).

These examples show that there was not a fixed rate of costs for response activates. They changed with different internal and external factors such as farm type or in terms of the regional availability of resources.

Farmers were compensated for work assistance in response activities using so-called cooperative compliance agreements (USDA, 2016d). The costs associated with these are paid by governmental accounts as well.

Approximately $200 million was paid for indemnification during the entire outbreak (USDA, 2016d). 232 commercial appraisals and 44 tra-

Table 15

Average virus elimination costs for flock type
Source: Johnson et al. (2016)

Turkey Grow-Out Farm	Commercial Layer Farm
$170,000	$8,000,000
100%	4705%

Table 16

Response activity costs per bird
Source: Johnson et al. (2016)

Minnesota	Iowa
$ 4.63	$ 14.47
100%	312.53%

ceouts were issued (USDA, 2016d). For data privacy reasons, there is no information publicly available as to the exact amounts of indemnity payments for each farm. In addition, there is no data on how many farm operators carried out cleaning and disinfection themselves or participated in the process. A study by Decision Innovation Solution (2015) calculated the exact insurance amounts using estimates; these are described in more detail in the direct consequential cost (DCC) category.
When the outbreaks occurred, the states of Iowa, Minnesota, Nebraska, and Wisconsin declared a state of emergency, allowing them to make use of additional resources provided by partnering state agencies, as well as the US Department of Homeland Security. Iowa in addition requested a Stafford Act declaration to obtain more resources on the federal level (it was denied (USDA, 2016d)). Since expenditures for the mitigation of the outbreak quickly outgrew the appropriated avian health funds, the Secretary of Agriculture made use of the Commodity Credit Corporation (CCC) (USDA, 2016d). The purpose is stated on the website:

"*The Commodity Credit Corporation (CCC) is a Government-owned and operated entity that was created to stabilize, support, and protect farm income and prices. CCC also helps maintain balanced and adequate supplies of agricultural commodities and aids in their orderly distribution.*"[1]

Monetary funds in the amount of $393 million were transferred in April and May. These were followed by $305 million in July and $291 million in September of 2015. In total, $989 million were transferred from the CCC fund, of which $850 million were directed towards response activities (USDA, 2016d).

Table 17 displays an overview of all government spending for the 2014-2015 outbreak. They are entirely direct costs that farmers are not required to incur.

6.6 Direct consequential costs (DCC)

Direct consequential costs (DCC) are discussed in this section. As outlined in chapter 5.2, the starting tableau by Saatkamp et al. (2014) defines major cost categories.
The costs described in this section were incurred after the initial days of the outbreak. DCC arise as a result of downtime and idle production that occur after barns have been processed. On July 5th, 2015 there was a hearing before the US Congress on this topic, with experts explicitly noting that future lost production, i.e. DCC, was not addressed at all in terms of indemnity payments (CONGRESS, 2002). Johnson et al. (2016) make clear that although indemnification is intended for response and clean-up, "Production or income losses incurred during downtime or other business disruptions" (Johnson et al., 2016) are not covered by indemnification payments. Compensation to farmers was equivalent to the fair market value of the animals, but did not pay for the loss of production. Loss of production occurred for two reasons. The presence of movement restriction zones (MRZ), named regulatory control areas (RCA) by the APHIS (USDA, 2016d) prevented farmers from returning to operation. Second, the loss of breeder

[1] https://www.fsa.usda.gov/about-fsa/structure-and-organization/commodity-credit-corporation/index , Retrieved: February 22nd, 2018

Table 17

Government spending in the 2014-2015 HPAI outbreak
Sources: Johnson et al. (2016) and USDA (2016d) and Johansson et al. (2016)

Field of application	Funds applied
Depopulation*, cleaning, disinfection	$ 610 Million
Indemnification	$ 200 Million
Overtime, travel, supplies for vet services	$ 35 Million
Fall planning costs	$ 34 Million
Total	$ 879 Million

*includes disposal of animals

stock animals in both the layer and turkey industry prevented producers from returning to pre-crisis capacities immediately (USDA, 2016b). All information available concerning idle production based on MRZ or breeder stock loss is discussed in this section, which concludes with estimates on how this production disruption impacted the economy. Based on previous research using so-called IMPLAN analysis, data is calculated that shows the financial impact across all stakeholder groups.

6.6.1 MRZs, permitting, and restocking speed

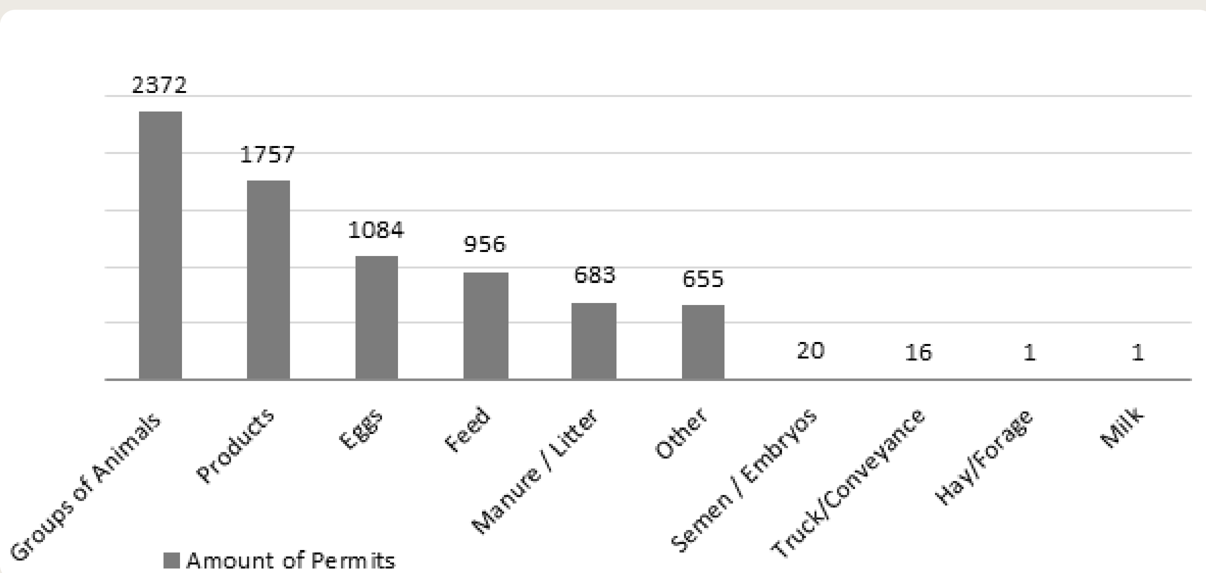
During the 2014-2015 US outbreak, a total of 7,800 permits were issued that permitted approximately 20,000 movements between local stakeholders (Thompson & Pendel, 2016). These permits were based on both intra- and interstate movement. The latter accounted for 61 percent of all movements (Thompson & Pendel, 2016). The involved governmental institutions across the USA used an emergency management response system (EMRS) software to record permitting activities. Although the amount of omitted permits is believed to be minor (Thompson & Pendel, 2016), in some cases, procedural problems resulted in non-tracking of permits, meaning that some movement could have occurred without showing up in this data.

Figure 40 shows the number of permits issued per item. The movement of groups of animals, products, and eggs were permitted the most. Semen/embryos and truck/conveyance was permitted the least. Categories such as hay/forage and milk were permitted once and can be regarded as exceptions. The overview shows the importance of being able to move animal and animal products for the layer and turkey industry.

In terms of local distribution of permits, figure 41 (p. 78) shows that the majority of all permits were issued in either Iowa or Minnesota. This comes as no surprise since the outbreak's hotspot areas were located here. Figure 40 and figure 41 show that a considerable amount of permits were issued. It is crucial to notice that each permit is a transaction in itself, in which the personnel working on a farm has to apply for the permit and provide proof of its necessity, and where governmental institutions have to assess and

Figure 40

Number of permits issued by item permitted
Source: (USDA, 2016b)



process the application as a result. Although there is no data available as to how significant the delays in daily operation were, it can be expected that some did in fact occur due to the constant permit administration going on at this particular time.

Figure 42 shows the average times from NVSL confirmation until depopulation complete status, until virus elimination/cleaning and disinfection complete, and restock approval. The official NVSL confirmation date is the date an outbreak was entered into the EMRS software. During the height of the outbreak, a confirmed H5-type virus was sufficient for an official NVSL entry into the EMRS; it did not require additional subtype data (USDA, 2016d). The time spans shown in figure 42 are averages across all incidents, and exclude dangerous contact premises. The average time from NVSL confirma-

Figure 41

Number of permits issued by state of origin
Source: USDA (2016a)

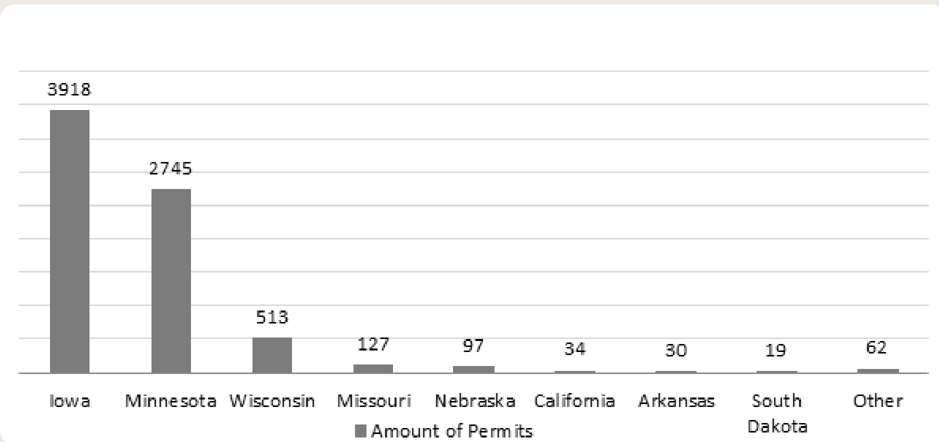
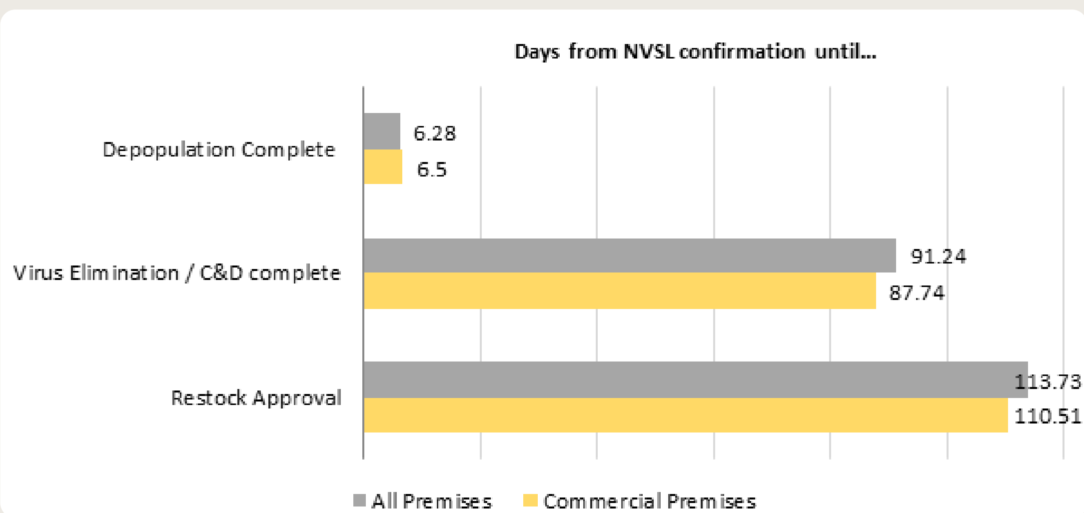


Figure 42

Average times to depopulation complete, to cleaning and disinfection complete, and restock approval for commercial premises and all premises; in days
Source: Own adaptation with data from USDA (2016d) and USDA (2016a)



tion until depopulation complete was 6.28 days for all premises and 6.5 days for commercial premises only. Cleaning and disinfection activities took on average 91.24 days and 87.74 days for all premises and commercial premises respectively. Restock approval occurred after 113.73 days for all premises and after 110.51 days for commercial premises. Backyard premises were quicker to be depopulated, yet slower to have completed virus elimination activities. Because animal numbers are significantly lower with backyard operations, a quick depopulation is to be expected. Virus elimination here was noted to have taken longer because 57 percent of all backyard operations chose an extended fallow period as their disinfection method, explaining the more extended period for all premises in figure 42 (p. 78).

Figure 43 shows the amount of RCAs released during the outbreak

Figure 43

Number of control areas released by month for all premises
Source: USDA (2016a)

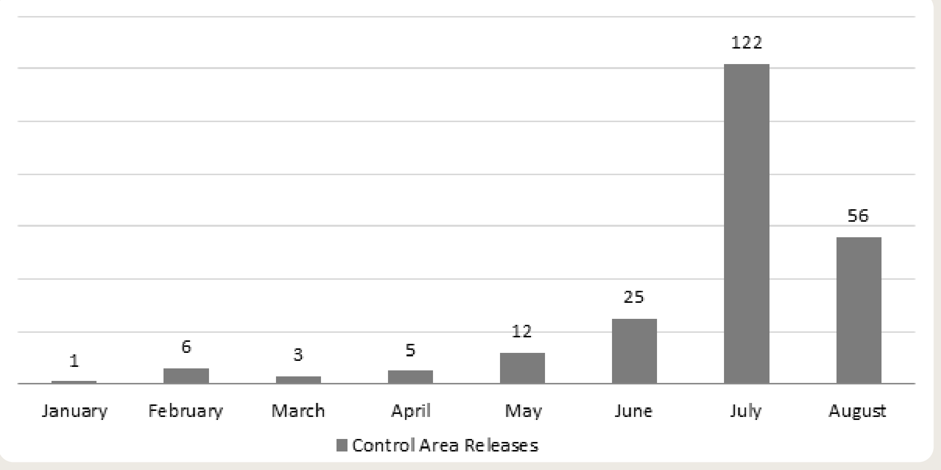
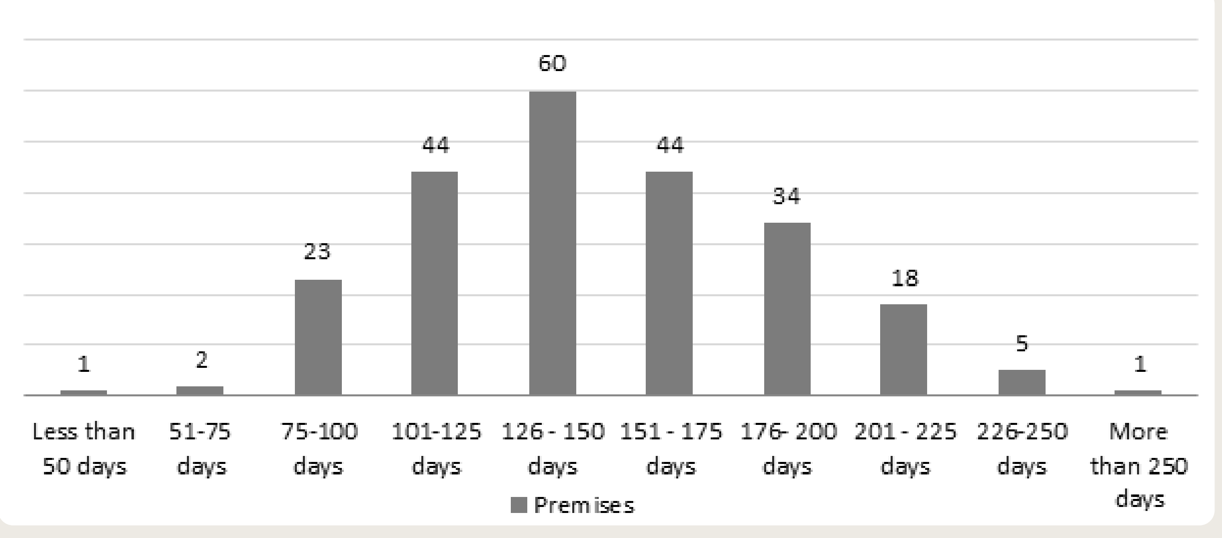


Figure 44

Length of quarantine for all premises
Source: USDA (2016a)



and its aftermath. It can be seen that the release of control areas lagged respective of the duration of depopulation, cleaning, and disinfection activities. The month of July with 122 RCA released was the month with the highest release rate.

Figure 44 (p. 79) shows the length of quarantine for all affected premises. The total number of premises here is higher because some new premises were placed in quarantine for preventive reasons even though they did not have an HPAI outbreak (USDA, 2016b). The figures indicate that the majority of all affected premises were under quarantine between 126 to 150 days. Figure 44 also shows that almost half of all the affected premises were under quarantine restrictions for more than 150 days. The average length for all premises was 149 days. This is significant in light of the fact that the APHIS does not pay compensation for production downtime. Commercial premises and backyard premises were in idle status for 147 and 157 days respectively.

Overall it can be seen that it took considerable time – almost a third of a year – until operations were potentially able to restart production. This was especially detrimental with regard to breeder stock operations whose capacities were needed in the industry to restock after the outbreak was fully contained. This is the reason why the industry took even longer than that to fully recover. The following section goes into further details concerning exact downtimes.

6.6.2 The IMPLAN model

Research has been done on the specific topic of the post-outbreak effects of the 2014-2015 outbreak. Both the University of Minnesota Extension (2015) and the private company Decision Innovation Solutions (2015) conducted in-depth research using an IMPLAN model. The results of these studies are used in this section to describe the outbreak's DCC in detail.

6.6.2.1 The IMPLAN methodology

IMPLAN analysis is based on an input-output (I-O model) of the American economy. I-O models were initially developed by Wassily Leontief in 1938 and have since been a favorable model for impact analysis in the US economic sector (Leontief, 1986; Miller & Blair, 2009). IMPLAN (impact analysis for planning) was initially developed by the US Forest Service, the Federal Emergency Management Agency, and the US Department of the Interior Bureau of Land Management to create a tool that assists in land and resource planning. The model is a regional input-output model type (Lynch, 2000). Along with other I-O models such as REMI (regional economic model), RIMS (regional input/output modelling system) or RIMS II, these are the most widely used I-O modeling concepts (Lynch, 2000). With advances in computer speed since the 1950s, this type of economic modeling grew in importance and eventually led to the foundation of the International Input-Output Association in 1998 (Miller & Blair, 2009).

Today the IMPLAN model incorporates a total of 536 industries in its analysis and how these interact on a national and regional level (IMPLAN Group, 2018). If crucial data is not publicly available, this information is computed using econometric data. The analysis can be scaled down to county or ZIP code levels. Data is updated continuously and composed of publicly available information provided by the US Bureau of Economic Analysis, the US Bureau of Labor Statistics, and the US Census Bureau (IMPLAN Group, 2018). If crucial data is not publicly available, this is computed using econometric data (IMPLAN Group, 2018).

The IMPLAN model analyzes economic impacts on three levels: direct, indirect, and induced. Applied to the layer and turkey industry, it shows a loss of flocks as follows. The direct impact is an "initial change in the economy" (Extension, 2015) meaning the initial flocks lost and the corresponding decrease in demand for pullets, feed, vet services, and other inputs (Decision Innovation Solution, 2015). The supplier of these services in return will purchase fewer goods because their service is not needed for the time of the outbreak. This is referred to as the indirect effect. The third effect, the induced effect, describes the lost income of employees of all of these suppliers. Lacking income during an outbreak, these employees will likely spend less money in the local economy, which will in return affect all these businesses (Extension, 2015). The sum of all three effects is the total multiplier effect (Decision Innovation Solution, 2015). The impact effects can be traced up and down the value chain using IMPLAN analysis (IMPLAN Group, 2018). For a thorough understanding of DCC, the effects on other stakeholder groups are essential; the data generated in these IMPLAN studies are suitable for describing it.

6.6.3 DCC calculation

The information provided by the studies (Decision Innovation Solution, 2015; Extension, 2015) was computed while the outbreak was still underway. The University of Minnesota for example conducted an emergency economic impact analysis (EEIA) and explicitly indicated that a final analysis with updated data would have to be conducted after the outbreak (Extension, 2015). All information presented here is updated with the official APHIS data. Both the University of Minnesota Extension and Decision Innovation Solutions provided data that potentially allows for an analysis based on lost jobs in the processing industry. There is however no precise official data available as to how many jobs were lost. For this reason, the calculations are based on impacts resulting from idle production on the farm level.

6.6.3.1 Value of lost layer production 2014-2015

Table 18 shows the value of the layer production that was lost during and after the 2014-2015 HPAI outbreak. The calculation displays the lost egg production over the time it took to regain full produc-

Table 18

Lost value layer sector in the 2014-2015 HPAI outbreak
Sources: "Lost hens (Millions)": (USDA, 2016b), "Lost pullets (Millions)": (USDA, 2016b), "Lost breeder": (USDA, 2016b), "Days until production recovery": see chapter 6.2, "Average daily egg laying rate hens": (Elam, 2015), "Percentage breaker eggs (%)": (Elam, 2015), "Percentage shell eggs (%)": (Elam, 2015), "Pre-crisis value breaker eggs / dozen ($)": (Elam, 2015), "Pre-crisis value shell eggs / dozen ($)": (Elam, 2015), "Loss breaker eggs ($, Millions)": Own calculation, "Loss shell eggs ($, Millions)": Own calculation, "Total loss layer industry ($, Millions)": Own calculation

Description	Amount	Calculation
Lost hens (Millions $)	35.9	
Lost pullets (Millions $)	5.93	
Lost breeder*	45,455	
Days until production recovery	365	
Average daily egg laying rate hens	0.8	
Dozen eggs per lost hen and pullet	24.3	365 x 0.8 / 12
Percentage breaker eggs (%)	64	
Percentage of shell eggs (%)	36	
Pre-crisis value breaker eggs / dozen ($)	0.96	
Pre-crisis value shell eggs / dozen ($)	1.29	
Loss breaker eggs (Millions $)	624.52	41.83 x 24.3 x 64% x 0.96
Loss shell eggs (Millions $)	472.05	41.83 x 24.3 x 36% x 1.29
Total loss layer sector (Millions $)	1,096.57	624.52 + 472.05

*not included in value lost calculation

tion. Chapter 6.4 described the continuation of production after the outbreak and when production reached pre-crisis levels again. Breeders are not included in either calculation. There was also no data available regarding the value of breeder animals. It is likely that this value changes from one operation

Table 19

Lost value turkey production in the 2014-2015 HPAI outbreak
Sources: "Live pounds per heavy male turkey (lbs.)": (Elam, 2015), "Live pound per light male turkey or hen (lbs.)": (Elam, 2015), "Live pound per heavy hen (lbs.)": (Elam, 2015), "Processor value heavy male turkey / pound ($)": (Elam, 2015), "Processor value light male turkey or hen / pound ($)": (Elam, 2015), "Heavy male turkey lost (Millions)": (USDA, 2016b) (Elam, 2015), "Light male turkey and hen lost (Millions)": (USDA, 2016b) (Elam, 2015), "Turkey breeder lost (Millions)": (USDA, 2016b), "Total direct loss ($, Millions)": Own calculation, "Subsequent heavy male turkey lost (Millions)": (Elam, 2015), "Subsequent heavy male turkey lost (lbs., Millions)": (Elam, 2015), "Subsequent loss ($, Millions)": Own calculation, "Seasonal surplus hens (Millions)":(Elam, 2015), "Hens used for breeder replacement (Millions)": (Elam, 2015), "Surplus hens (Millions)": (Elam, 2015), "Net gain surplus hen production (lbs., Millions)": Own calculation with data from (Elam, 2015), "Net gain surplus hen production ($, Millions)": Own calculation, "Total loss turkey sector ($, Millions)": Own calculation

Description	Amount	Calculation
Live pounds per heavy male turkey (lbs.)	45	
Live pounds per light male turkey or hen (lbs.)	16	
Live pounds per heavy hen (lbs.)	25	
Processor value heavy male turkeys/pound ($)	1.29	
Processor value light male turkeys or hens/pound ($)	0.90	
Direct loss		
Heavy male turkeys lost (millions)	4.24	
Light male turkeys and hens lost (millions)	3.54	
Turkey breeders lost* (millions)	0.6	
Total direct loss ($, millions)	297.1	45 x 4.24 x 1.29 + 16 x 3.54 x 0.9
Subsequent loss		
Subsequent heavy male turkeys lost (millions)	4.35	
Subsequent heavy male turkeys lost (lbs., millions)	196	4.35 x 45
Subsequent loss ($, millions)	252.84	196 x 1.29
Surplus hen gain		
Seasonal surplus hens (millions)	5.57	
Hens used for breeder replacement (millions)	4.41	
Surplus hens (millions)	1.16	5.57 – 4.41
Net gain surplus hen production (lbs., millions)	29	1.16 x 25
Net gain surplus hen production ($, millions)	26.1	29 x 0.9
Total loss		
Total loss turkey sector ($, millions)	523.84	297.1 + 252.84 – 26.1

*not included in value lost calculation

to another depending on their genetic potential, thus allowing no uniform value to be determined. The calculation above is based on updated post-outbreak data, and shows that the economic impact effect on the layer sector accounted for $1,096.57 million in losses. This is the financial impact to the layer sector resulting from idle production during and after the outbreak, and does not include any costs incurred for depopulation or cleaning activities.

6.6.3.2 Lost value of turkey production

Table 19 (p. 82) shows the lost value of turkey production due to the 2014-2015 HPAI outbreak in the USA. For the turkey sector analysis, a separation is made between the initial direct loss of turkeys, the subsequent loss, and gains allowed by being able to use surplus hens that otherwise would not have been fed to higher weights. The initial loss was the depopulation of affected turkey flocks, including breeder animals. The subsequent loss is the loss of production due to the inability to restock operations due to a lack of breeder animals after the outbreak. Once production commenced again, there was in fact a gain in using surplus hens, because under normal circumstances there are more hens than needed, mainly out of season in summer and winter. A part of these surplus hens are then used for breeder operations. In this instance it is not efficient to grow these hens to higher weights, as feed consumption is higher and live pounds before slaughter are lower when compared to male turkeys. The loss of turkey flocks during the HPAI outbreak however made it possible to use all surplus hens. The majority were used for repopulating breeder operations,

Table 20

Focus on the hotspot area around Minnesota and Iowa during the outbreak
Sources: “Indemnity estimate / turkey ($)”: (Elam, 2015), “Indemnity estimate / layer ($)”: (Elam, 2015), “Indemnity percentage turkey sector (%)”: (Elam, 2015), “Indemnity percentage layer sector (%)”: (Elam, 2015), “Indemnity paid total ($, Millions)”: (USDA, 2016b)

Description	Amount
Indemnity percentage turkey sector (%)	44
Indemnity percentage layer sector (%)	56
Indemnity paid total ($, millions)	200
Indemnity paid total turkeys ($, millions)	88
Indemnity paid total layers ($, millions)	112

Table 21

Total loss to poultry industry in the 2014-2015 HPAI outbreak
Sources: Own calculation with data from table 18, table 19 and table 20

Description	Amount	Calculation
Total loss layer industry ($, millions)	1,096.57	
Total loss turkey sector ($, millions)	523.84	
Indemnity paid total ($, millions)	200	
Total loss to poultry industry ($, millions)	1,420.41	1,096.57 + 523.84 - 200

while the rest were fed to higher weights for slaughter (Elam, 2015).

The calculation above shows that the turkey sector was financially impacted by idle production during and after the outbreak in the amount of $523.84 million.

6.6.3.3 Indemnity payments

The APHIS does not publish details on indemnity payments beyond the total amount paid. This section nonetheless highlights further details and uses estimates made by Decision Innovation Solution (2015) as a basis. Indemnity payments made by APHIS are essential to take into consideration in the IMPLAN analysis which is based on lost economic activity. The layer and turkey sector suffered a loss of flocks and downtimes in production. Parts of these losses were compensated by indemnification payments made through the APHIS. These payments are deducted from the overall loss of both sectors for the following assessment.

Table 20 (p. 83) shows estimates of the study by Decision Innovation Solution (2015) concerning indemnification payments during and after the outbreak to the layer and turkey sectors. According to these estimates, the turkey sector received 44 percent of all indemnification payments, and the layer

Table 22

Impacts in up- and downstream industries at the producer level
Source: Data of Extension (2015)

Impacts at losses in producer level of $1,000,000				
	Absolute		Percentage (%)	
	indirect	induced	indirect	induced
Other animal feed manufacturing	230,000		23.0	0
Poultry and egg production	80,000		8.0	0
Wholesale trade	50,000	5,000	5.0	0.5
Grain farming	55,000		5.5	0
Truck transportation	20,000	2,000	2.0	0.2
Soybean & oilseed processing	5,000		0.5	0
Real estate	1,000	5,000	0.1	0.5
Rail transportation	3,000		0.3	0
Maintenance of buildings	2,000	1,000	0.2	0.1
Electric power	1,500	1,500	0.2	0.15
Banks	1,000	4,000	0.1	0.4
Vet services	3,000		0.3	0
Doctors		3,000	0.0	0.3
Hospitals		5,000	0.0	0.5
Housing		40,000	0.0	4
Total	451,500	66,500		
Combined total	518,000			

industry 56 percent. In the 2014-2015 outbreak, considerably more layers were affected than turkeys. The fair market value as calculated by the APHIS is higher for a turkey than for a layer bird. Decision Innovation Solution (2015) estimates that on average, APHIS paid $14.39 for a turkey and $3.75 for a layer. This explains why the layer sector accounted for only 1.27 times the total indemnity payments, even though 5.81 times the amount of birds were affected.

Table 21 (p. 83) is a summary of the above results. The combined loss of both the layer and turkey industry offset against the paid indemnity values results in a loss of $1,420.41 million to the poultry industry.

6.6.3.4 Impacts in up- and downstream industries

The IMPLAN analysis by Extension (2015) was conducted while the outbreak was still underway. It was anticipated however that the outbreak would continue for some time. Because of this, the study provides a model in which impacts to the economy are described as a percentage per million dollars of loss. The calculation in table 22 (p. 84) uses this concept to calculate the economic impact in different up-downstream industries, with the results of table 21 (p. 83) applied to do so.

Table 23

Impacts in up- and downstream industries for total loss at the producer level
Source: Own adaptation with data of Extension (2015)

Loss at producer level: $1,420,410,000				
	Absolute		Percentage (%)	
	indirect	induced	indirect	induced
Other animal feed manufacturing	326,694,300	0	23.0	0
Poultry and egg production	113,632,800	0	8.0	0
Wholesale trade	71,020,500	7,102,050	5.0	0.5
Grain farming	78,122,550	0	5.5	0
Truck transportation	28,408,200	2,840,820	2.0	0.2
Soybean & oilseed processing	7,102,050	0	0.5	0
Real estate	1,420,410	7,102,050	0.1	0.5
Rail transportation	4,261,230	0	0.3	0
Maintenance of buildings	2,840,820	1,420,410	0.2	0.1
Electric power	2,130,615	2,130,615	0.2	0.15
Banks	1,420,410	5,681,640	0.1	0.4
Vet services	4,261,230	0	0.3	0
Doctors	0	4,261,230	0.0	0.3
Hospitals	0	7,102,050	0.0	0.5
Housing	0	56,816,400	0.0	4
Total	641,315,115	94,457,265		
Combined total	735,772,380			

Table 23 (p. 85) projects the results of table 22 (p. 84) to the actual loss of $1.42 billion.

Other animal feed manufacturing was impacted by $327 million through indirect losses. Poultry and egg production was impacted by $114 million, wholesale trade by $71 million, and grain farming by $78 million. An additional ten industries were impacted to a significantly smaller degree, i.e. truck transportation, soybean & oilseed processing, real estate, rail transportation, maintenance of buildings, electric power, and banks. The highest induced impact is estimated to have happened in the housing industry, impacted by up to $57 million. The second most significant induced impacts are estimated to have happened in the wholesale trade industry, the real estate industry, and hospitals with an impact of about $7 million each. Overall total indirect and induced impacts amounted to $735,772,380.

Table 24

Summary of costs US outbreak
Source: Author

Type of costs	Amount ($)
DC	879,000,000
DCC primary sector	1,420,410,000
DCC secondary sector	735,772,380
DCC total	2,156,182,380
Total	3,035,182,380

6.7 Summary AI impacts USA

In summary, the costs of the 2015 HPAI outbreak in the USA amounted to more than three billion dollars (table 24). Of this amount, 879 million dollars were spent on DC, which are the costs for all direct mitigation efforts such as euthanization, cleaning, and disinfection and rendering of virus material. In terms of DCC, the primary industry was impacted with economic losses of 1.42 billion dollars. These costs arose as a result of idle time in production after mitigation activities were concluded. Secondary industries were impacted in the amount of more than 735 million dollars after the outbreak due to idle production time.

7 AI Impacts Germany 2017

This chapter covers the economic analysis of the 2016/2017 HPAI outbreak in Germany. Included is a time-spatial analysis with a focus on the area in Germany that was impacted the most. The estimations for the economic impacts of the outbreak follow the framework defined by Saatkamp et al. (2014). Because HPAI also occurred in other European countries, HPAI events across Europe in the same year are included in this chapter as well.

The 2016/2017 outbreak was the largest ever recorded incidence of HPAI in Germany. First reports were officially confirmed to the OIE on November 7th, 8th and 9th. At the Plöner See in Schleswig-Holstein in the north of Germany, 58 tufted ducks, great black-beaked gulls, and common coots were found dead and confirmed HPAI-positive by the FLI on the first day. Thirteen wild ducks, one goose, one gull, six birds of prey, and one grey heron were found dead in the same area and later confirmed HPAI-positive one day later (OIE, 2017). On the third day, the first captive birds were confirmed HPAI-positive. A small commercial operation with 110 animals was depopulated upon discovering 18 turkeys from this operation had HPAI (they had shown known symptoms (OIE, 2017)). In the following month, and lasting until April 7th 2017 1,151 wild birds were confirmed as having HPAI. Along with wild birds, there were a total of 69 cases at commercial poultry premises, 23 affected backyard operations, and 15 confirmed cases in zoos or smaller animal parks (LAVES, 2017). Lower Saxony, the state with the most confirmed HPAI cases of captive birds, and the center of the disease event, had a total of 45 confirmed cases, leading to the depopulation of more than 830,000 thousand birds in this one state alone. By the end of December 2016, fifteen out of the sixteen German states were affected by HPAI, and the FLI strongly urged the industry to maintain a high level of biosecurity measures to prevent further outbreaks in captive birds, specifically in commercial poultry operations (FLI, 2016). By the end of the outbreak, a total of 1.4 million birds had to be depopulated, making this outbreak the largest in recorded history in Germany (OIE, 2017).

7.1 HPAI outbreaks in Europe

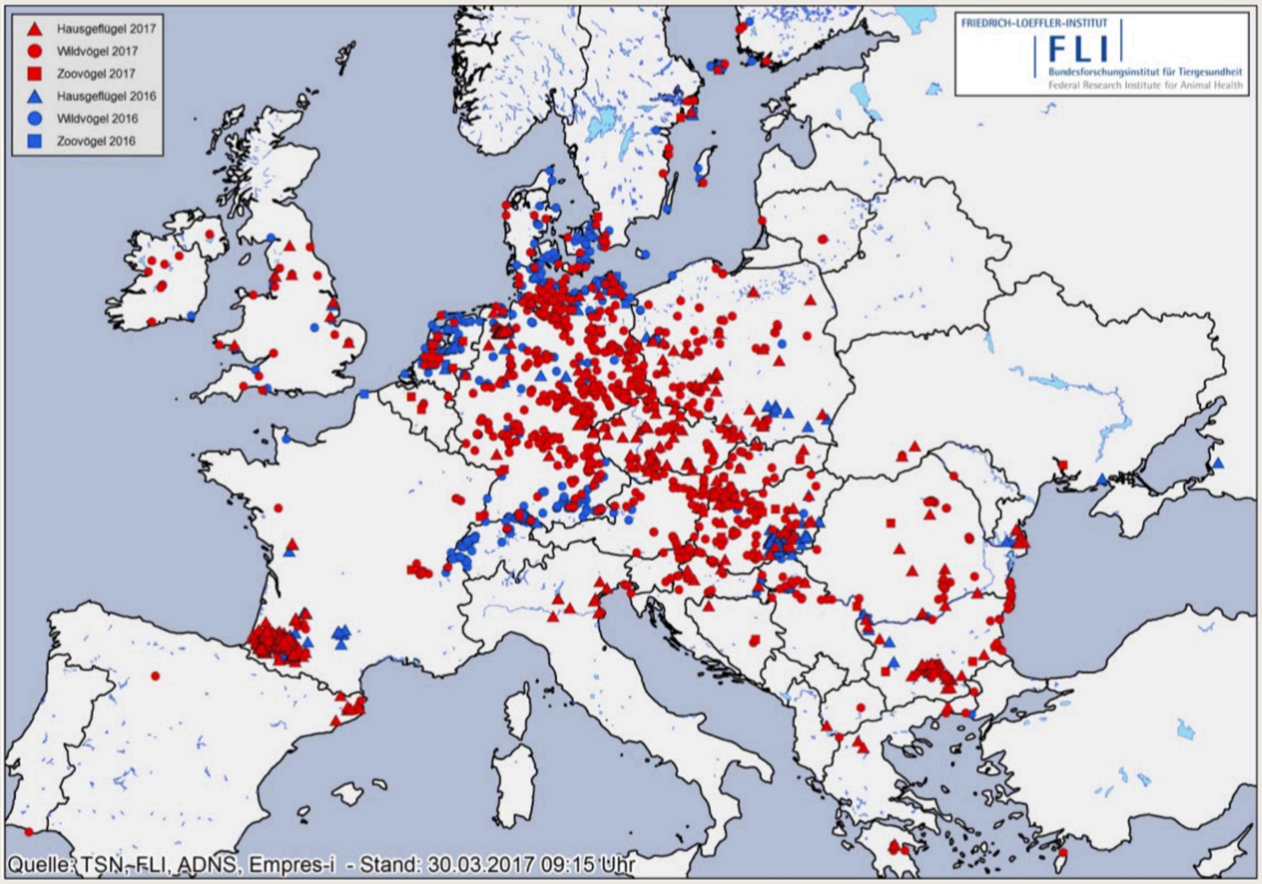
The 2017 HPAI outbreak was part of a larger trans-continental HPAI development. A number of outbreaks had occurred across Europe as early as 2016. This section highlights the outbreak situation in other European countries, and helps to understand the 2017 HPAI outbreak in Germany as one part of a larger development instead of a merely singular and short-term event. While there were 587 officially confirmed HPAI cases in Europe outside of Germany in the entirety of 2016, in 2017 1,252 had been confirmed by March 31st. Figure 45 (p. 88) gives an overview of the HPAI spread across the continent. Red depicts 2017, and blue 2016. A triangle symbolizes captive birds; a rectangle symbolizes zoo or animal park birds; and circles symbolize wild bird findings. It's seen that the majority of all European countries were affected by the HPAI outbreak. Along with the dominant H5N8 virus strain, there were also several confirmed cases of H5N5 and H5N6, of which none showed any zoonotic potential (FLI, 2017c).

Table 25 (p. 89) provides an overview of all European countries affected by the 2016/2017 outbreak. Data was collected using the Animal Disease Notification System (ADNS) as initiated by the European Commission. ADNS is used to "register and document the evolution of the situation of important infectious animal diseases" (European Commission, 2018). Non-EU countries also use the application, which gives officials in the EU a good understanding of the disease situation in neighboring countries (Brown et al., 2017). Table 25 (p. 89) shows that in total there were 1,590 wild bird cases in 30 different European countries as recorded by the ADNS system. 741 of these were in Germany. Out of all 1,590 cases, there were 15 non-H5N8 cases of H5N5. In the poultry and captive industry, there were 1,207 cases, of which nine were non-H5N8. With 488 cases, France had the most outbreaks, followed by Hungary with 243 cases, and Germany with 104.

The data shows that the outbreak was spread widely across the European continent. An HPAI event of this size, together with its "heavy infection pressure" was unprecedented in Europe (Gavinelli, 2017). In some areas, the ubiquitous presence of the virus developed into a

Figure 45

Officially confirmed HPAI cases in Europe, 2017
Source: FLI (2017c)



local phenomenon with considerably high outbreak rates. The European Commission acknowledged the situation for high density poultry areas, and categorized lateral spread as an additional key issue (Gavinelli, 2017). The 2017 HPAI outbreak in the southwest of France (see figure 45) was a clear example of this lateral spread. In total, there were 488 confirmed cases of HPAI in the vicinity of Pas-de-Calais. In the process of virus mitigation, two million ducks were depopulated due to confirmed infections, with a total of 6.8 million animals depopulated as part of preventive measures to clear the region of high-risk birds (Andronico et al., 2019). Research has shown that the outbreak progressed at a rate of about 5.5 km per week locally before the preventive depopulation measures slowed it significantly (Guinat et al., 2018).

7.2 HPAI outbreaks in Germany

This section describes the outbreak situation in Germany in 2016 and 2017 in greater detail. As seen, there were outbreaks across nearly all European countries, with the virus spread evenly across the continent. While there were HPAI findings throughout Germany, the following highlights the HPAI development in the state of Lower Saxony.

Figure 46 (p. 90) shows a map of Germany on December 28th, 2016. By this time, the outbreak had been ongoing for about two months. The colored circles indicate confirmed HPAI domestic cases, while the colored triangles indicate wildfowl findings. The map shows that the majority of states in Germany had

Table 25

Wild bird, poultry, and captive HPAI cases in European countries
Source: Brown et al. (2017)

	Wild Bird			Poultry and Captive				
Country	H5N8	H5N5	Total	H5N8	H5N5	H5N6	Total	Total
Germany	741	1	742	104	3	0	107	849
France	51	0	51	488	0	0	488	539
Hungary	86	1	87	243	0	0	243	330
Romania	93	0	93	47	0	0	47	140
Poland	66	2	68	65	0	0	65	133
Switzerland	92	0	92	0	0	0	0	92
Bulgaria	13	0	13	73	0	0	73	86
Czech Republic	39	0	39	38	1	0	39	78
Slovakia	58	0	58	11	0	0	11	69
Netherlands	47	2	49	18	0	0	18	67
Austria	55	1	56	3	0	0	3	59
Denmark	51	0	51	2	0	0	2	53
Slovenia	41	3	44	0	0	0	0	44
Italy	8	1	9	35	0	0	35	44
Sweden	30	0	30	6	0	0	6	36
UK	23	0	23	13	0	0	13	36
Republic of Serbia	20	0	20	4	0	0	4	24
Croatia	11	1	12	7	4	0	11	23
Belgium	3	0	3	15	0	0	15	18
Finland	16	0	16	1	0	0	1	17
Greece	8	1	9	5	0	1	6	15
Spain	2	0	2	10	0	0	10	12
Ireland	10	0	10	0	0	0	0	10
Ukraine	3	0	3	3	0	0	3	6
Lithuania	5	0	5	0	0	0	0	5
Luxembourg	0	0	0	4	0	0	4	4
Bosnia and Herzegovina	1	0	1	2	0	0	2	3
Montenegro	0	2	2	0	0	0	0	2
FYRO	1	0	1	1	0	0	1	2
Portugal	1	0	1	0	0	0	0	1
Total	1,575	15	1,590	1,198	8	1	1,207	2,797

encountered wild bird HPAI cases by this point. A smaller fraction of the states in Germany furthermore had confirmed positive domestic bird HPAI cases. It can also be seen that the wild bird findings were centered in the north of Germany around the North Sea and the south, with one hotspot near Lake Constance on the Swiss border. Figure 47 (p. 91) shows a map of Germany from March 2017 provided by the FLI (2017c). Here the legend is different: colored triangles show captive bird findings, and circles indicate wild birds. Figure 47 (p. 91) shows that the size of the outbreak significantly increased over the three months since December of the previous year. By the end of March 2017, all states of Germany saw wild bird infections, and 13 out of the 16 states also had confirmed captive bird infections. Wild bird findings can be seen evenly across Germany, with many in the proximity of rivers or open water. Wild bird cases in the north and south were also increasing. In the state of Lower Saxony, an area with a large number of new outbreaks in commercial captive bird operations was visible; this is the area of this paper's focus.

7.2.1 Quantities, operations, and states

Figure 48 (p. 91) shows the number of birds lost per state in Germany during the 2017 outbreak. The data includes commercial poultry, backyard operations, zoos, and other leisure parks. The data also includes birds at premises that were depopulated because of a direct link to an HPAI-positive location. It can be seen that Lower Saxony (NI) was forced to depopulate about 820,000 birds, making it the state with the highest loss rate. It was followed by North Rhine-Westfalia (NW), Mecklenburg-Hither Pomerania (MV), Brandenburg (BB), and Saxony-Anhalt (ST). These states depopulated around 200,000; 180,000; 110,000; and 45,000 birds respectively. All other German states combined depopulated two-thirds of the amount of Lower Saxony, making clear the predominant role of Lower Saxony in the 2017 outbreak.

Figure 46

Wild bird and captive HPAI cases in Germany until December 2016
Source: FLI (2016)

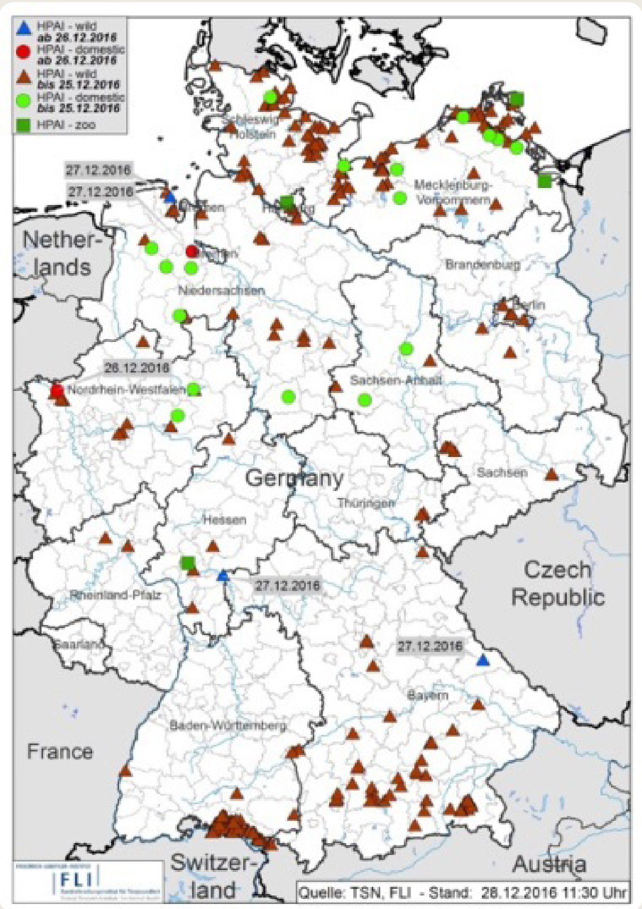


Figure 49 (p. 92) shows the confirmed HPAI wild bird and captive bird findings per state in Germany during the 2017 outbreak. One can see here that the states of Bavaria, Lower Saxony, Brandenburg, Mecklenburg-Hither Pomerania, North Rhine Westfalia, Thuringia, and Hessia had the most confirmed HPAI cases in total. When looking at the wild bird and captive cases separately, it shows that Bavaria in the south of Germany had the most wild bird HPAI cases by far. There were twice as many wild bird cases in Bavaria compared to e.g. Lower Saxony. The latter on the other hand had the most cases with captive birds.

Table 26 (p. 92) shows the number of outbreaks in different bird types in Germany. "Zoo" and "backyard" contain different bird types and should be considered as mixed. It is obvious that turkeys were the bird type affected the most; there were more outbreaks in turkey operations than in all other types combined. The second largest amount of outbreaks happened in zoos, generally affecting a variety of different birds (OIE, 2017). Of note is that zoos and animal parks should be considered differently in the context of contagious animal disease. If HPAI is confirmed in a zoo, this does not necessarily mean that all adjacent birds require depopulation. Because zoos and animal parks can enforce rigid biosecurity measures, and because some of the birds there are either rare or very high in value, not all birds are automatically depopulated (FLI, 2017c). Broilers were not affected at all during the entirety of the outbreaks in Germany. In spite of this, in November 2016 in the county of Cloppenburg, a broiler operation had to be depopulated as part of precautionary measures to reduce the risk of further spread.

Figure 47

Wild bird and captive HPAI cases, November 2016 – March 2017
Source: FLI (2017c)

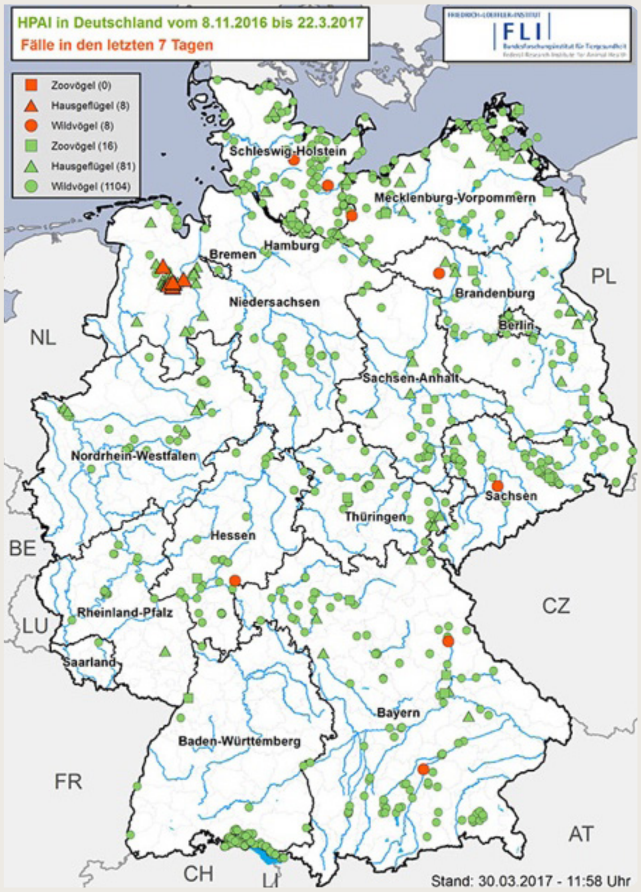


Figure 48

Amount of birds lost per state in Germany
Source: OIE (2017) and TSK (2018)

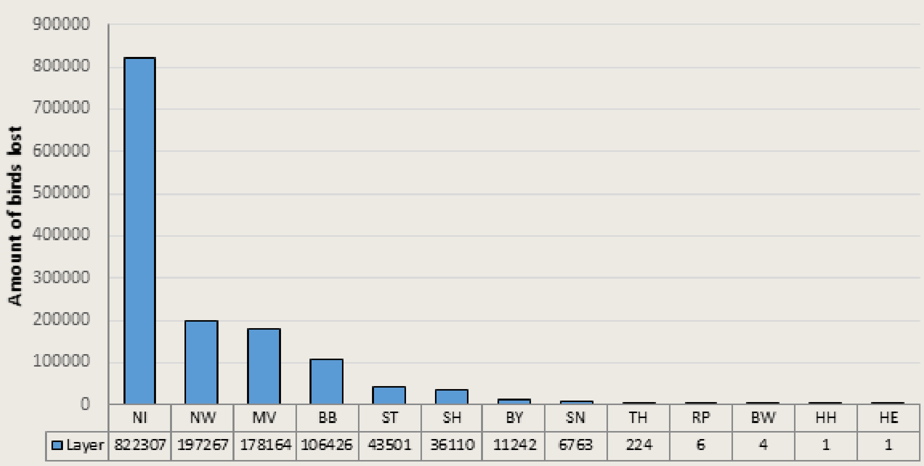


Figure 49

Confirmed HPAI wild bird and captive bird findings per state in Germany
Source of data: (European Commission, 2017)

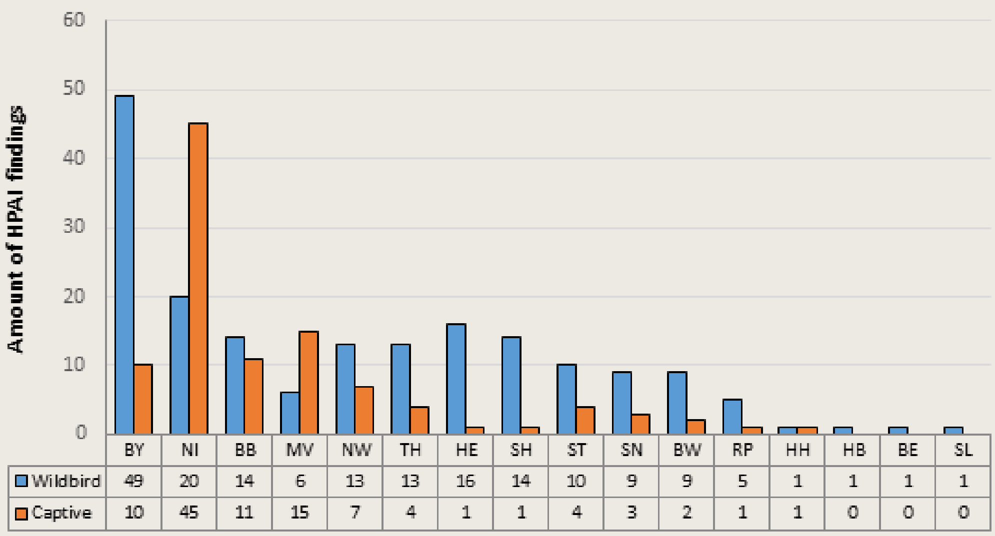


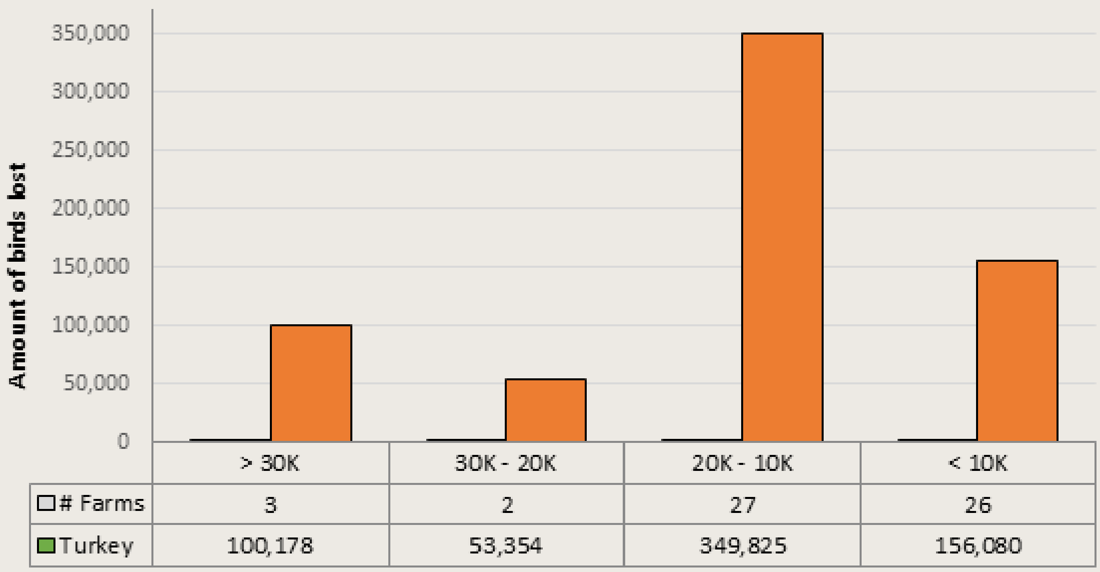
Table 26

Outbreaks divided according to bird types
Source of data: LAVES (2017)

	Turkey	Layer	Duck	Goose	Zoo	Backyard
Germany	52	6	9	2	15	23

Figure 50

Size structure in HPAI-affected farms in Germany
Source: TSK (2017b)



7.2.2 Age and size distribution of affected farms in Germany

Figure 50 (p. 92) shows the sizes of HPAI-affected turkey farms in Germany. The data is limited to an overview of turkey farms, the vast majority of farms affected in Germany. The HPAI-positive turkey farms are partitioned into four groups. All farms with a flock larger than 30,000 birds are grouped together. A second group comprises all farms between 30,000 and 20,000 birds. The remaining two groups contain farms between 20,000 to 10,000 birds and all farms smaller than 10,000 birds. Figure 50 displays that three farms were affected that had more than 30,000 birds; two farms with flock sizes between 30,000 and 20,000 birds; while the largest group, 27 farms in total, were farms having between 20,000 and 10,000 birds. A total of 26 smaller farms in the group of

Figure 51

Amount of outbreaks in different flock ages
Source: Leßmann (2018)

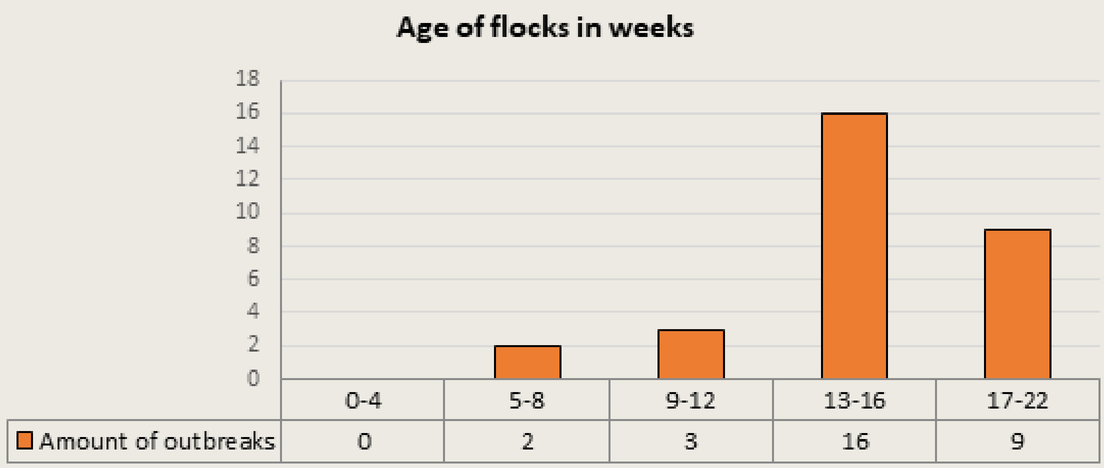


Figure 52

Age distribution and average indemnity paid per bird in € in Lower Saxony
Source of data: TSK (2017a)

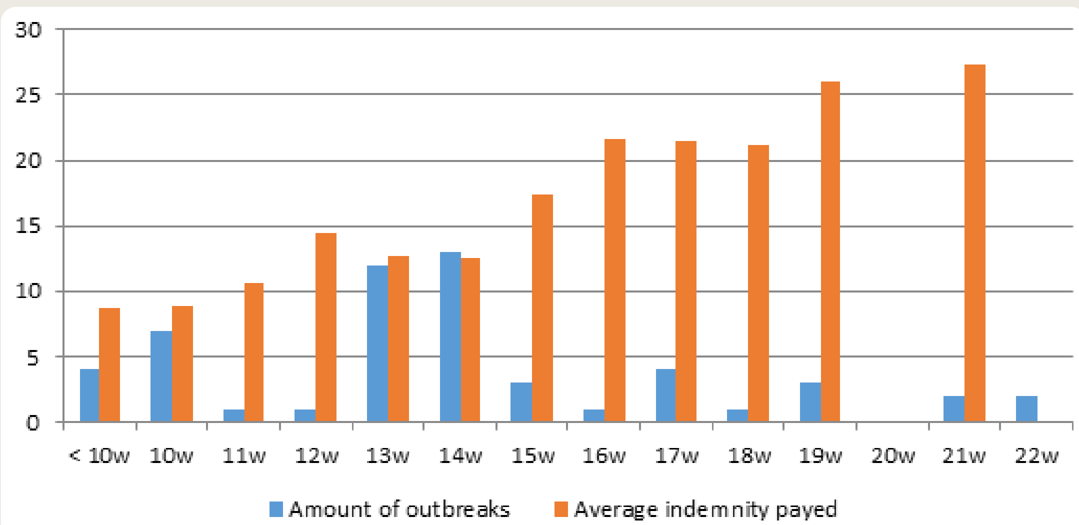


Figure 53

Turkey density in Lower Saxony in 2017, 5 km grid
Source: LAVES (2017)

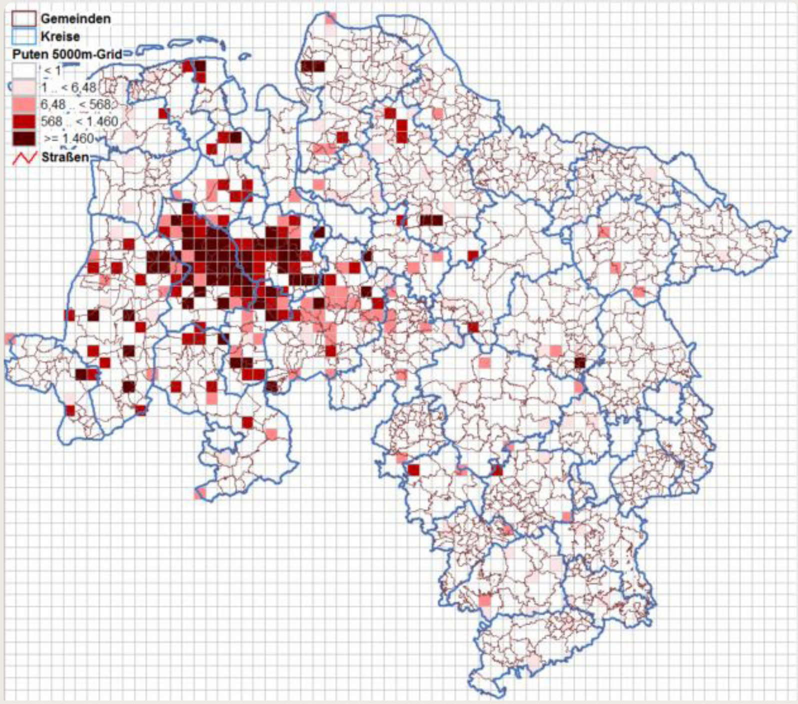
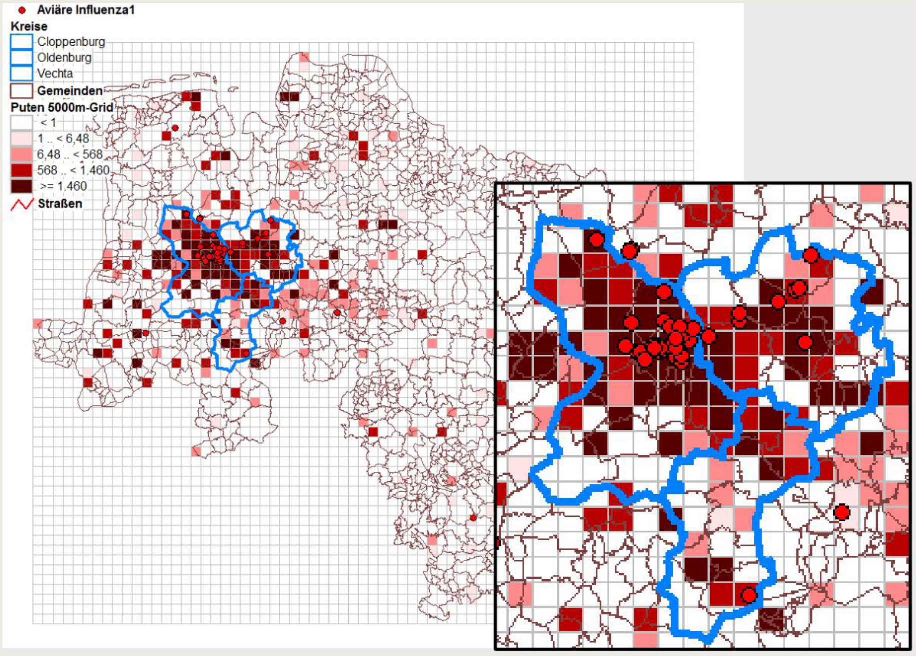


Figure 54

Turkey density and HPAI outbreaks during the 2016/2017 outbreak
Source: LAVES (2017)



10,000 birds or less were affected. The data shows that a majority of affected farms had fewer than 20,000 birds, of which half had fewer than 10,000 birds.

Figure 51 (p. 93) shows the amount of affected flocks and the different flock ages. These are split into four groups: turkeys between 0 and 4 weeks, 5 to 8 weeks of age, 9 to 12 weeks, 13 to 16 weeks, and 17 to 22 weeks. Young turkey flocks were significantly less often affected in comparison with older flocks. It can be seen that only five flocks up to the age of 12 weeks were affected. In the age group 13 to 16 weeks, a total of 16 flocks were affected. In the age group of 17 to 22 weeks, a total of nine operations were affected. Leßmann (2018) concludes that the high frequency of bedding renewal for older flocks might be a reason for the noticeable difference in age distribution. In Germany, it is common to use wood chips or straw for bedding material. The higher the age of the flocks, the more often litter has to be replaced. The regular application of straw could be a potential route for virus introduction, and might explain the noticeably high amount of affected farms in this age group.

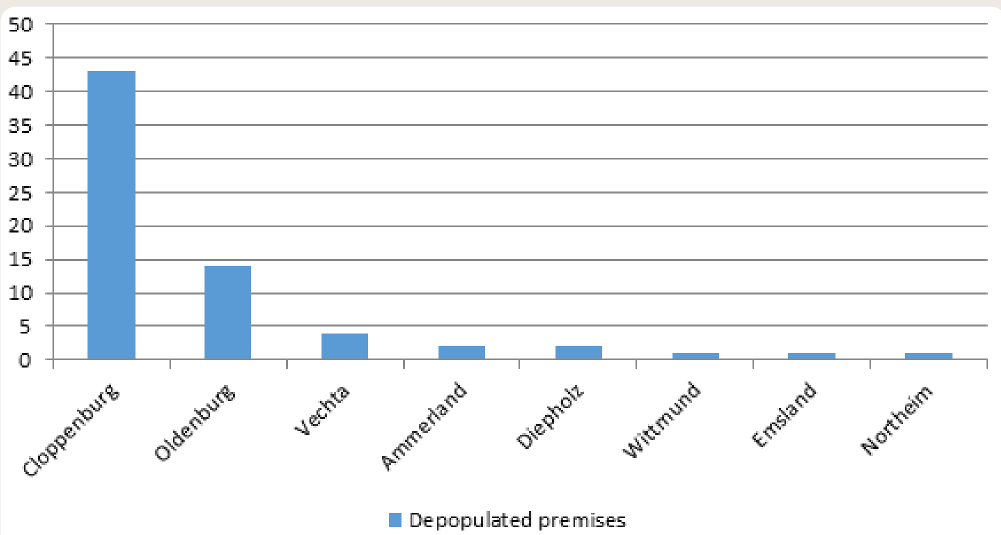
Figure 52 (p. 93) shows the age distribution of affected turkeys and the average indemnity paid per bird in euros for flocks in Lower Saxony during the 2016/2017 outbreak. In terms of age distribution, figure 52 (p. 93) shows that there were fatalities across all age groups of turkey flocks except for 20-week-old turkeys. The highest numbers of affected flocks were in the age groups of 12 and 13 weeks, with more than 10 outbreaks each. Figure 52 also shows that the payout system as applied by the Animal Disease Fund of Lower Saxony during the 2017 HPAI outbreak in Germany in effect indemnified older turkey flocks more than younger flocks (there had been cuts in indemnification for operations displaying a lack of biosecurity measures (TSK, 2017). Figure 52 (p. 93) shows that older flocks were generally indemnified at higher rates despite these funding decreases.

7.3 The role of Lower Saxony as part of the 2017 HPAI outbreak

Lower Saxony is one of Germany's major agricultural goods and food producers. Especially in terms of animal husbandry, Lower Saxony ranks the highest among the German states. During the 2017 HPAI outbreak, one of the high density poultry production areas of Lo-

Figure 55

Amount of depopulated premises per county in Lower Saxony
Source: TSK (2017b) and OIE (2017)



wer Saxony around the county of Cloppenburg was hit with a series of HPAI outbreaks. This section focuses on this area in particular and concludes with an in-depth spatial analysis.

According to the Ministry of Food, Agriculture and Consumer Protection of Lower Saxony, the Lower Saxony agricultural industry is Germany's largest, with a yearly production value of 11.9 billion euros (ML, 2018). The animal husbandry sector, which includes pork, milk, poultry, and beef production represents its largest sub-sector. Along with these value-added numbers, Lower Saxony also ranks highest in Germany in terms of agricultural land use, with 2.6 million hectares (ML, 2018). In addition, Lower Saxony features some areas with a very high density of animal husbandry activities. These are foremost the counties of Cloppenburg, Vechta, and Emsland. During the 2017 HPAI outbreak, these areas where hit especially hard.

Figure 53 (p. 94) displays a map of Lower Saxony showing turkey density within a five-kilometer grid, shaded in different intensities of red depending on the respective local density. It can be seen that turkey density is high around the counties of Cloppenburg, Vechta, and Oldenburg. Figure 53 shows that the turkey farming industry is centered in these counties. Other areas of Lower Saxony show less or no turkey inventory.

Figure 54 (p. 94) shows the same grid and turkey density as figure 53, and additionally depicts the HPAI outbreaks of Lower Saxony. Figure 54 also shows an extract of the high density areas. It can be seen that a majority of the outbreaks occurred in the high density poultry cluster of Cloppenburg. Out of the three counties with the highest turkey density, two were intensely affected by HPAI outbreaks.

Figure 55 (p. 95) shows the counties of Lower Saxony that were affected the most during the outbreak, as well as the number of operations that had to be depopulated either because they experienced an initial outbreak and were HPAI-confirmed, or were dangerous contact premises without an HPAI confirmation. In either case, the operation was depopulated. It can be seen that Cloppenburg depopulated the

Figure 56

Amount of depopulated birds per county in Lower Saxony
Source: TSK (2017a) and OIE (2017)

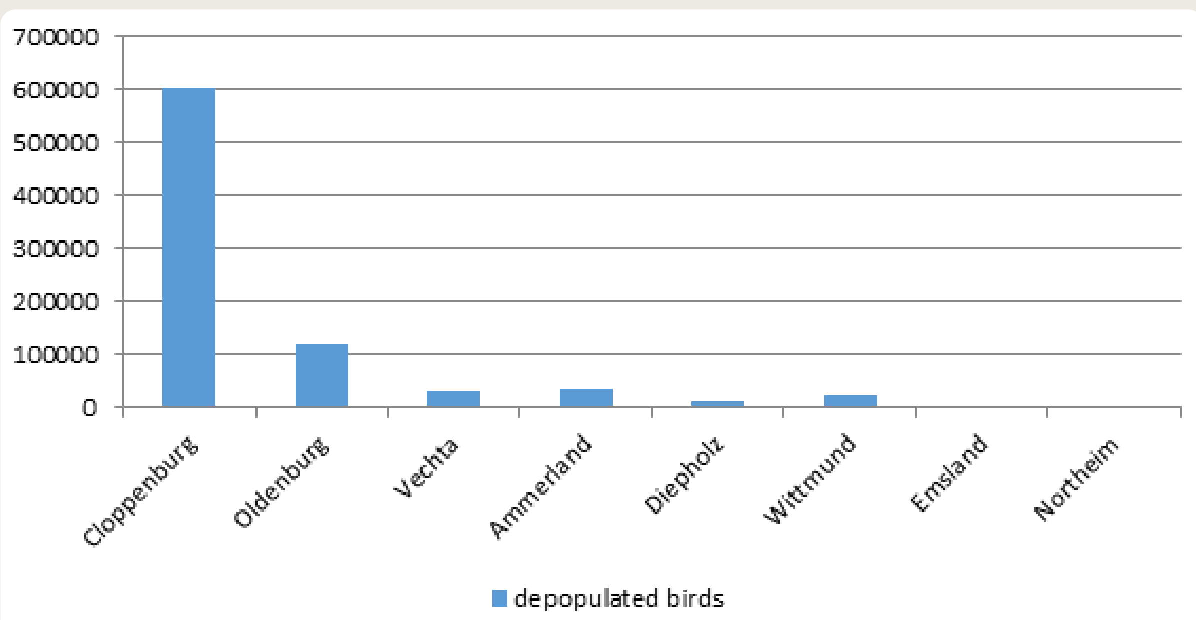


Figure 57

Poultry operations around the municipality of Garrel
Source: Personal communication with local expert (July 2018) and data from OIE (2017)

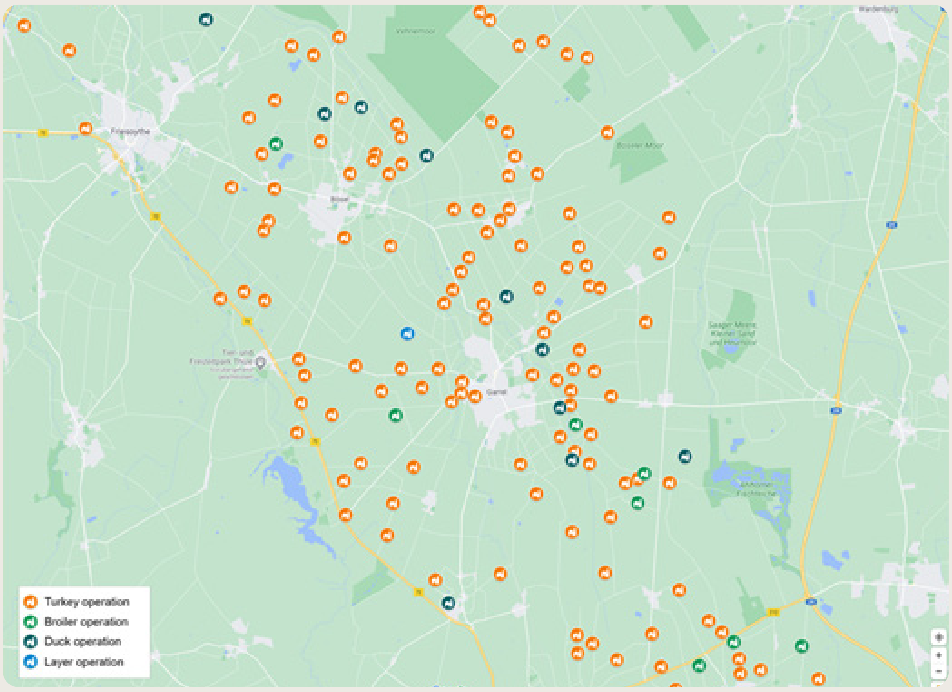
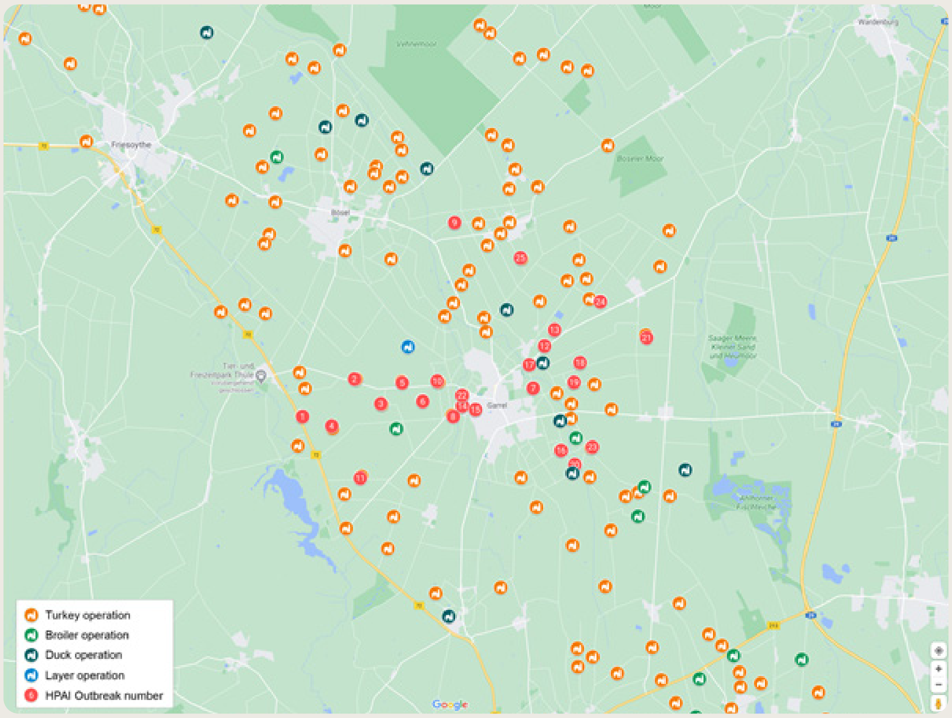


Figure 58

Affected and non-affected poultry operations around Garrel
Source: Personal communication with local expert (July 2018) and data from OIE (2017)



most operations (43) during the outbreak. Oldenburg depopulated 14 operations, making it the county with the second highest amount of depopulated operations. The county of Vechta depopulated four operations and therefore was only mildly affected. Ammerland, Diepholz, Wittmund, Emsland, and Northeim were affected with one or two depopulated premises each.

Figure 56 (p. 96) shows the amount of depopulated birds per county in Lower Saxony. The numbers of depopulated birds are for the most part congruent with the number of outbreaks. The county of Cloppenburg depopulated the most birds, more than 600,000, followed by Oldenburg with more than 100,000 birds. Vechta and the remaining counties depopulated slightly above 100,000 birds combined.

7.3.1 Spatial development of the outbreak in Lower Saxony

The municipality of Garrel is located in the county Cloppenburg, and is the primary center of turkey farms in Lower Saxony. This section describes the spatial development of the 2017 HPAI outbreak around the village of Garrel in detail. The HPAI outbreaks as shown below are limited to outbreaks occurring after February 25th, 2017 and before April 6th, 2017. As mentioned in section 7.2, the HPAI outbreak had started prior to February 25th in 2016, and there were occasional outbreaks in this area that did not result in serial outbreaks like those seen after February 25th. The majority of HPAI cases and economic impacts occurred in this time frame, making this particular area in this time span of particular interest.

Figure 59

Affected poultry operations around the municipality of Garrel
Source: Expert interviews and data from OIE (2017)

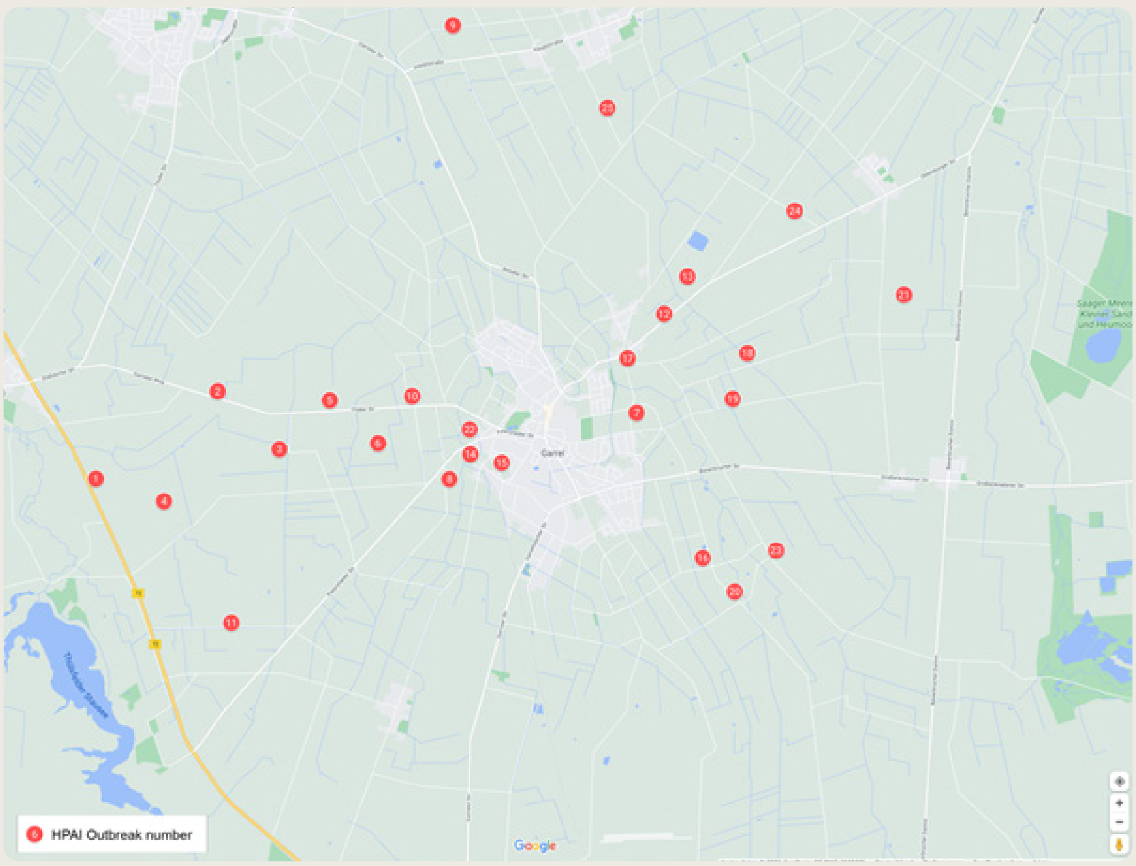


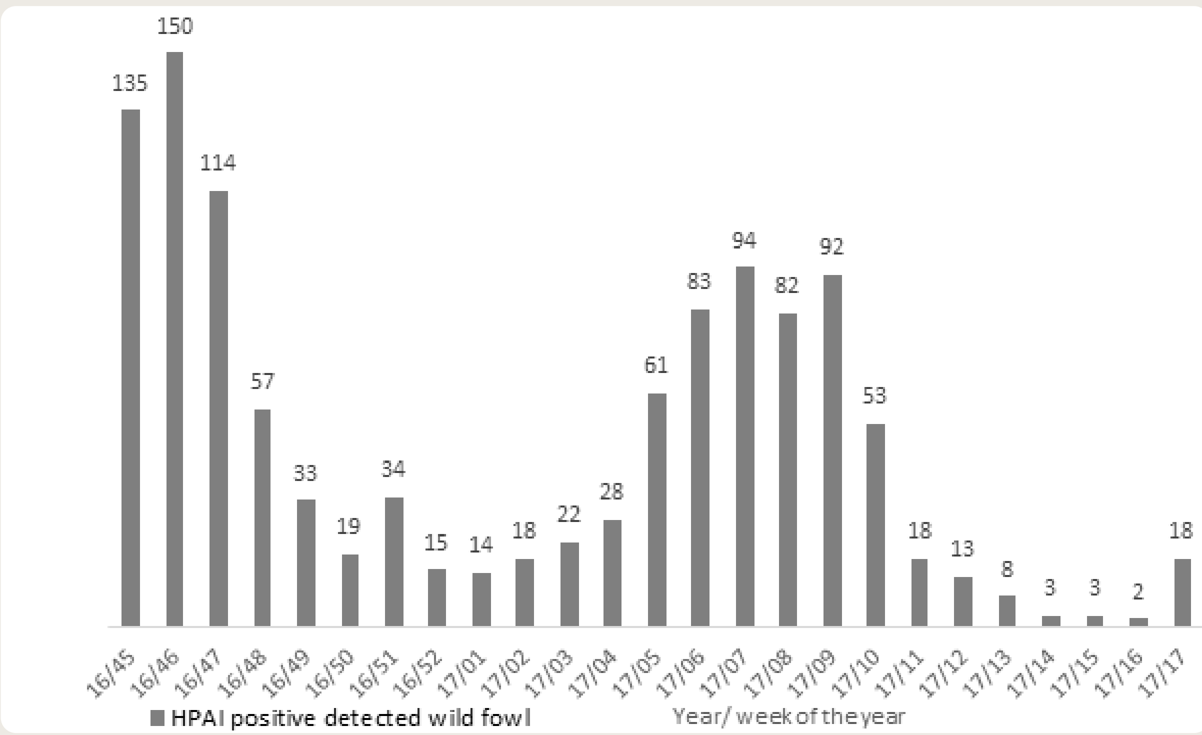
Figure 57 (p. 97) shows the mentioned high density of poultry operations in the area. The majority of operations are turkey premises, with some layer and broiler operations as well. In many cases, these operations are less than 400 meters apart, and some even in direct proximity to each other.

Figure 58 (p. 97), adding to the former figure, shows the same area, this time including the outbreak cases. The outbreaks are numbered according to their time of official recognition by the OIE as an HPAI-positive case. It can be seen that the outbreaks are located around the center of Garrel. Although many operations in Garrel were affected, there were still a multitude of operations without an outbreak of HPAI in this area.

Figure 59 (p. 98) yet again shows the area of Garrel, this time only displaying the outbreak cases numbered according to their officially recognized occurrence by the OIE. It can be seen that the outbreak started west in the proximity of the lake Thülsfelder Stausee and the federal road 72 (#1). From there, it progressed east and affected a total of six poultry operations (#1-#6), of which one was a dangerous contact premise. On March 8th the virus made a major leap across the village to the east (#7). No clear spatial direction of progression was recognizable in the area following this point. As can be seen in figure 59, new outbreaks occurred in both the east and west of Garrel, and the overall economic impact increased further until April 6th. In the northeast, some premises were affected for the second time (#13, #24, #25) after having been already affected in December 2016 in the same outbreak.

Figure 60

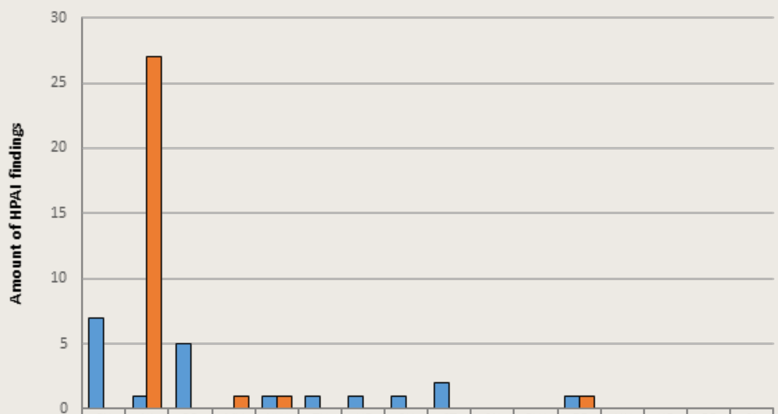
HPAI positive wildfowl findings in Germany in 2016 and 2017
Source: OIE (2017)



In addition to this spatial analysis, figure 60 (p.99) describes HPAI-positive wild bird findings in Germany in 2016 and 2017 on a time scale. It can be seen that during the end of 2016 in CW 46, there was a first peak with 150 new wild bird findings in one week. The week prior to and after CW 46 also had more than 110 wild bird findings. Levels this high were not reached again for the rest of the outbreak. New findings lessened to 14 per week in CW 14 of 2017. A second smaller peak of new findings was reached around CW 7 of 2019. Two weeks prior, and three weeks after this second peak in CW 7, the number of new findings was back up again to around 80 findings per week. By the end of March 2017 in CW 13, there were barely any new HPAI wildfowl findings. CW 17 of 2017 was the last week with significant new HPAI findings. After that, there were no new findings in 2017.

Figure 61

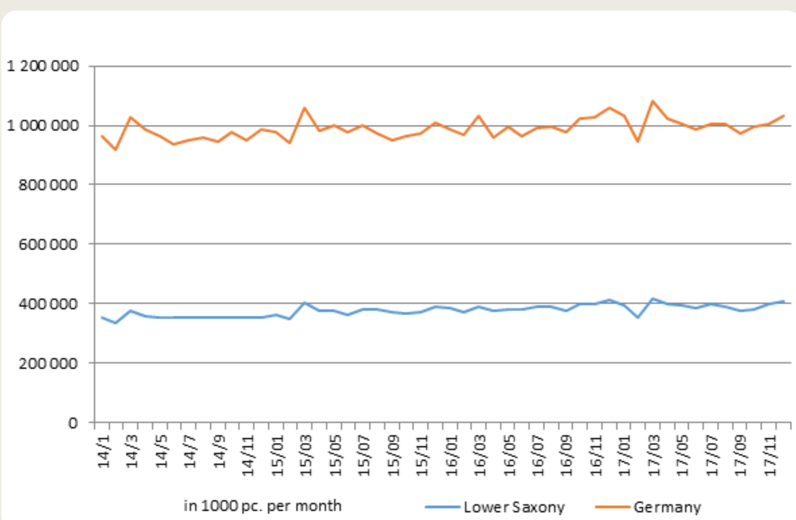
HPAI findings in wild and captive birds after the 25th of February
Source of data: OIE (2017)



	BY	NI	BB	MV	NW	TH	HE	SH	ST	SN	BW	RP	HH	HB	BE	SL
Wildbird	7	1	5	0	1	1	1	1	2	0	0	1	0	0	0	0
Captive	0	27	0	1	1	0	0	0	0	0	0	1	0	0	0	0

Figure 62

Egg production in Germany and Lower Saxony from 2014 to 2017
Source: DESTATIS (2015, 2016a, 2017, 2018)



Taking into consideration the HPAI outbreaks in commercial poultry during the same time, it is plausible to point out a correlation between wild bird findings and outbreaks in captive bird operations. The first peak of wild bird findings was accompanied by the first outbreaks in captive bird operations. The second peak of wild bird finding around CW 8 of 2017 was followed by the large outbreak scenario in Lower Saxony. Based on these findings, it is highly plausible that through the widespread presence of virus material in the environment, captive operations came in contact with it, generating HPAI-positive cases.
As can be seen in figure 61, the outbreaks around the city of Garrel occurred at a point where the overall outbreak was in decline.
Figure 61 describes HPAI wild and captive bird findings in the states of Germany after February 25th. Before this, there were significant wild bird HPAI findings across 11 German states (OIE, 2017). Figure 61 singles out findings after February 25th. After this, there were only a few wild bird HPAI confirmations across Germany. Bavaria accounted for seven findings; the state of Brandenburg accounted for five HPAI findings. All other states combined had only eight additional HPAI wild bird

findings, showing that there was no further significant virus activity. Figure 61 also shows the captive bird HPAI findings after February 25th. Outside of Lower Saxony, there were only three findings in captive birds across all of Germany. In Lower Saxony however, there were a total of 27 new outbreaks after the 25th of February, i.e. the bulk of all outbreaks were in Lower Saxony, meaning this state incurred the majority of economic impacts in Germany. While the virus was in decline in early February, the increased outbreaks in Lower Saxony stand in strong contrast to the development in the rest of Germany at this time of the outbreak.

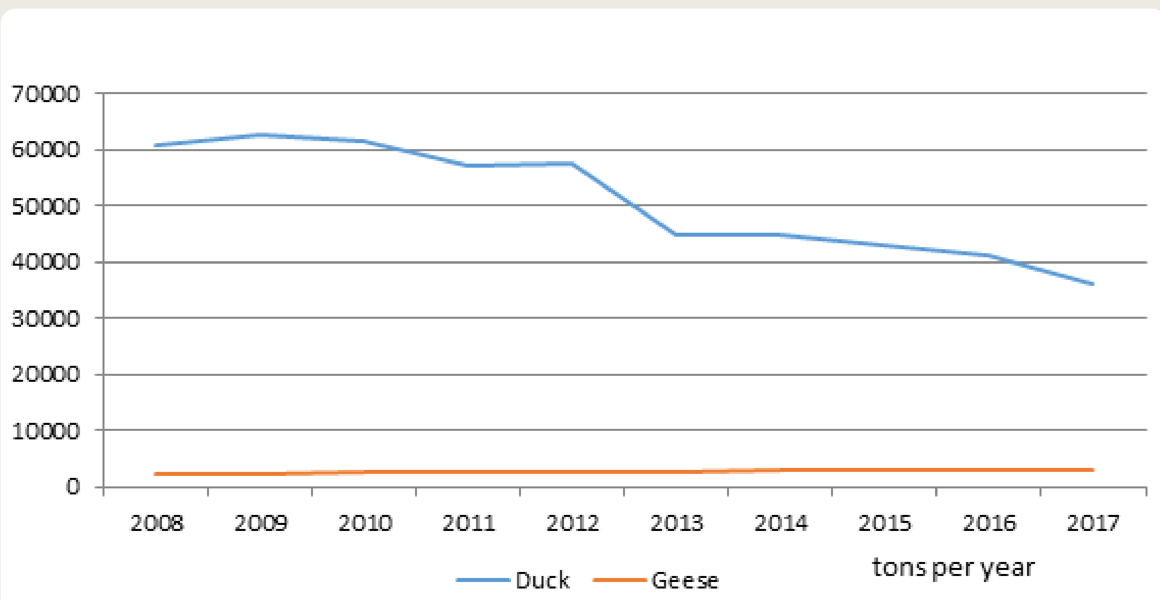
It can in conclusion be stated that it is highly likely that outbreaks around the municipality of Garrel were originally caused by wild birds and the introduction of virus material through them. The general environmental virus pressure was very high prior to the outbreaks around Garrel. But while an increasing number of outbreaks unfolded there, virus progression halted in the rest of Germany, and even came to a complete stop. This suggests that a multitude of outbreaks around Garrel were not caused by wild bird virus introduction, but through human or other vectoring in and around the municipality of Garrel instead.

7.4 Impact on poultry and egg production in Germany

The 2017 virus event was the largest HPAI outbreak in Germany to date (LAVES, 2017). This section highlights the effects of the outbreak on the output of poultry products in Germany before and after the outbreak.
Figure 62 (p. 100) shows egg production of Germany in 1,000 pieces per month from 2014 until the end of 2017. It can be seen that both the production in Lower Saxony and Germany slightly increased over time starting in 2014, progressing normally with a slight dip in February/March/April of 2017. Over this three-year time span, the volatility in production was highest during March and April. In March, a peak in production was reached followed by a noticeable decline. This is a typical yearly development connected to Easter when more people buy and paint eggs as a holiday tradition. During the year of the outbreak, the production numbers during Easter appear higher, with production numbers stabilizing

Figure 63

Production of duck and goose meat in Germany between 2008 and 2017
Source: DESTATIS (2017)



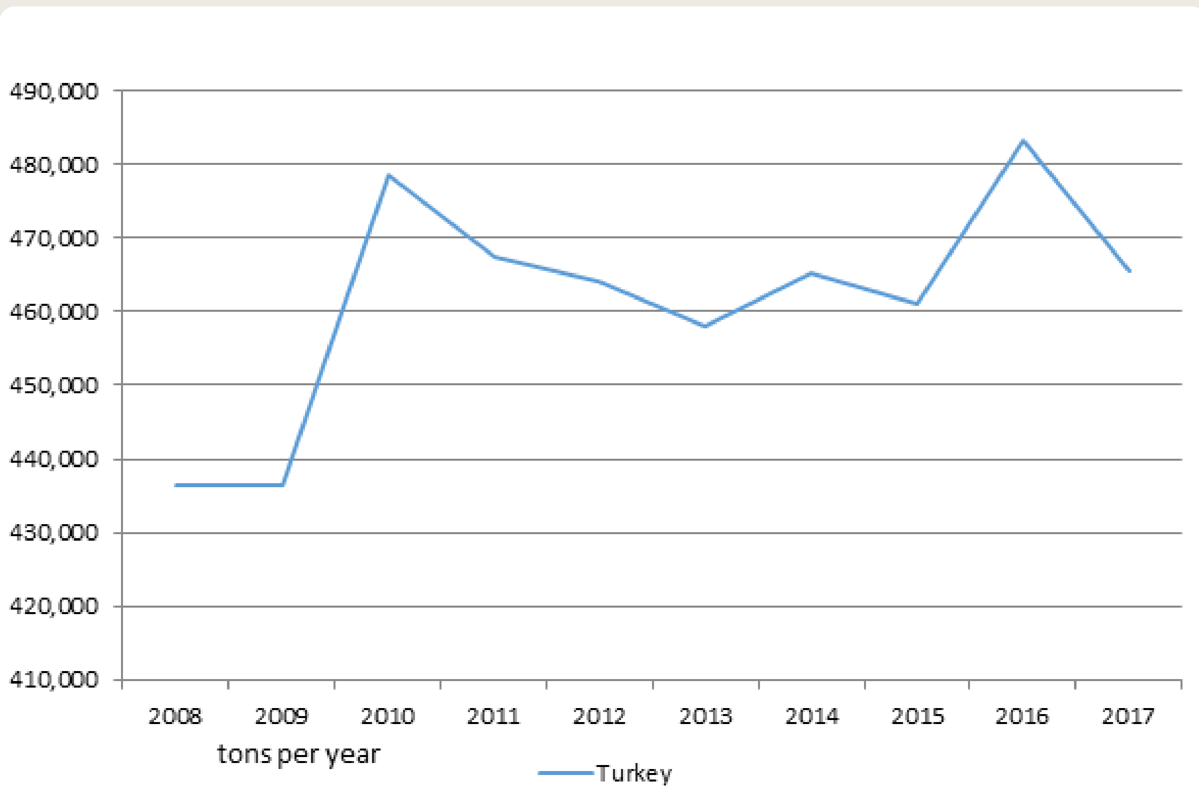
quickly again and returning to the overall trend of small and steady growth. Although not striking, it is possible that this changed amplitude was due to the 2017 HPAI outbreak. Although barely any layer operations were depopulated, it is possible that the presence of a virulent HPAI outbreak in the poultry industry and the associated media attention had this effect on egg production and consumption.

Figure 63 (p. 101) shows the production of duck and goose meat in Germany between 2008 and 2017 in tons per year. Figure 63 shows that duck meat had been in decline since 2008, with a noticeably sharper decline in production starting in 2012. During the HPAI outbreaks in 2016 and through 2017, an ongoing decline was noticeable, although not as strong as in 2012. It can be concluded from this that the outbreak did not noticeably affect duck meat production in Germany. Figure 63 also shows the production of goose meat since 2008. The amount of goose meat produced in Germany was significantly lower than duck meat, albeit more stable. The production of goose meat remained low but consistent over the years depicted in figure 63. No change was noticeable during the time of the outbreak in 2016 and 2017. This is an indication that goose meat production was not affected by the outbreak at all.

Figure 64 shows the production of turkey meat in Germany from 2008 to 2017 in tons per year. From 2008 to 2016, production increased from below 440,000 tons to more than 480,000 in 2016. In 2010, a first peak with almost 480,000 tons of total production was reached. In 2017, production declined noticeably. The reason for this decline

Figure 64

Turkey meat production in Germany from 2008 to 2017
Source: DESTATIS (2017)



is possibly the HPAI outbreak. In 2016, the German agricultural census counted 1,848 turkey farmers with 12,359,886 turkeys (DESTATIS, 2016b). During the outbreak, a total of approximately 688,000 turkeys were lost, which represents 5.6% of the total turkey population in Germany (TSK, 2018; OIE, 2017). Based on this, it is reasonable to assume that the outbreak impacted turkey meat production in Germany during the outbreak.

Breeder animals were affected by the outbreak as well. The economic impact of losing breeder animals in an outbreak is potentially higher than losing fattened conventional stock. First, the monetary value of breeder stock is higher in comparison. The Tierseuchenkasse Niedersachsen (TSK, the Animal Disease Fund of Lower Saxony), defines the value of a breeder bird as 41% higher than a ready-to-slaughter heavy male turkey. Second, a loss of breeder stocks later creates an inability to repopulate lost flocks; poultry operations are simply not able to restock as quickly as needed. Kamina Johnson (2017) describes this as the lagged effect of depopulating breeder birds. Table 27 gives an overview of all lost breeder flocks during the 2016/2017 outbreak.

7.4.1 Changes in poultry and poultry product prices before and during the outbreaks in Germany

This section illustrates the changes in poultry prices and market in Germany during the time of the 2017 outbreak and prior years. As shown above, outbreaks occurred primarily in turkey operations. This section also looks at price developments in other poultry types.

Table 27

List of lost breeder animals in Germany in the 2016/2017 outbreak
Source: OIE (2017)

Type of Bird	Amount	Location	Comment	Date
Broiler	36,000	Schleswig-Holstein, Twedt	Grandparent stock	11/12/16
Goose and duck breeding stock	2,821	Nordrhein-Westfalen, Rietberg	2,800 breeding geese and 21 ducks	12/20/16
Turkey breeding stock	4,000	Delbrück, Nordrhein-Westfalen	NA	01/10/17
Turkey breeding stock	9,053	Brandenburg, Kyritz	NA	01/10/17
Turkey breeding stock	9,376	Brandenburg, Alt Zauche-Wußwerk	NA	01/17/17
Goose breeding stock	3,000	Niedersachsen, Gersten	NA	01/23/17
Duck breeding stock	2,850	Brandenburg, Neuhardenberg	NA	02/01/17
Duck breeding stock	16,404	Brandenburg, Wriezen	NA	02/16/17
Duck breeding stock	33,572	Niedersachsen, Edewecht	NA	03/20/17

Figure 65 shows turkey prices for large male turkey and hens from 2014 to 2017 in euros for live weight birds. In early 2014, the price of both large male turkeys and hens was around 1.40€/kg. From there, a slight decrease in prices can be seen over the subsequent years. During the first HPAI outbreaks in 2016, the overall decline in prices intensified slightly. For unknown reasons, there are no data sets available for the end of 2016. In the beginning of 2017, the price was significantly lower than last recorded in 2016, but gained positive momentum again starting in May 2017.

Figure 66 shows the monthly slaughter of turkeys in Germany from 2014 to 2017 in 1,000 pieces per month. Considerable volatility can be seen between 2.5 and 3.5 million birds slaughtered per month, at no point more than 3.5 million turkeys or less than 2.5 million birds. At the end of 2016,

Figure 65

Prices for large male and hen turkeys from 2014 to 2017 in Germany
Source: Beck (2018)

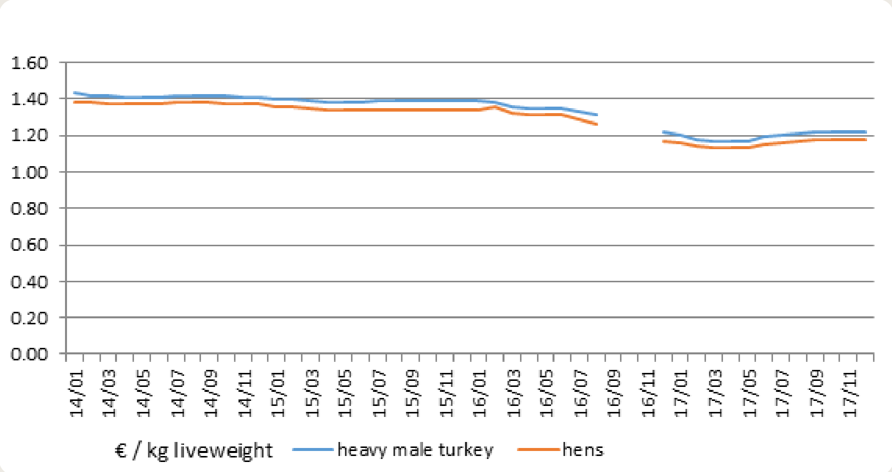
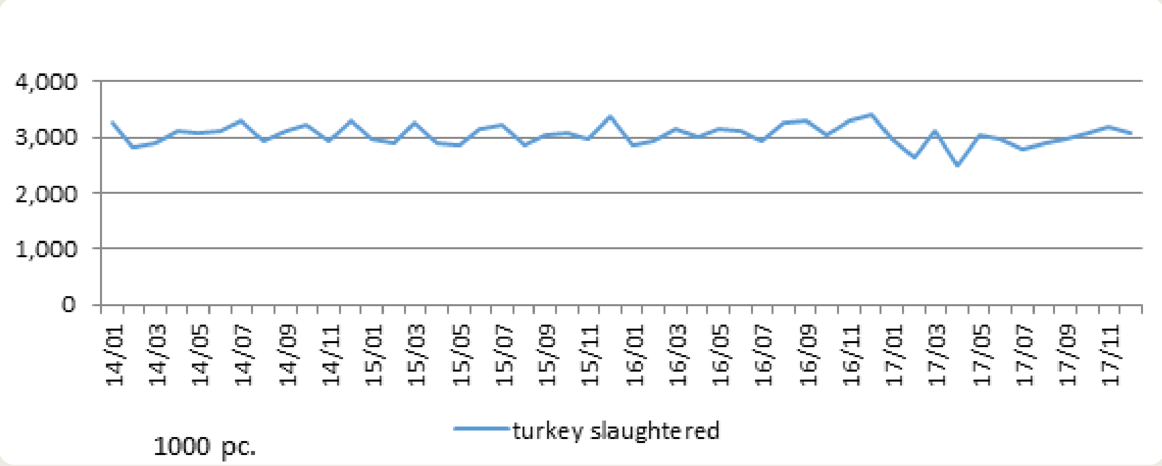


Figure 66

Amount of turkeys slaughtered per month in Germany from 2014 to 2017
Source: Beck (2018)



monthly slaughter reached a temporary high to almost 3.5 million birds. In the subsequent months until May 2017, slaughter decreased to an overall low of 2.5 million birds. After May of 2017, the numbers of turkeys slaughtered in Germany slowly recovered again to above 3 million birds.

Taking both figure 66 (p. 104) and figure 65 (p. 104) into account, it can be seen that the 2017 outbreak indeed had effects on turkey production in Germany. Prices for turkey slightly decreased, while at the same time the volatility in quantities slaughtered increased slightly as well. It also has to be taken into account that the 2017 outbreak was the largest in the history of turkey production in Germany. From this perspective, it can be concluded that the outbreak's effects on the turkey industry were minor. Although the effects of an outbreak of this size is typically reflected in prices and slaughter quantities, the

Figure 67

Consumer egg prices from 2014 to 2017 in Germany
Source: Beck (2018)

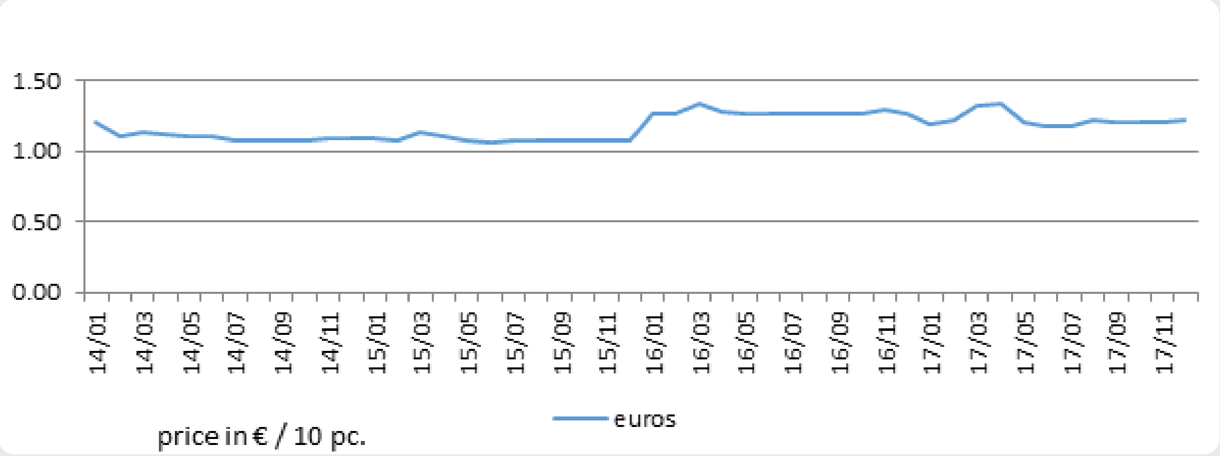
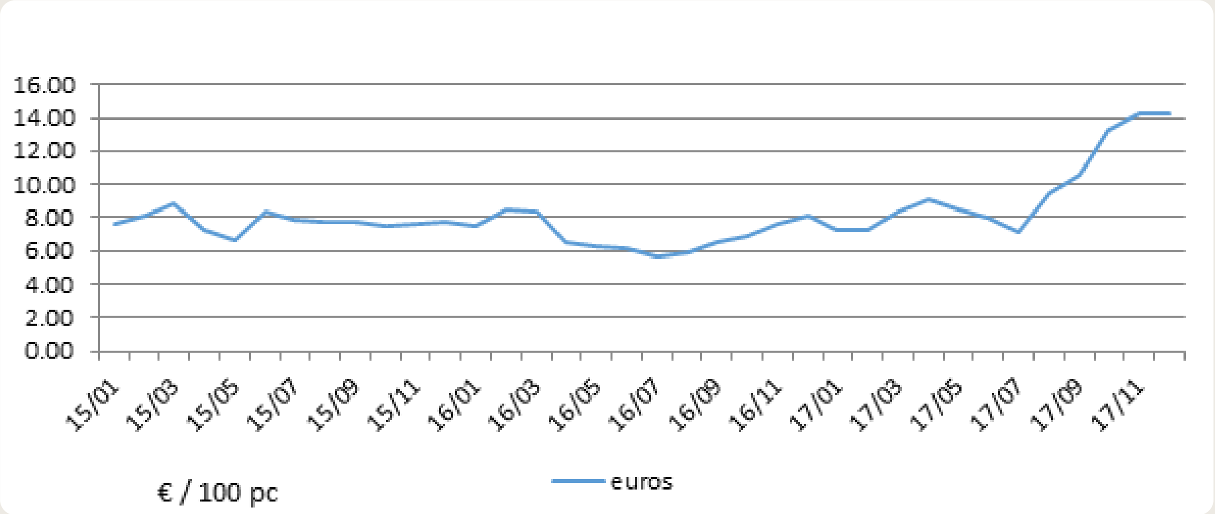


Figure 68

Sales prices for pasture-raised eggs in Germany between 2014 and 2017
Source: Beck (2018)



effects of this outbreak interestingly almost stayed within the scope of regular volatility. In summary, it can be stated that although there were in fact some effects on the German poultry market during the 2017 outbreak, they stayed within manageable boundaries and did not lead to major market distortions.

Figure 67 (p. 105) and figure 68 (p. 105) analyze whether there were noticeable market disruptions in the layer industry. The figures show consumer prices for eggs and sale prices for farmers from 2014 to 2017. Figure 67 shows consumer egg prices during the outbreak in euros per 10 pieces for pasture-raised eggs in size M. It can be seen that egg prices remained between 1 and 1.20 euros from 2014 to the end of 2015. At the beginning of 2016, a stark increase in price can be noted, with prices almost reaching 1.40 euros in March of 2016 and staying high with some volatility until the end of 2017. The noticeable increase in price is likely based on international market distortions due to the 2015 HPAI outbreak in Minnesota and Iowa (also discussed in this thesis). The demand of eggs in the USA was met with eggs from Europe, increasing prices in Europe. The previously mentioned volatility occurred precisely during the time of the German outbreak, starting at the end of 2016 and reaching a peak in April 2017. It is possible that the German HPAI outbreak is the cause of this volatility.

Figure 68 (p. 105) shows egg market prices for farmers from 2015 to 2017 in euros per 100 pieces, size L, pasture-raised, and white color. Generally, some volatility is noticeable, ranging between nine and six euros per 100 eggs. During the time of the outbreaks in Germany, although prices indeed reached the lowest point in these three years, of important note is that the decline started before the HPAI crisis, with the lowest point reached in July of 2016, which was earlier than the initial outbreaks in Germany. In March of 2017, during which the main bulk of the HPAI outbreaks occurred, prices reach an interim high. In July of 2017, prices dramatically increased to almost double the previous amounts. This was an effect of the Fipronil crisis[1] that played out independently of the HPAI outbreaks (Beck, March 2018).

In light of this, it could be stated that the 2017 HPAI outbreak in Germany did not substantially affect the layer industry in Germany. Although consumer eggs prices saw some increased volatility, these were not major changes. Prices for producers also saw some volatility during the time of the outbreaks, but they were not major and stayed within previous price ranges. Some months after the outbreaks, a noticeable increase in producer prices in Germany occurred. This development however can be related to the Fipronil crisis and not the HPAI outbreaks.

7.5 Plausible causes for local HPAI escalation

The previous sections showed the particular development of the outbreaks in Germany. While overall virus pressure was declining in Germany, the municipality of Garrel saw exceptionally high numbers of outbreaks in a spatially confined area in specific types of commercial poultry flocks. This section explains possible reasons for this particular development. Local authorities, especially the veterinary inspection office of the county of Cloppenburg, conducted research on possible dissemination routes of the virus in this spatial setting.

The veterinary inspection office noted that locals reported the presence of large quantities of wildfowl in the area prior to and during the outbreaks (Leßmann, 2018). This is an indicator that the general virus pressure was high at the time the outbreaks started. Despite the ubiquitous presence of wildfowl, testing by the inspection office of scattered fecal matter and infrequent live bird sampling in the area produced only one positive HPAI finding (Leßmann, 2018).

[1] During the so-called Fibronil crisis, it was discovered that a Belgian company had illegally used the insecticide Fipronil in one of their cleaning products. Fipronil is especially effective against red fowl mites. This illegal substance was used excessively by a Dutch service provider in many Dutch and in some German layer operations (van der Merwe, D., Jordaan, A., & van den Berg, M. (2019)). Case report: Fipronil Contamination of Chickens in the Netherlands and Surrounding Countries. In Chemical Hazards in Foods of Animal Origin (pp. 363-373) Wageningen Academic Publishers. The Dutch layer industry is heavily dependent on German imports, which ceased almost completely during the crisis. German eggs were in high demand in Germany during this time, resulting in a noticeable price increase after the situation became public Windhorst, H.-W. (2017). Der wirtschaftliche Schaden des Fipronil-Skandals für die niederländische Eierwirtschaft. Wissenschafts- und Informationszentrum Nachhaltige Geflügelwirtschaft (WING).

It is however still possible that a first introduction in the area happened through the presence of wildfowl. In assessing the multitude of subsequent outbreaks, insufficient biosecurity conditions such as openly accessible straw storage were discovered by local authorities (TSK & Gerdes, 2018). These flaws in biosecurity very likely made the introduction of HPAI by wildfowl to commercial poultry possible, causing the first outbreaks in the area of Garrel.

As explained in sections 7.3.1 and 7.5, the general virus pressure decreased in the environment, while at the same time new outbreaks were almost exclusively happening in the immediate surroundings of Garrel. This leads to the conclusion that secondary infections in the area surrounding Garrel occurred due to human mistakes. Further investigations by the local veterinary inspection office discovered various flaws in biosecurity procedures, such as shared machinery for bedding renewal, shared personnel, and inadequate carcass disposal (Leßmann, 2018). Although it is not possible to point out a distinct and unambiguous dissemination route in Garrel, the facts point to flaws in basic biosecurity measurements resulting in subsequent and ongoing outbreaks there.
Along with flawed biosecurity at the farm level, the mitigation efforts themselves possibly caused further outbreaks. Leßmann (2018) and Sieverding (2018) mention problems during mitigation efforts. As explained, carcasses and virus material were taken from infected premises to rendering plants by truck. On some occasions, this process was conducted under strong wind conditions with neighboring poultry operations in close proximity (Sieverding, 2018). Despite improved precautions such as spraying disinfectants while loading and covering the handlers' buckets (Leßmann, 2018), it is likely that the process of removing carcass material under heavy winds caused further outbreaks.

Although these factors could possibly pinpoint the cause of the massive outbreaks around the municipality of Garrel, other cases are not consistent with this argumentation. The HPAI outbreak also affected a layer operation where outstanding biosecurity protocols and procedures were practiced, one of the reasons being because the operation housed genetically valuable grandparent stock animals. The premise is outside the high density poultry area in the state of Schleswig-Holstein in a poultry-isolated area. It remains to date unclear how virus material was able to penetrate this facility (Leßmann, 2018). Another case in the high density area of Garrel is particularly interesting and raises further questions concerning virus dissemination routes. In Garrel, two operations were affected that are located 9.3 kilometers apart from each other. Research showed that there was no connection of any known kind between them. Genomic sequencing also showed that HPAI virus material in these operations was of the same genetic cluster. This is another example where the exact virus dissemination route is inexplicable (Leßmann, 2018).

7.5.1 Reasons for the decline in HPAI outbreaks

As mentioned in chapter 2.3, the HPAI virus is susceptible to heat and UV light. The further a year progresses from winter to spring to summer, the more difficult it is for the virus to survive. This potentially lessened the virus' progression, starting in February of 2017.

Figure 69 (p. 108) shows the number of sun hours during the month of the outbreak in Germany as recorded in the city of Bremen, which is in the proximity of the outbreaks. Figure 69 also shows that starting in February of 2017, the number of sun hours increased noticeably and surpassed eight hours on some days. Particularly in the middle and end of March, the amount of sun hours increased further, surpassing ten hours per day.

Figure 70 (p. 108) shows the maximum temperatures each day during the time of the outbreaks. In January, temperatures were low and on some days below the freezing point. After the 12th of February, daily temperatures climbed noticeably. In the middle of March, they hovered around 12 degrees. In the beginning of April, temperatures reached their first peak of the year, climbing to above 20 degrees. The 2017 HPAI outbreak in Germany ended with a last positive HPAI case on April 6th. Increasing daily sun hours typically occur together with increasing temperatures, making it plausible that this had a significant impact on virus progression in the area. It is very likely that the change in environmental conditions was one of the main reasons why virus progression halted, starting in late March of 2017.

Figure 69

Hours of sun during the month of the outbreak in Germany
Source: WetterOnline (2017a)

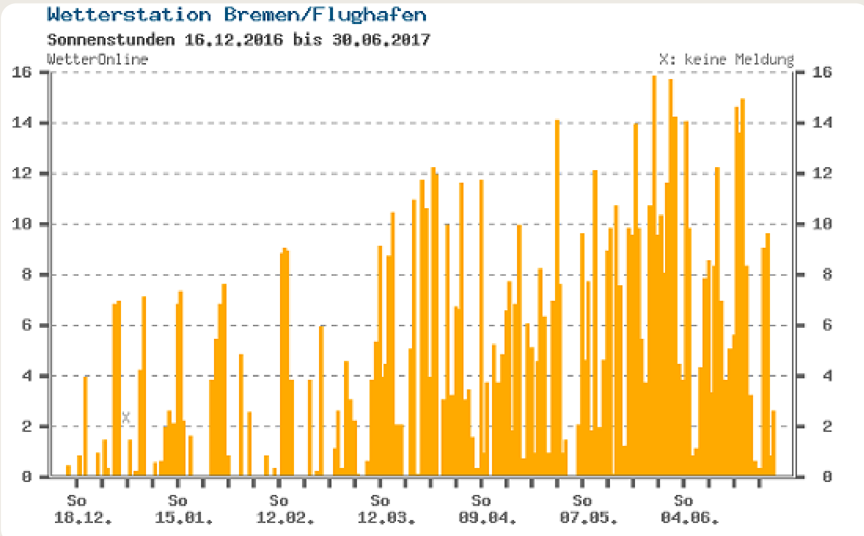
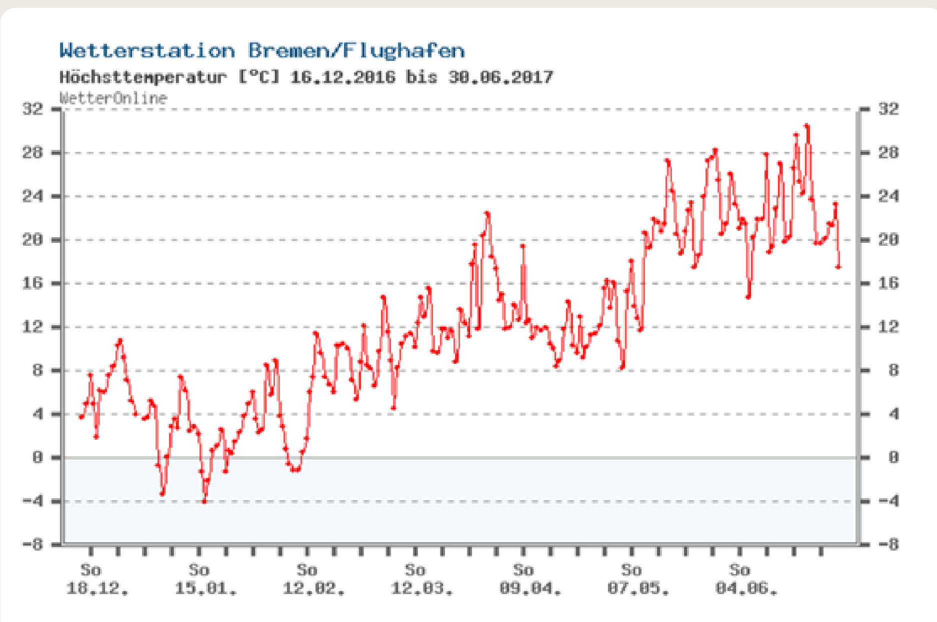


Figure 70

Area temperatures at the time of the outbreaks in Germany
Source: WetterOnline (2017b)



7.6 Direct costs

This chapter ascertains the direct costs (DC) of the 2017 HPAI outbreak. A definition of DC can be found in section 5.3.1. Using the framework of analysis as defined there, this section works out the economic impacts for all relevant stakeholders. The information of the previous section is applied to the economic analysis in this one. The section following this one calculates DCC.
As elaborated in section 5.3.1, DC are entirely incurred by governmental and supra-governmental organizations. Saatkamp et al. (2014) define that costs occurring as part of mitigation efforts directly after official HPAI confirmation have to be paid by governments. Euthanasia, disposal, and cleaning and disinfection are organized by governmental institutions in Germany. Like indemnification payments, these activities are also paid for by governmental institutions. The primary sector, i.e. farming operations, are not affected by DC.
This section calculates costs that are exclusively paid by governments, separating them into impacts in the state of Lower Saxony and the remaining states of Germany. This section further distinguishes between costs for indemnification, culling, cleaning, and disinfection and disposal. These type of costs are all part of DC (Saatkamp et al., 2014).

7.6.1 Lower Saxony

As mentioned earlier, Lower Saxony was affected the most in terms of HPAI incidents in captive bird operations. The Tierseuchenkasse Niedersachsen (TSK, Animal Disease Fund of Lower Saxony) provided detailed information to the author about all relevant expenditures in association with the HPAI outbreak. Table 28 shows total DC in Lower Saxony for the different mitigation activities. Indemnification genera-

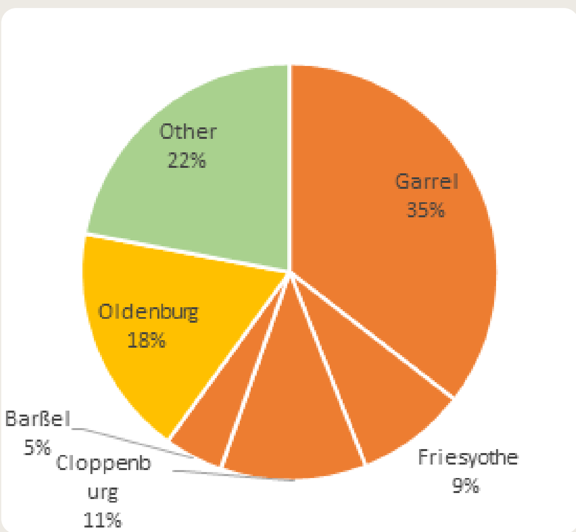
Table 28

Total DC in Lower Saxony
Source: TSK (2017a)

Indemnification	Euthanasia	Cleaning and Disinfection	Disposal
9,230,117.04 €	4,413,380.75 €	559,548.93 €	1,001,607.78 €

Figure 71

DC in counties and municipalities of Lower Saxony
Source: TSK (2017a)



ted costs of more than nine million euros. Euthanasia created costs of more than four million euros, cleaning and disinfection accounted for more than half a million euros, and the disposal of birds generated costs of more than one million euros. It can be seen that costs for indemnification were by far the highest in comparison. In total, DC in Lower Saxony amounted to €15,204,654.50.

Table 29

DC in regions of Lower Saxony
Source: TSK (2017a)

Region of Lower Saxony	Organizational type	Total DC
Oldenburg	County	2,738,066.30
Garrel	Municipality	5,392,096.33
Friesoythe	Municipality	1,306,299.82
Cloppenburg	Municipality	1,722,592.76
Barßel	Municipality	696,091.58
Other	Counties and Municipalities	3,349,507.71

Table 30

DC in different bird categories in Lower Saxony
Source: Own calculations based on data provided by the TSK (2017a)

Turkey (Costs in €)				
	Indemnification	Euthanasia	Cleaning & Disinfection	Disposal
per operation	149,039.68	64,274.34	8,317.21	17,225.62
per animal	14.85	6.35	0.84	1.67
Turkey Day Old Chicks (Costs in €)				
	Indemnification	Euthanasia	Cleaning & Disinfection	Disposal
per operation	81,636.30	121,418.46	4,979.25	6,587.32
per animal	3.98	4.47	0.26	0.23
Broiler (Costs in €)				
	Indemnification	Euthanasia	Cleaning & Disinfection	Disposal
per operation	160,123.32	36,870.96	10,442.13	19,132.49
per animal	1.80	0.41	0.12	0.22
Ducks (Costs in €)				
	Indemnification	Euthanasia	Cleaning & Disinfection	Disposal
per operation	34,436.52	94,614.82	9,253.44	3,084.85
per animal	2.0	5.32	0.37	0.19
All (Costs in €)				
	Indemnification	Euthanasia	Cleaning & Disinfection	Disposal
per operation	135,737.02	66,869.41	8,881.73	14,729.53
per animal	13.76	7.98	0.8	1.38

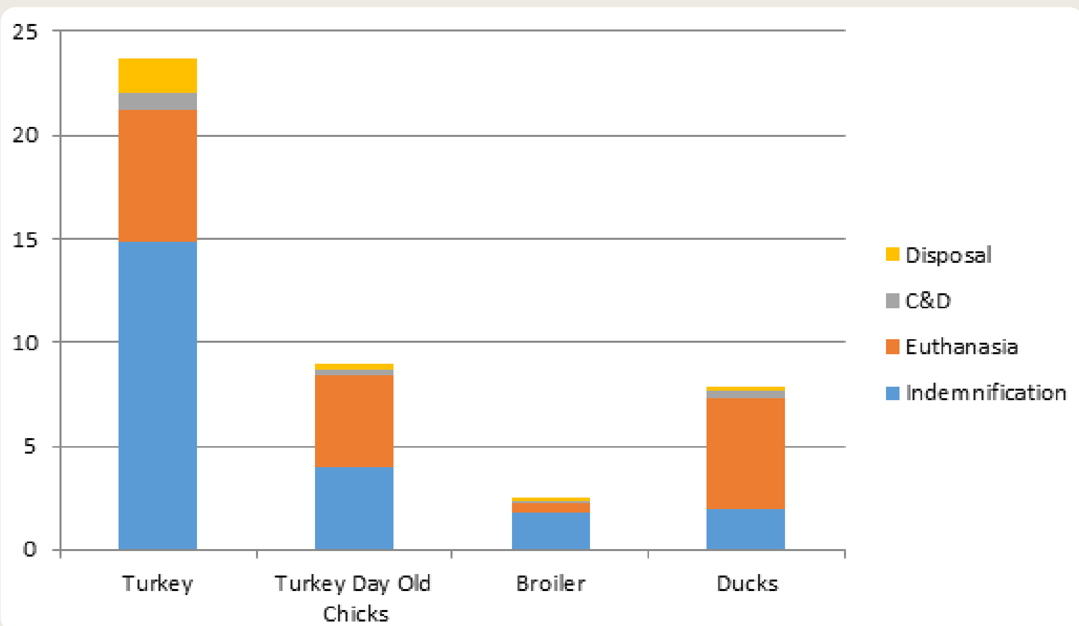
The area in Lower Saxony with a very high density of poultry rearing was described above. Figure 71 (p. 109) shows how DC in Lower Saxony were allocated throughout counties and municipalities. The municipalities of Garrel, Friesoythe, Cloppenburg, and Barßel are all part of the county of Cloppenburg. Oldenburg is another county that was significantly impacted. All remaining counties of Lower Saxony are summarized in “Other.” The figure shows the dominant role of the Cloppenburg municipality, being responsible for more than 60% of all DC in the state of Lower Saxony.
Table 29 (p. 110) further elaborates upon the exact numbers. It can be seen that the comparatively small municipality of Garrel was responsible for more than five million euros in DC, which is significantly more than any other region of Lower Saxony.

Table 30 (p. 110) shows an overview of DC in Lower Saxony for different types of birds, calculated for every type of bird per operation and animal. Geese are not mentioned because only one parent stock operation was affected. Backyard operations that were not entitled to indemnification, and other parent stock operations are also not included. Parent stock operations are described separately because bird value differs significantly in these instances.
It can be seen in table 30 (p. 110) that turkeys are more expensive to indemnify, euthanize, clean and disinfect, and dispose of. The costs per operation are highest for broiler flocks, which can be explained by the fact that broiler operations are significantly larger in general in comparison to operations having other bird types.
The fact that mitigation efforts are highest for turkey operations contributed to high economic impacts during the 2017 HPAI outbreak in Germany.

Figure 72 shows the costs of mitigation efforts in different bird categories in Lower Saxony during the 2017 HPAI outbreak. The figure is a visualization of table 30. Costs here are subdivided into the four categories of disposal, cleaning and disinfection, euthanasia, and indemnification mentioned above. The figure shows that mitigation efforts in the turkey sector were the most expensive by a wide margin. Costs for

Figure 72

Costs for mitigation efforts in different bird categories in Lower Saxony
Source: TSK (2017a)



indemnification in the turkey sector alone were higher than all the other bird categories combined. Bird size, the length of the fattening period, and the overall value of each bird make HPAI mitigation efforts in the turkey sector very expensive. This claim is based on the data of the Animal Disease Fund of Lower Saxony; although not generalizable, it does in fact point out the significant role of the turkey industry in an outbreak situation.

7.6.2 Germany

Although the 2017 HPAI occurred primarily in Lower Saxony, there were some outbreaks in other German states as well. This section describes the outbreaks in the remaining German states in more detail.

7.7 Direct consequential costs (DCC)

The second key category of economic costs as defined by Saatkamp et al. (2014) is direct consequential costs (DCC). This section calculates DCC for the 2017 HPAI outbreak in Germany; an exact description of DCC can be found in chapter 5.3.1. DCC arise once cleaning and disinfection as well as disposal of the dead animals have been completed. While all active mitigation efforts are paid for by government accounts and are therefore accrued under DC in this research, imposed production stops are not covered by indemnification payments or other insurance coverages. DCC are based on economic losses due to lost production and general downtime after active mitigation efforts are concluded. DCC are absorbed by farming operations, as well as primary and secondary industries. The secondary industry includes all business that provide services or goods to farming operations. If production stops, these industries are equally out of business for the duration of the downtime. This section describes in detail economic losses of the primary and all relevant secondary industries. The sub-sections are divided accordingly.

Table 31

Total DC in Germany per state excluding Lower Saxony
Source: BMEL (2019), LWK NRW (2019), TSK (2017b)

State	Indemnification	Operative costs			Total
		Euthanasia	Cleaning and Disinfection	Disposal	
NI	9,230,117.04	4,413,380.75	559,548.93	1,001,607.78	15,204,654.50
NW	1,846,367.40	1,753,498.35	539,233.67	229,576.21	4,368,675.63
MV	716,870.42	501,160.63			1,218,031.05
BB	2,656,085.93	1,051,020.39			3,707,106.32
ST	181,669.29	160,793.59			342,462.88
SH	1,516,612.90	708,558.99			2,225,171.89
BY	148,694.05	192,132.37			340,826.42
SN	303,819.50	112,766.87			416,586.37
TH	2761.62	1,128.41			3,890.03

7.7.1 Primary industry

After HPAI confirmation, the affected farming operations undergo thorough mitigation activities such as euthanasia of the remaining birds, cleaning, disinfection, and carcass disposal. These are followed by a predefined waiting period in which no new stock can be put into the operation. Restocking begins only after concluding the waiting period and once the absence of virus material has been confirmed (BMJV, 2007).

In Germany, these procedures are clearly defined in the so-called Avian Influenza Act (*Verordnung zum Schutz gegen die Geflügelpest, Geflügelpest-Verordnung GeflPestSchV*) (BMJV, 2007). The Avian Influenza Act regulates among other things the duration of halted production. Paragraph 32 of the Avian Influenza Act states that in areas with a poultry density higher than 500 birds per square kilometer, the local administration is authorized to halt the restocking of affected and cleaned barns. In addition, restocking can also be stopped in barns in the neighboring area that were emptied because their flock was ready for slaughter (BMJV, 2007). Local authorities in Cloppenburg made use of this for both affected and non-affected premises. Among other reasons, the poultry density in the particular area with a multitude of outbreaks was also significantly higher than 500 birds per square kilometer. At the time of the outbreaks, there were more than 18,900 birds per square kilometer in the municipality of Friesoythe, more than 14,400 birds in Garrel, and more than 12,300 birds per square kilometer in Bösel (CLP, 2017b).

The halting of restocking is limited to the respective bird categories and to an area of not more than 25 kilometers around outbreak operations (BMJV, 2007). In general, restocking can be halted for 30 days, but the directive can be renewed if the local authority deems it necessary. The restocking halt was prolonged in the area of Cloppenburg once (CLP, 2017b).
For the economic analysis of this paper concerning the economic impacts in Germany, poultry operations in Germany are divided into three groups. Group 1 includes all HPAI-affected operations in Germany outside the area of Bösel, Friesoythe, and Garrel in Cloppenburg. For all affected operations in group 1, standard mitigation procedures and waiting periods with idle production applied. For simplification and due to a lack of more detailed information, it is assumed that the waiting period in these operations did not extend beyond the standardized 21 days as predefined by the Avian Influenza Act (BMJV, 2007). Group 2 includes HPAI-affected operations inside the area of Bösel, Friesoythe, and Garrel that underwent prolonged waiting periods. Group 3 encompasses all operations inside the area of Bösel, Friesoythe, and Garrel and were not affected by a direct HPAI outbreak. These operations made it through the DCC fairly well because standard restocking was permitted and waiting periods increased. Table 32 shows detailed information concerning group 1, which encompasses affected operations out-

Table 32

Group 1 of affected turkey operations in Germany
Source: Author with information see below

Group 1	**Affected operation outside of high density area, standard procedures**	
Days of idle production*	Amount of operations**	Amount of birds affected***
21	42	442,835
Total forgone production days		9,299,535
Daily revenue turkey operation €****		0.013
Total lost production value €		120,893.96

* (BMJV, 2007) ** (OIE, 2017) *** (OIE, 2017) **** Provided by KTBL (2016, p. 723), average of daily revenue (Einzelkostenfreie Leistung €/(TP x a))

side of the high density area where standard mitigation procedures were applied. The exact amount of affected farms is known from the outbreak statistics provided by the (OIE, 2017).

Table 33 explains further details concerning group 2 of the affected turkey operations in Germany. Group 2 encompasses farmers inside the high density area who were not allowed to restock for prolonged periods of time after mitigation activities were concluded. The exact amount of birds affected is known from outbreak statistics provided by the OIE (2017) and TSK (2017b). The amount of idle production days is assumed to be 69, based on the occurrence of the second wave of outbreaks that started on February 26th, 2017 and ended on May 8th, 2017. There were outbreaks before the 26th of February, but restriction zones and restocking halts did not affect the whole of the area in the same manner after this date. This means that the results of this calculation are likely to generate lower numbers than what occurred in reality.

Table 34 (p. 115) explains details of the third group of farmers affected by DCC. Group 3 encompasses farm operations inside the high density area that were not affected by HPAI but were not able to restock after their flock was slaughtered following the standard fattening phase (this did not include early slaughter). The exact amount of birds is known through subtracting the amount of birds in group 2 from the amount of birds present in the area during the time of the outbreak. The amount of birds present in the area was provided to the author by the local veterinary service authority.

Since not all premises were emptied at exactly the same time when the outbreaks started, this calculation derives the relative increase of idle production across the year. KTBL (2016, p. 702) defines the standard idle time after emptying the premises at 13 days, which represents 3,567%. An increase in idle time by an additional 69 days represents an increase to 15.334% idle time relative to the whole year. This increase in idle time is therefore accounted for.

In summary, in the three different groups described above, a total of 50,460,277 production days were lost to farmers in Germany. This production loss is a DCC for the primary sector because losses due to idle production were not indemnified. The combined total monetary value of losses in all three groups was € 681,983.61.

7.7.2 Secondary industry

The agricultural secondary industry is directly interconnected with production in the primary sector. When production in the primary sector halts, ripple effects are felt throughout all secondary sectors. This section highlights the economic impacts in the secondary sector

Table 33

Group 2 of affected turkey operations in Germany
Source: Author with information see below

Group 2	Affected operations inside of high density area, prolonged waiting periods	
Days of idle production*	Amount of operations**	Amount of birds affected***
69	28	393,427
Total forgone production days		25,146,463
Daily revenue turkey operation €****		0.013
Total lost production value €		352,904.02

* Describes the second wave of outbreaks, starting end of February (CLP, 2017e) in Friesoythe until beginning of May when all restrictions were lifted (CLP, 2017c)

** (OIE, 2017) *** (OIE, 2017) **** Provided by KTBL (2016, p. 723), average of daily revenue (Einzelkostenfreie Leistung €/(TP x a)) and adjacent industries during the 2017 HPAI outbreak in Germany.

This section builds on the calculations of the previous chapter. In Germany, the KTBL (Kuratorium für Technik und Bauwesen in der Landwirtschaft) institute, a board for engineering and construction in agriculture, provides detailed information annually on among other things the turnover of secondary industries. KTBL describes this turnover as costs for the primary production sector. The information is presented in the series Agricultural Plant Engineering (Betriebsplanung Landwirtschaft) which is intended as a planning tool for upcoming investments in farms. The information from this for the year 2016/2017 is used in this section to calculate losses in the secondary industries. While the previous section elaborated on the total amount of lost production days due to HPAI outbreaks in Germany, this chapter builds on this by calculating monetary losses in the secondary industry per day of lost production.

The following industries and service providers are considered part of the secondary industry: animal feed manufacturing; veterinary service providers and medication; litter material providers; maintenance and repair services and goods; energy providers for heating, ventilation, and lighting; animal render services; cleaning and disinfection service and goods; and water suppliers. Some of the goods and services described in this chapter can also potentially be provided by the farm's operation through own personnel or resources. Other services might be provided by the same company such as energy for heating and energy for ventilation or lighting. Due to the lack of more detailed information on how each operation in Germany is organized, the calculations are set up respective to the available information from the KTBL institute. If the services mentioned are executed in-house without external services, there are opportunity costs to consider, which then are covered as part of this elaboration. The accounts of overall economic impacts in the secondary industry remain correct, independent of the exact allocation of these costs.

7.7.2.1 Animal feed manufacturing

Turkey rearing and fattening requires considerable amounts of feed. About 75% of direct costs in turkey can be attributed to feed costs (KTBL, 2016). As a consequence, the animal feed manufac-

Table 34

Group 3 of affected turkey operations in Germany
Source: Author with information see below

Group 3	Non-affected operations inside of high density area, prolonged waiting periods before standard restocking		
Increase of idle production period *	Amount of birds potentially affected**	Amount of birds statistically affected***	Days of idle production****
15.334%	1,513,573	232,091	69
Total forgone production days			16,014,279
Daily revenue turkey operation € *****			0.013
Total lost production value €			208,185.63

* Standard idle production period is 3.567% (KTBL, 2016, p. 702)

** Total amount of birds present in the three municipalities: 1,907,000 (Seelhorst, 2017) minus the amount of birds in group 2

*** Amount of birds potentially affected x increase of idle production period

**** Describes the second wave of outbreaks, starting end of February (CLP, 2017a) in Friesoythe until beginning of May when all restrictions were lifted (CLP, 2017d)

***** Provided by KTBL (2016, p. 723), average of daily revenue (Einzelkostenfreie Leistung €/(TP x a))

turing industry incurred losses due to production stops in the primary sector.
The following statistics are specific for the years 2016 and 2017. There are different rearing systems in place making use of differing feeding practices in Germany. In general and independent of the feeding practice, hens require 39.66 kg of feed until ready for slaughter, and heavy male turkey require 70.32 kg of feed until ready for slaughter in week 24 (KTBL, 2016, p. 706). Further, the KTBL (2016, p. 704) suggests that hens and male turkey be present in Germany at a 46% to 54% ratio, which is also used as a basis for the calculation. Turkey are ready to slaughter between 2.3 to 2.9 times per year per barn operation, resulting in an average of 2.6 cycles per year per barn (KTBL, 2016, p. 704). This is also taken as a basis for this calculation. Animal losses range between 4.2% in hens and 10.9% in male turkeys (KTBL, 2016, p. 704). Taking into account the hen and male turkey ratio, this results in a weighted average of 7.8% of animal losses in production. The cost for feed in 2016 ranged between 0.30€/kg and 0.38€/kg depending on the age of the flock and the phase of the feed program. KTBL (2016, p. 721) suggests an average of 0.31€/kg as feed costs. Further, KTBL (2016, p. 704) defines the standard length of no production in between flock cycles per year to be between 12 and 14 days depending on the rearing system. For the calculation, an average length of 13 days of no production between cycles is assumed.

Table 35

Monetary impacts in the animal feed manufacturing industry
Source: Own calculations based on data provided by the KTBL (2016)

Animal feed manufacturing, 2016/2017					
Cycles of production / year	Total feed hens kg	Total feed toms kg	Animal losses %	Days of no production / year	Feed costs €/kg
2.6	39.66	70.32	7.8	13	0.31
Calculation	((2.6 x (39.66 + 70.32) -7.8%) / (365-13)) x 0.31				
Losses per day per bird €					0.2517
Total losses based on total lost production days*					12,700,851.72

* Based on calculations from Chapter 7.7.1

Table 36

Monetary impacts in the maintenance and repair services and goods industry
Source: Own calculations based on data provided by the KTBL (2016)

Maintenance and repair services and goods, 2016/2017		
	Building costs € / year / animal	Share of building costs for short, medium, and long-term repairs, %
	5.79	17.6
Calculation	(5.79 x 17.6%) / 365	
Losses per day per bird €		0.0027
Total losses based on total lost production days*		136,242.75

* Based on calculations from Chapter 7.7.1

Table 35 (p. 116) summarizes the information above and calculates losses per day per bird for animal feed manufacturing stakeholders during the 2017 HPAI outbreak.

In summary, the animal feed manufacturing stakeholders were impacted with monetary losses at a turnover of approximately 0.2517€ per bird per day of lost production.

7.7.2.2 Maintenance and repair services and goods

In times of standstill, maintenance and repair activities are halted as well. This chapter calculates the losses for maintenance and repair service and goods providers during the 2017 HPAI outbreak.

Yearly building costs range between 4.61€ and 7.24€ per year and animal (KTBL, 2016, p. 210). The exact costs depend on the size of the operation and the rearing system. For reasons of simplification and due to a lack of more exact information about farms in Germany, the average of the range is calculated at 5.79€ per year and animal. Of these yearly building costs, 17.6% are for short, medium, and long-term repairs, resulting in costs of 1.02€ per year per animal in repairs (KTBL, 2016, p. 710). This leads to repair costs per day and turkey of 0.0027€. Table 36 (p. 116) gives an overview of this calculation.

Per day per animal, maintenance and repair services and goods providers registered monetary losses of 0.0027€ per bird.

7.7.2.3 Cleaning and disinfection services and goods

Cleaning and disinfection services and goods are required daily in turkey production. Turnover and costs data in the area of cleaning and disinfection service and goods are available through the KTBL (2016, p. 709). The lump sum per animal per year is described as 0.05€ for cleaning and disinfection services and goods. This results in costs of 0.00014€ per animal per day which can be regarded as lost turnover to the respective provider industry. This calculation is summarized in table 37.

7.7.2.4 Veterinary services and medication

Another important secondary industry is the veterinary services industry. Veterinary services and the administration of medication were also halted during the time of primary production. Costs in this industry are defined by the KTBL (2016, p. 721) in lump sum amounts as 1.38€ per animal per year. This leads to costs of 0.0038€ per day per animal which is shown in table 38 (p. 118).

Table 37

Monetary impacts for the cleaning and disinfection services and goods industry
Source: Own calculations based on data provided by the KTBL (2016)

Cleaning and disinfection services and goods, 2016/2017	
	Lump sum costs € / year / animal
	0.05
Calculation	0.05 / 365
Losses per day per bird €	0.00014
Total losses based on total lost production days*	7,064.44

* Based on calculations from Chapter 7.7.1

Table 38

Monetary impacts for veterinary services and medication providers
Source: Own calculations based on data provided by the KTBL (2016)

Veterinary service providers and medication, 2016/2017	
	Lump sum costs € / year / animal
	1.38
Calculation	1.38 / 365
Losses per day per bird €	0.0038
Total losses based on total lost production days*	191,749.05

* Based on calculations from chapter 7.7.1

Table 39

Monetary impacts for the litter industry
Source: Own calculations based on data provided by the KTBL (2016)

Litter material providers, 2016/2017					
Straw usage kg / year / animal	Daily straw usage kg / year / animal	Costs for straw € / kg	Wood chips usage kg / animal	Wood chips kg / day / animal	Costs for wood chips € / kg
5.73	0.016kg	0.12	0.63	0.0046	0.23
Calculation	(((1.5*2.6*0.46) + (2.8*2.6*0.54) / (365 - 13)) x 0.12) + (0.63 x 2.6 / (365 - 13) x 0.23)				
Losses per day per bird €					0.218
Total losses based on total lost production days*					11,000,340.39

* Based on calculations from chapter 7.7.1

7.7.2.5 Animal litter providers

Service and goods providers of barn litter depend on production in the primary sector as well. As soon as this is unexpectedly halted for longer periods, monetary economic losses occur. The KTBL (2016) describes the amount and type of litter usage in turkey production. In turkey production in Germany there is a need for at least two different kinds of litter material: wood chips in the rearing phase until the sixth week of life, followed by straw after the sixth week. The rearing of hens requires considerably less straw compared to the rearing of heavy male turkeys. Hens require a total of 1.5kg of straw during their life spans, whereas male turkeys require 2.8kg of straw. Again, considering 2.6 cycles per year and a hen-to-male turkey ratio of 46% to 54% as described above, there is a need of straw per animal per year of 5.73kg. This results in a daily straw consumption of 0.016kg per animal. The KTBL (2016, p. 721) describes the costs of straw in 2016 as 0.12€/kg, resulting in daily costs of 0.217€ for straw. Per animal, an amount of 0.63kg of wood chips is required for the rearing period, resulting in a total need per year of 1.638kg. In 2016, wood chips were priced at 230€ per ton. At 0.0047kg of wood chips per day per animal, this amounts to costs of 0.001€ for wood chips per animal per day. This calculation is presented in table 39. The litter material provider industry thus had total economic impacts of 0.218€ per day per animal of lost production.

Table 40

Monetary impacts in the energy sector
Source: Own calculations based on data provided by the KTBL (2016)

Energy, 2016/2017					
	Energy consumption lighting kWh / year	Energy consumption ventilation kWh / year	Energy consumption heating kWh / year	Costs for electricity €/kWh	Costs for liquid gas €/kWh
	0.15	0.14	4.2	0.24	0.04
Calculation	((0.15*2.6*0.24) + (0.14*2.6*0.24) + (4.2*2.6*0.04)) / (365-13)				
Losses per day per bird €					0.0018
Total losses based on total lost production days*					90,828.5

* Based on calculations from chapter 7.7.1

Table 41

Monetary impacts in the animal rendering service sector
Source: Own calculations based on data provided by the KTBL (2016)

Animal rendering services, 2016/2017		
	Costs for animal rendering, turkey, €/ animal	Weighted average losses in turkey production %
	0.64	7.80%
Calculation	(0.64 x 7.8% x 2.6) / 365	
Losses per day per bird €		0.00036
Total losses based on total lost production days*		18,165.7

* Based on calculations from chapter 7.7.1

7.7.2.6 Energy costs

The energy sector is yet another important secondary industry to consider for economic losses. Poultry production facilities use energy for heating, ventilation, and lighting. Energy consumption is calculated in this chapter with information based on details provided by the KTBL (2016, p. 713).

Energy consumption per animal for lighting is 0.15 kWh and 0.14 kWh for ventilation. Heating requires an average of 4.2 kWh per animal. Taking 2.6 cycles per year as given, this results in a total usage of 11.674 kWh per animal per year and 0.032kWh per animal per day. Costs for electricity for ventilation and lighting in 2016 on average were 0.24€/kWh. Liquid gas for the heating system was priced at 0.04€/kWh in 2016.
Combining the costs for the different kinds of energy, table 40 shows that costs per day of lost production amounted to 0.0018€.

7.7.2.7 Animal rendering service providers

Animal render service providers depend on primary production. When primary production is halted, economic losses occur. This section highlights these economic impacts during the 2017 HPAI outbreak. The KTBL (2016, p. 709) describes the costs for animal rendering as on average 0.64€/animal. With a weighted average of 7.8% losses in turkey production, this leads to costs for rendering per animal of

0.048€. With 2.6 production cycles per year in turkey production, this results in costs of 0.125€ per animal per year and 0.00034€ per day. This calculation is presented in table 41 (p. 119).

7.7.2.8 The water supply sector

When primary production is halted, water usage ceases and the provider sector incurs economic losses. This section calculates economic losses with regard to water usage.

The KTBL (2016, p. 721) outlines the usage and costs of water in turkey production. Per year per animal, there is an average need of 0.25m^3 of water, which relates to costs of 0.46€ per animal per year taking into account costs of 1.80€/m^3. This results in economic losses per day per bird of 0.0013€ for water provider stakeholders, which is presented in table 42.

7.7.2.9 Animal management and movement

In Germany it is common to contract external animal handling crews for activities such as movement of birds or vaccination. This is especially true for the loading and unloading of birds prior to slaughter, as well as for bird movements during the rearing or fattening phases of production. These service providers were also affected during times of no primary production. The KTBL (2016, p. 715) clearly defines the amounts of time per

Table 42

Monetary impacts in the water provider sector
Source: Own calculations based on data provided by the KTBL (2016)

Water supply, 2016/2017		
	Water usage m^3 / year / animal	Costs for water €/m^3
	0.25	1.8
Calculation	(0.25 * 1.80) / (365 -13)	
Losses per day per bird €		0.0013
Total losses based on total lost production days*		65,598.36

* Based on calculations from Chapter 7.7.1

Table 43

Monetary impacts for animal movement contractors
Source: Own calculations based on data provided by the KTBL (2016) and information provided to the author (Voßmann, July 2018)

Animal handling costs, 2016/2017		
	Costs for removal € per hen	Costs for removal € per male turkey
0.16	0.2	
Calculation	((0.16 x 0.46) + (0.2 x 0.54) x 2.6) / (365 -13)	
Losses per day per bird €		0.001
Total losses based on total lost production days*		50,460.28

* Based on calculations from Chapter 7.7.1

bird for these handling procedures in 2016. For this calculation, it is assumed that only the removal of birds from the operations was performed by external service providers, whereas the other procedures as described above were done by the farmers and their personnel. Costs for the removal of birds from the barn are 0.2€ per animal for male turkeys and 0.16€ per animal for hens (Voßmann, July 2018). Taking into account the male turkey and hen ratio as applied above, daily costs of removal account to 0.001€ per bird per day. The calculation is shown in table 43 (p. 120).

Table 44 shows an overview of the previously calculated economic impacts to the secondary industry in Germany. It shows that the animal feed manufacturing industry was impacted the most with losses of more than 12 million euros. The litter material provider industry was impacted almost as severely with losses of more than 11 million euros. The remaining industries were impacted much less, with none of them registering losses of more than 200,000 euros. In total, the secondary industry in Germany was impacted with economic impacts of more than 24 million euros.

7.8 Summary AI Impacts Germany

Germany saw economic losses of 52,700,000 euros during the outbreaks of 2017 in total. DC of this outbreak were more than 27 million euros. DCC in the secondary industry amounted to more than 24 million euros, while DCC in the primary industry amounted to more than 600 thousand euros.

Table 44

Overview total DCC in €, HPAI outbreak Germany 2017
Source: Author with information above

Type of business	Amount
Animal feed manufacturing	12,700,851.72
Litter material providers	11,000,340.39
Veterinary service providers and medication	191,749.05
Maintenance and repair service and goods	136,242.75
Energy	90,828
Water supply	65,598.36
Animal handling costs	50,460.28
Animal rendering services	18,165.70
Cleaning and disinfection services and goods	7,064.44
Total DCC	24,261,300.69

8 Expert Interviews

This chapter describes the procedures for and completion of the expert interviews and their results. The chapter concludes with their first degree analysis.

8.1 Interview planning and execution

8.1.1 Schedule of interview execution

The interview procedures were subdivided into four different phases and defined in chapter 4.4.1. Table 45 shows the interview planning and dates of completion as part of the research. First organizational arrangements as well as gathering background information for the interviews were completed as early as 2017. In calendar week 9 (CW 9) of 2018, the problem analysis phase was concluded. Here, key problems and research objectives were defined and empirical data was gathered. The interview guideline was completed by CW 19 of 2018 as part of the guideline design phase, and updated again with the knowledge gained during the pilot phase in CW 22. The guideline design phase also included the completion of a first draft of the interview guideline and questions. During the subsequent pilot phase from CW 20 to CW 21, the preparation, completion, and evaluation of a test interview were completed. The conduct phase included a four-week journey to Minnesota and Iowa in CWs 22-26 of 2018, during which all US experts were interviewed. The interviews in Germany were completed mainly during CWs 26-31, with some remaining interviews being held in early August 2018. The steps of the subsequent processing phase, such as transcription, revision, inductive category formation, and qualitative content analysis were worked on and completed from CW 31 to CW 40 of 2018.

8.1.2 Test interview

The test interview in the pilot phase showed potential for improvements that were later incorporated into the actual interviews. The original interview guidelines used pre-formulated probing, focus, and ad-hoc questions. The use of these pre-for-

Table 45

Interview planning and completion of tasks
Source: Author

Organizational unit	Task	Time period
Problem Analysis Phase	Background information	CW 25-50, 2017
	Problem description	CW 8, 2018
	Gathering of empirical data	CW 8, 2018
	Definition of objectives	CW 9, 2018
Guideline Design Phase	First draft interview guideline	CW 14, 2018
	First draft interview questions	CW 14, 2018
	Checklist for interview guidelines	CW 15, 2018
	Final draft interview guidelines	CW 19, 2018
Pilot Phase	Preparation test interview	CW 20, 2018
	Completion test interview	CW 21, 2018
	Evaluation test interview	CW 21, 2018
	Update interview guidelines	CW 22, 2018
Conduct Phase	Completion interviews USA	CW 22-26, 2018
	Completion interviews GER	CW 26-31, 2018
Processing Phase	Transcription and revision	CW 31-35 2018
	Inductive category formation	CW 36-37, 2018
	Qualitative content analysis	CW 37-40, 2018

mulated questions was defined in chapter 4.4.2; they were prepared in accordance with the research objectives of the thesis. The test interview however showed that the use of pre-formulated questions too often resulted in awkward silences. It became obvious to the interviewee that these questions did not derive from the current conversation but instead were pre-formulated. These pre-formulated ad-hoc questions would have been a disturbance in an actual interview situation because they interrupted the natural flow of the conversation. To improve the conversational quality, the author refrained from pre-formulated questions during the actual interviews, and instead relied on having the major topics written down in the interview guidelines. This enabled him to guide the conversation towards key topics and objectives within a natural conversation flow.

As part of chapter 4.4.5, it was furthermore defined that the interviewer would take notes on the major statements by the interviewee during the conversation. The test interview however showed that

Table 46

List of experts USA and Germany
Source: Author

Int. #	Name, Title	Organization	Country, State	Date	Location
1	Andreas Hemme, Dr.	Praxis Windhaus und Hemme	GER, NI	08/15/2018	Telephone interview
2	Andreas Voßmann	Voßmann Group	GER, NI	09/07/2018	Offices of the Voßmann Group
3	Barbara Gottstein, Dr.	Niedersächsisches Ministerium für Ernährung, Landwirtschaft und Verbraucherschutz	GER, NI	11/01/2018	Telephone interview
4	Ben Wilemann, Dr.	Select Genetics	USA, MN	06/08/2018	Offices of the MPTL, Willmar, Minnesota
5	Bernd Kalvelage	Heidemark GmbH	GER, NI	09/20/2018	Offices of Heidemark GmbH
6	Caitlin McKenzie	Daybreak Food Inc.	USA, WI	06/11/2018	Telephone interview
7	Dale Lauer, Dr.	Minnesota Poultry Testing Laboratory	USA, MN	06/04/2018	Offices of the MPTL, Willmar, Minnesota
8	David Schmitt, Dr.	Iowa Department of Agriculture	USA, IA	06/19/2018	Offices of the Iowa Department of Agriculture and Land Stewardship, Des Moines, Iowa
9	Dieter Oltmann	Niedersächsische Geflügelwirtschaft	GER, NI	09/25/2018	Telephone interview
10	Emily Reynolds	Iowa Poultry Associations	USA, IA	06/14/2018	Offices of the Iowa Poultry Association, Urbandale, Iowa
11	Erwin Sieverding, Dr.	Praxis am Bergweg	GER, NI	08/23/2018	Offices of Praxis Am Bergweg, Lohne
12	Gretta Irwin	Iowa Turkey Federation	USA, IA	06/18/2018	Offices of Iowa Turkey Federation, Ames, Iowa
13	Hartmut Meyer, Dr.	Moorgut Kartzfehn	GER, NI	08/28/2018	Offices Moorgut Kartzfehn, Bösel
14	Hermann Seelhorst, Dr.	Landkreis Cloppenburg	GER, NI	10/02/2018	Offices of Landkreis Cloppenburg
15	J.T. Dean	Versova Management	USA, IA	06/18/2018	Offices of the Iowa Poultry Association, Urbandale, Iowa
16	James A. Roth, Dr.	Center for Food Security and Public Health	USA, IA	06/13/2018	Offices of the campus @ Iowa State University
17	Jessica Heitzhausen, Dr.	Landkreis Oldenburg	GER, NI	10/26/2018	Telephone interview
18	John Zimmerman	P&J Products Co.	USA, MN	06/21/2018	Offices of Minnesota Turkey Growers Association

this procedure was ineffective. The author was not able to take notes fast enough to allow uninterrupted conversation flow. During the test interview, a laptop proved to be the most efficient tool for taking notes, which also allowed the author to look at the interview guidelines displayed on the computer as well. The test interview showed that pre-formulated interview questions were not conducive towards a natural conversation flow. They were as a result dropped and replaced by general topics. Additionally, it was decided to not take notes by hand, but instead use a computer to allow for a more continuous and effective notation.

8.1.3 List of experts

Table 46 shows the alphabetical list of experts interviewed. The organization the experts were employed/active at during the time of the outbreaks is listed for each name. In addition, the country, state, date and exact location of the interview are shown. A total of 36 interviews

Int. #	Name, Title	Organization	Country, State	Date	Location
19	Joni Sheftel, Dr.	Minnesota Department of Health	USA, MN	06/12/2018	Telephone interview
20	Josef Diekmann, Dr.	Niedersächsisches Landesamt für Verbraucherschutz und Lebensmittelsicherheit	GER, NI	10/04/2018	Telephone interview
21	Kevin Stiles	Iowa Poultry Association	USA, IA	06/14/2018	Offices of the Iowa Poultry Association, Urbandale, Iowa
22	Matthias Voss, Dr.	Lohmann Tierzucht	GER, NI	09/05/2018	Offices Lohmann Tierzucht Büro
23	Mia Kim Torchetti, Dr.	National Veterinary Service Laboratory	USA, IA	06/13/2018	Offices of the NVSL Laboratory, Ames Iowa
24	Michael Boland, Dr.	The Food Industry Center	USA, MN	06/05/2018	Offices at the University of Minnesota, Minneapolis
25	Michelle Kromm, Dr.	Jennie-O Turkey	USA, MN	06/04/2018	Offices of the MPTL, Willmar, Minnesota
26	Mike Starkey	Minnesota Department of Agriculture	USA, MN	06/07/2018	Offices at the Minnesota Department of Agriculture, Minneapolis
27	Myah Walker	Sparboe Farms	USA, MN	06/15/2018	Offices at Sparboe Farms complex
28	Nils Reimann, Dr.	Big Dutchman	GER, NI	08/22/2018	Offices of Big Dutchmann Vechta
29	Patricia Fox, Dr.	National Veterinary Service Laboratory	USA, IA	06/13/2018	Telephone interview
30	Pete Block	Hy-Line North America	USA, IA	06/19/2018	Offices of Hy-Line North America, Des Moines, Iowa
31	Peter Behr, Dr.	Anicon GmbH	GER, NI	09/06/2018	Offices Anicon GmbH
32	Shauna Voss, Dr.	Minnesota Poultry Testing Laboratory	USA, MN	06/04/2018	Offices of the MPTL, Willmar, Minnesota
33	Simon Robbers	Best 3 Geflügelernährung GmbH	GER, NI	09/07/2018	Offices WING Vechta
34	Travis Schaal	Hy-Line International	USA, IA	06/19/2018	Offices of Hy-Line International, Des Moines, Iowa
35	Ursula Gerdes, Dr.	Tierseuchenkasse Niedersachsen	GER, NI	09/14/2018	Offices of the Tierseuchenkasse Niedersachsen
36	Yuko Sato, Dr.	Iowa State University	USA, IA	06/12/2018	Offices of the Egg Industry Center, Iowa State University

were conducted by the author, 21 of which were completed in the USA, and 15 in Germany.

The experts were deliberately chosen according to their occupational history during the outbreaks and/or current occupation. Each critical area of the value chain is represented by at least one expert from both the USA and Germany. These include the animal husbandry farming industry (primarily the poultry industry), up- and downstream farm or animal husbandry-related businesses, the veterinary profession, and governmental institutions. Each expert is a representative of his or her work in the field, and was heavily involved with at least one of the outbreaks in question.

For the majority of the interviews, the meeting was prepared beforehand. Contact was made with the expert in advance and the approximate issues of the interview were explained. The experts knew about the general open nature of the interview as well. In the majority of cases the author visited the facilities of the interviewee in accordance with what was described in chapter 4.4.

On some occasions, the interviewee pointed the author towards an additional interviewee in order to get a better understanding of the topic being discussed. If an interview with the suggested additional expert was possible on short notice, these people were added to the list of interviewees. In cases where a personal visit was not possible, the interview was concluded by phone. A total of eight interviews were conducted by phone, of which three were in the USA and five in Germany.

8.1.4 Anonymity during the interviews

Chapter 4.4.4 made clear that experts with a decidedly high variety of opinions should be selected to maximize research knowledge. Differing opinions are crucial for research, making it important to enable interviewees to speak as freely as possible. Prior to the actual interview, several of the interviewees raised the issue of anonymity. It was important for some of the experts for two reasons: First, they did not want to give away valuable information about their own organization to competitors. Second, some experts openly criticized their superiors or organizations, and feared consequences resulting from their comments. For these reasons, the author guaranteed anonymity to all interviewees. Table 46 (p. 124-125) shows all the interview participants. However, the order of the interviews was randomized, making it impossible to trace the statements and claims back to any of them. For inductive category formation and qualitative content analysis, the names of the interviewees were deleted and replaced with information about their personal occupation, the role of the organization, and the personal background of the interviewee. This enabled the author to maintain an understanding of the person's background and the organization during the analysis, while at the same time guaranteeing a sufficient degree of anonymity to all the experts.

8.1.5 Recording, transcription, and analysis

As a first step, the main statements were recorded in a transcript using a laptop during the interview. The interviews were not recorded word for word. As part of the conversation, the author checked back with the interviewee to make sure the main points were recorded correctly and ensure that nothing was misinterpreted.

As stated in chapter 4.6, the goal of the analysis was to identify consistent patterns and correlations among the experts' statements using inductive category formation. Accordingly, all statements were analyzed again on an individual basis. As part of this process, every main point, i.e. every statement, was assigned a category. Hence, every category represents a statement given by one of the experts. Because the interview addressed nine major topics, nine different category groups were used in the analysis. These are labelled “A” to “I” as well as “A1, A2, A3, B1, B2...”

For a better understanding, table 47 shows an overview of the category groups A to I.

Naturally, some statements were mentioned multiple times by different experts. Every time a category was supported by another expert, i.e. agreed upon, this was noted and given a consensus count. The greater the amount of experts agreeing to the statement of the category, the higher this consensus count was. The consensus count differentiated between German and US experts. In cases where a statement was mentioned only by one expert, this category was entered into the list of singular statements. In some category groups there were several statements that the majority of experts agreed upon, whereas in other category groups barely any statements were consistent with the opinions of a majority of the other experts.

Several new categories were formed with every expert added to the analysis. The old categories were updated according to the experts' statements several times during the analysis. Every claim that was made by any of the experts was also represented in some category. Although in some cases the wording of the statement was different, the context was comparable to an already-existing category. The following section describes the results of this analysis.

8.2 Results

This section gives a short summary of the interview results analysis. Special emphasis is placed on the differences between the experts from the USA and Germany.

Table 48 (p. 128) displays "Consensus", "Contradiction", and "Majority" in the experts' statements. A consensus was reached if an ordinary majority of experts from both the USA and Germany mentioned the statement of the respective category. A contradiction was determined when there was an exceptionally high difference between the consensus count of German and US experts. If neither was true, but an ordinary majority was reached by either German or US experts, this is mentioned in table 48 (p. 128) as well and marked "Majority USA" or "Majority GER."

In the USA, a total of 21 interviews, and in Germany a total of 15 interviews were performed. This means that eleven experts from the USA and eight experts from Germany were needed to achieve an ordinary majority.

Table 48 (p. 128) shows that the experts from both countries agreed to a majority of the following facts:

- The 2015/2017 HPAI outbreaks impacted the personal life of the people involved.

Table 47

Overview of category groups
Source: Author

Category group	Description
A	The impact of the outbreaks on the personal and professional life of the interviewees
B	Non-financial impacts of an HPAI outbreak
C	The future development of the poultry industry
D	Change due to an HPAI outbreak
E	Main problems of the 2015/2017 outbreaks
F	Suggested improvements for future outbreaks
G	Suggestions for the best mitigation strategies
H	Vaccination as part of a mitigation strategy
I	Other remarks

- The 2015/2017 HPAI outbreaks required long working hours and caused a high work load for a longer period of time.
- The 2015/2017 HPAI outbreaks caused mental stress to the people involved.
- The 2015/2017 outbreaks changed the industry in a sustained manner.
- The 2015/2017 outbreaks made the industry rank the aspect of biosecurity higher.
- In cases of large HPAI outbreaks like in 2015 and 2017, vaccination does not work for the poultry industry with the vaccines currently available.
- The loss of trade partners or the loss in meat trade outweighs the short term advantages of using vaccines.

The following paragraphs describe categories in which the USA and German experts showed a disparity in opinions. This does not mean that the experts specifically disagreed on these topics. The experts from one country instead simply did not frequently mention the statement, or not at all, whereas the experts from the other country stated the opinion significantly more often. During the interviews, the author did not specifically ask

Table 48

Summary of interview results
Source: Author

Category A: Impact of the HPAI on the personal and professional life			
Consensus	Contradiction	Majority USA	Majority GER
A2, A6	A1, A5, A13	/	/
Category B: Non-financial impacts of an HPAI outbreak			
Consensus	Contradiction	Majority USA	Majority GER
B1	B2	/	B3
Category C: Development of the poultry industry in the next 20 years			
Consensus	Contradiction	Majority USA	Majority GER
/	C1, C12, C13	C2, C3 , C12	/
Category D: Change in the industry due to the HPAI outbreak			
Consensus	Contradiction	Majority USA	Majority GER
D1, D4	/	/	/
Category E: Main problems during the HPAI outbreak			
Consensus	Contradiction	Majority USA	Majority GER
/	E1, E3, E5, E6, E12	/	E7
Category F: Improvements for future outbreaks			
Consensus	Contradiction	Majority USA	Majority GER
/	F1, F2, F7,	F8	/
Category G: Optimal mitigation strategies			
Consensus	Contradiction	Majority USA	Majority GER
/	G7, G11	G3	/
Category H: Vaccination as a solution in an HPAI outbreak			
Consensus	Contradiction	Majority USA	Majority GER
H1	/	H4	/
Category I: Other remarks			
Consensus	Contradiction	Majority USA	Majority GER
/	I1	/	/

for detailed claims, but instead let the interviewee speak his or her mind. If a topic was not stated, it was assumed to be less important to the interviewee. The results are based on table 48 (p. 128).

In category group A, the results show that experts in the USA considered the 2015 HPAI outbreak to be a life-changing event, whereas German experts described the outbreak as significant. Category group B shows major differences in category B2: In the USA, many experts mentioned that the outbreak caused depression, while in Germany this statement was much less prominent. In category group C the majority of experts in the USA estimated that biosecurity will be more important in the future. This was not mentioned as often by German experts. When talking about future growth in the industry, there was also some dissent which can be seen in categories C3, C12, and C13. German experts were torn between the statements that there can be no further growth, and that there will be more growth in the future. On the contrary, US experts did not mention a negative outlook at all. Not a single expert in the USA was of the opinion that there will be no further growth. In category group D there were no statements with significant differences in approval. There were however many differences in category group E, with a majority of US experts endorsing the notions that depopulation activities took too long to commence; that there was not enough equipment, personnel and resources available; that available resources were not used efficiently due to misguided policies; and that the potential of an HAPI outbreak had been underestimated. All of these statements were not mentioned as often or not at all by the German experts, a majority of whom brought up the points that the bird and waste removal activities were problematic and caused additional outbreaks. In category group F there were three statements mentioned significantly more often by US experts than German ones. US experts suggested that the overall biosecurity of the industry has to be improved, that all response activities have to be faster, and that in the future there can be no hesitation in efforts to mitigate the disease. These statements were not supported as strongly among German experts. In category group G there were two categories of disagreement. In category G7 a large majority of US experts stated that composting and burial on-site or in the barn are the best strategies for the removal of waste and carcasses. Not a single German expert agreed with this statement. On the other hand, German experts without exception mentioned that the current procedures of euthanasia, disposal, cleaning, and disinfection work seamlessly and have proven effective for several years. In category group H there was no statement of disagreement. Category group I contains other remarks that were not covered by previous chapters. Here, the US experts stated in category I1 that they are afraid of industry stakeholders returning to pre-outbreak habits despite the need for a persistently high level of biosecurity. This concern was shared by only one German expert.

8.2.1 Categories with the highest total approval in the USA and Germany.

This section summarizes the categories that were approved of the most in the USA and Germany combined. A total of 29 out of 36 experts agreed that the outbreaks have changed the industry. This was captured in category D1, with this opinion shared by the majority of experts in both countries; it was the statement with the highest consent rate in both countries combined. The second most approved statement was from the same category group. Category D4 states that the outbreaks made the industry rank the aspect of biosecurity higher. 27 experts in total agreed with this statement. The third highest approval rate was seen in category A2, which named long working hours and a high work load for a longer period of time as the personal and professional consequences of an HPAI outbreak. The fourth most approved statement was part of the vaccination category group. The experts in both countries agreed that vaccination does not work with the currently available vaccines.

9 Summary of Results

This chapter summarizes the results and findings of the preceding chapters. The structure of this summary is based on the four major objectives that were defined in chapter 1.3. For each single objective the summary offers a subchapter in which all relevant findings of the paper are outlined and put into context.

9.1 Objective 1: Understanding how HPAI was able to develop in Germany and the USA

This chapter summarizes all available results of this paper that give an account of how HPAI was able to spread in Germany and the USA on such a large scale. The information gathered is about HPAI in general but also about insights that are specific for the outbreaks in Germany and USA. The specific information with regard to the outbreaks in Germany and the USA are also compared.

HPAI outbreaks had occurred prior to both outbreaks analyzed in this paper. Chapter 2.1 showed that HPAI outbreaks have been known by the industry for many decades. HPAI has been approached scientifically from many angles, and the overall mechanisms of these international events are generally well understood. Both the outbreak in Germany and in the USA were part of a large international HPAI development (see chapters 6.2 and 7.2). The outbreaks in the USA occurred in 2015 and were part of the global H5N2 pandemic; in Germany they were part of the international H5N8 pandemic. At the time of these outbreaks in Germany and the USA, the threat of HPAI was well known to decision makers in both countries. In Europe, the H5N8 strain was familiar as a result of findings in wild and domestic birds for many months before it eventually started to spread in Lower Saxony in Germany. In the USA, H5N1 slowly developed from the west coast eastward over a period of many months before it eventually hit the epicentres in Minnesota and Iowa. Both countries had considerable wild bird findings and a multitude of smaller outbreaks in domestic poultry operations. It was obvious that extensive virus material was present, and that the general risk of HPAI was very high. It in hindsight is clear that the viruses did not manifest suddenly in these high-density poultry production areas, but emerged over a considerable period of time before causing two major outbreaks.

Additionally, decision makers, experts, and the poultry industry in both countries at that point in time had enough experience with LPAI and HPAI to understand the destructive potential of major outbreak scenarios. This was true more for Germany than for the USA. Authorities in Germany had previously had to deal with a widespread LPAI outbreak in 2008 and 2009 that also resulted in mass euthanization of birds and large-scale mitigation measures. For the most part, the poultry industry members who dealt with the outbreak in 2017 were the same people who also handled the LPAI outbreak in 2008/2009. The last major outbreak in the USA on the other hand had occurred in 1983 and 1984 (see chapter 2), meaning the lessons learned had in the meantime most likely been forgotten when the next major outbreak unfolded in 2015. Notwithstanding, there had in fact been large HPAI outbreaks in other countries across the globe on a nearly annual basis. In 2003, the Netherlands was hit with a major outbreak that affected two major poultry production areas. This outbreak was very similar in terms of the size, development, and spatial spread of the disease in a high-density poultry production area. Previous outbreaks had occurred following the same pattern, as could be noticed during the two outbreaks examined in this paper: all of them started with isolated small outbreaks in wild birds and domestic poultry, and then slowly progressed until a high-density area was reached, where a major outbreak then unfolded. This reoccurring process was known in both Germany and the USA. So it is safe to say that there was sufficient pre-existing knowledge, and for Germany, even pre-existing experience allowing accurate assessment of the devastating potential of HPAI and how it spreads in poultry operations.
Despite these facts, biosecurity measures proved insufficient, with varying degrees of them in both countries. Although it was known to decision makers that virus pressure in the environment was significant at the time of the outbreaks, no substantial improvements were made to operations and processes in the high-density poultry pro-

duction areas of Germany and the USA. Even after the first outbreaks occurred in these areas, biosecurity processes were not adapted to the new situations. Virus pressure in general was high prior to the major outbreak scenarios, and the occurrence of first outbreaks in the high-density areas increased virus pressure even more dramatically, leading to additional outbreaks in the region. It is likely that this pattern was the case for both Germany and the USA, along with the fact that decision makers in Germany were generally better aware of HPAI's potential. And although some precautionary biosecurity measures were undertaken, they were not achieved to a degree where a subsequent outbreak scenario could be stopped from developing into a full-scale crisis. The poultry industry in the USA was unprepared to an even greater degree, as was seen in the expert interviews. When the crisis was over, a large majority of the experts in the USA agreed that a true understanding of biosecurity had been lacking before and during the crisis. Poultry industry decision makers in both countries did not act adequat to the actual magnitude of the HPAI outbreaks.

Research has shown that quick and thorough mitigation efforts have to be conducted to prevent a virus from spreading further. Once the outbreaks in the high-density poultry production areas of Germany and the USA were in motion, mitigation efforts did not effectively halt them. Once the amount of affected premises started to increase, the demand for mitigation resources dramatically increased as well. This demand could not be met, increasing the amount of affected premises even further. And because the authorities and the industry were largely unprepared to handle an HPAI outbreak of this size, the resources that were in place were depleted very early in the crisis. By the time large layer operations in Iowa were impacted, the outbreak was out of control. The lack of experience, resources, and effective processes led to the largest HPAI outbreak in the history of the USA. Germany on the other hand was better prepared for a large-scale outbreak thanks to prior experience with LPAI and HPAI in neighboring countries such as the Netherlands, along with other highly contagious animal diseases including swine fever. So although the large HPAI outbreak of 2017 did in fact strain existing emergency processes and resources, especially on the involved stakeholder level, at no point during the crisis was there an inability to respond to it. Although processes and resources were in place to quickly handle the situation, the development of the virus still showed that mitigation processes in Germany were faulty and inadequate in parts. Loading carcasses and other virus material in windy conditions might have led to additional outbreaks. In summary, the mitigation processes in both the USA and Germany were inadequate. The countermeasure resources and processes in the USA were overexerted very early during the crisis, leading to regional mass outbreaks. Although resources and processes in Germany were sufficiently in place to handle the situation, flawed execution of mitigation processes led to a multitude of new outbreaks.

9.2 Objective 2: Spatial-temporal development

This chapter summarizes the results with regard to the spatiotemporal development of the virus. Large outbreak scenarios follow a distinct pattern. These patterns are described in this chapter using the results of this paper. Spatiotemporal patterns additionally help to understand the origin of the outbreak and possible dissemination routes of the virus. This chapter also outlines any learning with regard to the latter. The spatiotemporal developments of the HPAI outbreaks in the USA and Germany show some significant similarities. At the same time, there are also some distinctions that must be made between the two outbreaks. This is also done in this chapter.

The development of the H5N8 virus started in the USA in December of 2014 when first positive wild bird findings showed its presence in the environment. A domestic case was reported in Oregon in December of 2014 as well. In March of 2015 the high-density poultry production area of Minnesota was hit, which then started mass outbreaks there. The HPAI outbreak can be separated into three temporal phases. During the first phase of the outbreak, i.e. the first three months, some isolated outbreaks occurred that did not result in subsequent large-scale developments. These first occurred in areas with relatively low densities of poultry production. In this first phase, a distinct progression of the virus from west to east was noticeable, occurring directly on the west coast, with subsequent outbreaks stretching further west until the upper midwest states of Minnesota and Iowa were impacted. This is when the second phase of the US outbreak started. As explained in the previous chapter, virus proliferation increased dramatically here in the second phase, which lasted about one and a half months from the middle of March until the end of April. Mass outbreaks in this phase occurred in Minnesota in medium-sized turkey barns around the epicenter of Lac qui Parle County. The virus then spread from here until it eventually reached the north of Iowa, where the third phase began. During the third phase, a second epicenter developed in Iowa, this time impacting large commercial layer operations with several million birds. The third phase lasted approximately one month until new outbreaks diminished in June of 2015.

A similar development took place in Germany. The HPAI outbreak started in 2016 in early November with the first officially confirmed HPAI H5N8 cases. Within a few days, the first domestic birds were confirmed positive, and the virus spread across the whole of Germany. Virus dissemination was not limited to Germany. There were findings in as many as 30 countries in Europe, indicating the ubiquity of the virus at that time. In Germany, the development can be separated into two phases, similar to the development of the virus in the USA. While the amount of positive findings in both wild birds and domestic poultry increased in November and reached a peak in December of the same year, the main HPAI outbreak situation developed later during the next year. The high-density poultry production area of Cloppenburg in the state of Lower Saxony was impacted as early as November 2016, albeit without subsequent outbreaks in the same area. Findings of positive wild birds declined noticeably in January of 2017, clearly indicating that the virus was in decline. At the beginning of February, some additional positive cases emerged in the region of Cloppenburg; these findings in this high-density poultry production area started the second phase of the German outbreak. For reasons mentioned in the previous chapter, these new incidents led to subsequent outbreaks in the region which presumably caused more outbreaks, resulting in the largest outbreak of HPAI in Germany's recorded history. Important to note is that when the major outbreak occurred, the virus was actually in retreat.

It can be seen from the summaries above that the outbreaks in the USA and Germany followed very similar patterns. In both cases, there obviously was considerable virus pressure in the environment. In 2015 in the USA and in 2017 in Germany, wild bird findings and domestic cases were common in both countries. At some point, the virus affected a poultry operation in a high-density poultry area, which then caused the major outbreak scenario to unfold. In the USA, a first outbreak epicenter leaped to the neighboring state and caused a second epicenter. This was not the case in Germany.
Both HPAI strains of H5N8 and H5N2 are known to be sensitive to UV light and higher temperatures. In both countries the virus scenarios unfolded during cold winter months and came to a halt when the weather became sunnier and warmer. The research in this paper has shown that in both cases, the virus was on the decline/declined during a period of warmer, sunnier weather. It is conceivable that the outbreaks could have lasted longer under different weather conditions.

9.3 Objective 3: Quantitative analysis and comparison

This chapter summarizes the results of the economic analysis of both outbreaks in the USA and Germany. The HPAI outbreak scenarios caused significant economic impacts to the primary and secondary industry of the poultry sector. This chapter highlights the important differences between direct and indirect economic impacts. In addition, the chapter highlights in which areas there are noticeable differences between the outbreaks in Germany and the outbreak in the USA.

The HPAI events were the largest ever in both the USA and Germany. In Germany, more than 1.4 million birds had to be euthanized, of which more than 830,000 were turkeys. The remainder were geese, ducks, and broiler and laying hens. In the USA, a total of 50.4 million birds were euthanized, of which 7.4 million were turkeys and 43 million laying hens. In each country, the outbreaks resulted in large-scale economic impacts to the primary and secondary industries, other adjacent businesses, as well as the local communities. The exact economic details are explained later in this chapter.

The outbreaks not only affected the local poultry industry, but in parts was noticeable on a national scale as well. This was especially true for the USA, where the amount of laying hens lost during the crisis represented as much as 10 percent of the average US inventory. Iowa, with the largest layer sector in the USA, lost 52 percent of its total layer inventory. In the turkey sector, more than seven percent of the average US turkey inventory was lost during the outbreaks. In Germany, 11.6 percent of the turkey inventory was lost to the virus' effects. These losses were seen in the production numbers of each country. As displayed in section 7.1.6 of this thesis, there was a noticeable volatility increase in the amount of turkeys slaughtered in Germany. Overall, a decrease in turkeys slaughtered was followed by a slow recovery in production. Because laying hens were not as affected in Germany, there was no noticeable volatility in German egg production. In the USA, the outbreak's effect on production and prices was more pronounced. The amount of turkeys slaughtered and total egg production in the USA decreased sharply during the crisis, which subsequently led to a short-term increase in prices. The outbreaks in both countries were so large that they had a noticeable effect on production in the respective sectors. The most severe impact of this was experienced in the US layer industry.

Can patterns be ascertained when analyzing the farm types and their sizes in both countries? Analyzing the size structure of affected farms provides additional insight here. Around the first outbreak epicenter in Minnesota, primarily turkey operations with less than 100,000 birds were impacted. In comparison with layer operations, these are relatively small farms. More than 140 operations of this size were affected, comprising the majority of cases. The second outbreak epicenter was located in the north of Iowa where primarily large layer operations were impacted. The majority of laying hens were lost in operations having more than one million birds. A mere 14 layer operations accounted for more than 30 million losses in birds. In Germany, the virus primarily affected turkey operations, so a comparison with layer operations in this case is not useful. Nevertheless, for the German turkey sector, the size structure of impacted farms was similar to the size structure of turkey farms in the USA. A total of 58 turkey operations were affected, of which 53 had less than 20,000 birds. These 53 operations lost a total of more than 500,000 birds, which represents 70 percent of all lost turkeys in the German HPAI outbreak. In total, the virus impacted a particular type of production system having a specific type of bird, with medium-sized turkey operations and very large-scale laying hen operations impacted the most.

Another important similarity between the outbreak in the USA and Germany is the outstanding role of single states or regions. In both countries the outbreaks evolved around one or two epicenters where the predominant amount of economic impacts and bird losses occurred. In the USA, this was the two-state region of Minnesota and Iowa. In Germany, the state of Lower Saxony was the setting for most of the HPAI crisis. The following data point out the special role of these states. In the USA, Minnesota and Iowa saw 80 percent of all losses in the turkey sector, and 77 percent of all losses in the laying hen sector. In Germany, the state of Lower Saxony showed losses of more than 58 percent of all lost birds. In both countries, the economic damage was heavily weighted in their respective epicenter states/regions. The ensuing paragraphs discuss this in more detail.

The exact definition of DC was given in chapter 5.3. DC are costs that arise through direct mitigation efforts. Comparing the DC of Germany and USA enables an understanding of how effective mitigation efforts were, and where inefficient use of resources led to increased costs. DC are foremost covered by governmental institutions, and include indemnification payments and costs for mitigation activities such as euthanization, cleaning and disinfection, disposal, and rendering. In Germany, total DC were just short of 28 million euros. More than 15 million euros of this were paid in the state of Lower Saxony, representing more than half of all indemnification expenditures. In Germany, the proportion of indemnity payments to total DC was 60 percent. This means that 60 percent of the money spent by government institutions was used to support farmers and farming operations to weather the virus crisis. From a different perspective, German authorities provided about 20 euros per bird in DC, of which 12 euros were paid out to farmers. For comparability, the following costs for the USA are given in euros. The exchange rate of 0.89177 calculated at the time is used for conversion in the following.

In the USA, total DC amounted to 783 million euros. Of this, 178 million euros were spent on indemnity for the farming sector, which represents about 23 percent of total costs. DC per bird in the USA were 15.5 euros per bird. Since in the USA two types of birds in different types of farming operations were affected, these numbers differed greatly between the regions and farm types. DC of 15.5 euros were the average. Looking at the role of the high-density poultry production areas, the states of Iowa and Minnesota combined saw 83 percent of all bird losses. Assuming that indemnity payments were evenly allocated across all affected states in terms of their individual amounts of lost birds, this means that Iowa and Minnesota alone caused 148 million euros of indemnity costs. What immediately stands out is the difference in the USA and Germany regarding the proportion of indemnity payments. In Germany, these represented 60 percent of all DC, whereas in the USA, indemnity payments only represented 23 percent. Further, the total DC per bird was lower in the USA compared to Germany. DC per bird through mitigation efforts, including the payment of indemnification, was 23 percent lower in the USA.

The following paragraphs summarize the results concerning the DCC of the outbreaks in the USA and Germany. DCC are especially challenging for the poultry industry and its adjacent industries because there is no reimbursement of any kind for these losses. While DC were covered by government institutions, DCC were not, and incurred directly by the poultry industry and its secondary industries. DCC are fundamentally caused by downtime and idle production in the poultry industry. Operations were idle during or after outbreaks either because they were directly affected by HPAI, or because authorities banned restocking or other measures, meaning that facilities could not operate at all, or with a significantly lower capacity. Additionally, facilities also layed idle because the value chain was interrupted, and restocking material was not available. DCC are therefore a good indicator of how well the industry and authorities are capable of rebooting routine business processes following an HPAI crisis.

DCC are generally not available through the statistics offices of the respective country, but have to be calculated and interpolated where needed (this has been indicated as such throughout this thesis). Because the database was not consistent across the two countries, the results cannot be compared directly, and must be placed in their own perspective for an analysis.

DCC in the USA were strongly influenced by a considerable amount of idle time during and after the outbreaks. In addition, the loss of breeder flocks resulted in added idle time because farmers were not able to restock even after movement restriction zones were lifted from the regions. The research in this paper showed that in the USA, depopulation took an average of 6.5 days, cleaning and disinfection took 88 days, and restock approval was granted after an average of 111 days. Added to this was an extended quarantine time, which extended idle time to 149 days on average for all premises in the USA. More than half of all premises were idle for longer than 150 days. In the layer sector, a return to full production capacity was reached in some cases only a full year after the crisis due to losses of breeder stock and the inability to restock operations. Based on this idle time, the primary sector alone (meaning the farming operations) endured economic losses of 1.27 billion euros, an amount that was not reimbursed at any point by indemnity payments. This research shows that the secondary industry also experienced economic impacts amounting to a total of 660 million euros. Among the secondary industries, animal feed manufacturing companies were impacted the most with losses of about 327 million euros. Economic losses in the secondary industries were also not reimbursed in any way. In total, DCC amounted to 1.93 billion euros in the USA and exceeded DC by more than 240 percent.

In Germany, DCC were also largely influenced by the amount of downtime during the crisis. In Germany, this lasted between 21 and 69 days. The difference can be explained by the location of the farm. Farming operations in the high-density poultry production areas were kept idle by authorities for longer periods to increase the effectiveness of mitigation measures. Overall, the idle time in Germany resulted in losses of 682,000 euros for the primary sector, which was not covered by any form of governmental reimbursement. There were also economic losses for the secondary industry in the amount of 24.4 million euros. Among the industries affected, the animal feed manufacturing industry was impacted the most (as in the USA) with more than 12.7 million euros in losses. The animal litter industry was impacted the second most with losses of more than 11 million euros (the litter industry was not mentioned as part of the affected industries in the USA, because typically in the USA no litter is used). These losses in the secondary industry in Germany were not covered by any governmental reimbursements. While DCC exceeded DC in the USA, in Germany, DCC was slightly lower in comparison. In Germany in total, DCC amounted to more than 25 million euros, making them three million euros short of the DC in Germany of 28 million euros.

9.4 Objective 4: Validating the results of the analysis and additional insights through expert interviews

This chapter summarizes the results of the expert's interviews. It will especially point out those results of the interviews that support results of other chapters or add additional information to results of previous chapter.

The previous chapter showed that there were differences in how the HPAI outbreaks affected the local economies in the USA and Germany. These differences are based on how effective and quick mitigation efforts were carried out and on how prepared industry and authorities in each country were for an outbreak scenario. Some of these differences also showed in the answers of the experts. This chapter summarizes all relevant results and findings of the expert's interviews.

The ensuing summary is structured according to the nine topics of conversation during the interviews.

The previous sections of this summary showed that the outbreak in the USA was larger in total. More birds were affected and the economic impact in total was significantly higher. On the one hand, the general extent of the outbreak was larger, while on the other hand, the individual stakeholders were impacted more severely. Previous sections of this thesis showed among other things that in the USA, indemnity payments represented a smaller portion of the overall DC, with mitigation efforts taking significantly longer in the USA. It is therefor to be expected that these differences show in the experts' evaluation of the situation. The following paragraphs summarize the expert interviews in each of the categories that were used to structure their respective dialogs.

The experts' choice of words in category group A shows that the outbreak in the USA had a more significant personal impact than in Germany. Only very few of the German experts went so far as to say that the HPAI event was "life-changing", while in the USA a large majority of the experts agreed with this statement. Despite this difference, the interviews showed that an HPAI event always extends into the personal life of the people involved, something experts in both countries agreed with. Although an outbreak was not perceived in this study as "life-changing" for experts in both countries, it is certainly demanding enough, and capable of extending into the own personal life. These results support the findings of the previous chapter. In both countries, the outbreak was the largest ever recorded. The outbreak in the USA was however significantly larger, impacting the local industry to a greater extent, which was acknowledged in the interview answers. In addition, experts in the USA claimed to have grown from the experience, something the German experts did not mention as frequently. This disparity in answers between the two countries is reasonable, since Germany had undergone a similar outbreak a few years prior to the severe outbreak of 2017.

The group B interviews covered the non-financial impacts of the outbreak. The results showed that the most important non-financial impact was emotional stress. While the experts from both countries agreed on this, there was a difference in the assessment of how strong this was. The outbreak was personally more significant and emotionally stressful in the USA. Only the US experts went as far as to say that the outbreak caused “depression”. Although some German experts also noted that the outbreak was “traumatic”, the word “depression” was not used at all by any German expert. This indicates that the event was emotionally more severe in the USA. These findings support what had become visible in category group A. Additionally, experts in the USA mentioned more often that the outbreak was “devastating” despite the large amount of indemnity payments. This was not mentioned in Germany at all. This correlates with the finding that indemnity payments in the USA covered a smaller fraction of the actual costs of the outbreak.

Group C contains the experts’ opinions on future developments in the poultry industry. Despite the higher magnitude of personal impacts and emotional stress, experts in the USA assessed possible future developments in the poultry industry more positively. The majority of German experts were of the opinion that there will be no further growth in the German poultry industry. Experts from both countries agreed that there will be a higher demand for poultry products in the future, most likely due to an increasing world population. German experts obviously do not see this growth in Germany but abroad. On the contrary, while US experts believe that the US poultry industry will in fact profit from the internationally increasing demand for poultry products, they also expect the US poultry industry to grow further in size and efficiency.

Another finding in category group C is that US experts expected to see more biosecurity efforts in the future. This opinion is most likely based on the negative experiences of the 2015 outbreak. Lacking biosecurity was one of the key factors for the rapid expansion of the virus. This new understanding of biosecurity was accompanied by a more serious consideration of geographic risk factors with regard to the construction of new poultry operations, showing that experts in the USA have accepted the importance of biosecurity on not only a farm level, but on a regional one as well. The fact that experts in the USA overwhelmingly discussed the importance of biosecurity shows that it was not well established before the outbreak unfolded. In Germany, experts also acknowledged the importance of biosecurity, while at the same time the concept was known and its importance acknowledged. It is plausible that the outbreak in the USA could have been contained more easily and faster, and hence economic impact avoided, had biosecurity been better established in the USA.

The questions of category group D discussed which processes, opinions, or general behavioral patterns changed during the outbreaks in Germany and the USA. The answers showed that several changes had already occurred while the outbreak was ongoing, with additional long-term changes implemented after they were over.

First, the experts in both countries agreed that the outbreaks have changed the industry in general. The approval rate of this statement was noticeably higher in the USA. This leads to the conclusion that experts in Germany were more aware of the potential threat of HPAI. A large-scale outbreak was not a completely new experience for them. In contrast, experts in the USA experienced a large-scale outbreak for the first time and hence were more deeply impacted by it.

Experts in both countries also agreed that the aspect of biosecurity will be ranked higher in the future. This estimation can be connected to the fact that there were biosecurity issues during the mitigation activities in both countries. Nonetheless, experts in the USA ranked this statement higher, hinting at the omnipresent lack of biosecurity when the outbreak occurred. Almost half of the US experts agreed in category D2 that the potential of HPAI had been largely underestimated before the outbreak. The recognition of HPAI as a major threat to the US poultry industry was a key learning effect following the outbreak, showing how it changed the perception of HPAI in the USA. German experts on the other hand did not specifically mention changes beyond the importance of biosecurity. This shows that stakeholders in Germany were aware of the destructive potential of HPAI to at least some degree.

Category group E describes the experts' evaluation of the main problems during the HPAI outbreaks. The perception of what aspects were most problematic was different between Germany and the USA. Experts from both countries did not agree as a majority on a single statement.

In categories E1, E2, E3, E5, and E8, the US experts criticized a lack of resources, a lack of timely response, poor completion of depopulation, and a general inefficiency in mitigation activities. This shows that stakeholders in the USA dealt with essential/fundamental challenges during the outbreak. Looking at the aspects that were mentioned by US experts, it's seen that some very key parts of the mitigation activities were subject to critique. In Germany on the other hand, problems were more specific, the main one defined by the German experts being a lack of biosecurity during the ongoing mitigation, and explicitly during the removal of dead birds from operations. German experts defined this specific process as problematic. The interview statements made clear that US authorities were not prepared for an outbreak in 2015, and the previous section showed that the destructive potential of HPAI was in fact underestimated. This section shows that this underestimation was the basis for a pre-outbreak situation in which no solid preparations were in place for a large outbreak, which probably helps explain why during and after the outbreak, the available mitigation procedures were at a less than acceptable standard. The German authorities and industry on the other hand had processes in place that allowed for an appropriate response. And even though the results in this category show that the processes in place in Germany were also faulty, there were no problems on a basic level. This difference between the countries was clearly manifested in the interviews results.

The results of category group F underline the findings of the two previous sections. Experts in both countries perceived the outbreak differently due to different problems and challenges. The solutions provided by the experts in this category group were different as well, with no consensus between German and US experts on what significant improvement for the future will look like. In categories F1, F2, and F7, US experts mentioned the speed of mitigation efforts, overall biosecurity, and a willingness to rapidly implement HPAI mitigation as important improvements for the future. These suggestions aim at very basic procedures, likely based on past negative experiences with them. None of these statements were supported by the German experts, who furthermore did not support any statement in this category group as a majority. There were of course suggestions by German experts in this direction, although these too were not supported by a majority, and tended to aim at very specific problems. F11, F12, and F14 were supported by a minority of the German experts. Suggestions were made here regarding smarter mapping of restriction zones, taking the current weather into account, and finding a European solution for meat trade during crisis situations. Important to note is that despite the large outbreak in Germany, the procedures to counter it were well developed and accepted by all stakeholder groups.

The statements of category group G showed further differing perceptions between Germany and the USA, with no single statement agreed upon by the experts in both countries. Most striking were the differences between categories G7 and G11. In G7 a large majority of US experts stated that composting and burial, if possible inside the barn, is the best disposal strategy. It can be assumed that the local circumstances in the USA allow for this procedure, and that the experience with it has been positive there. German experts did not agree with this, seen by the fact that not one of them supported this notion. At the time of the interviews, composting was legally not an option in Germany. On the contrary, German experts stated in category G11 that the system of depopulation and follow-up activities used in 2017 works seamlessly, and has proven effective for years. This statement of approval was not made once by any of the US experts, showing that in Germany, a widely accepted system for depopulation, disposal, cleaning and disinfections had been worked out prior to the outbreak. In the USA on the other hand, a system with comparable rates of approval was not in place.

Category group H deals with the use of vaccines as part of mitigation activities. The US and German experts largely agreed on crucial areas related to these. Category H1 features the statement that vaccination does not work for the poultry industry with the currently available vaccines. This statement was agreed upon by a majority of experts in both countries, with many of them seeing significant disadvantages in the use of vaccines. US experts named the loss of trade partners as one of the most important reasons to avoid vaccines, which was supported by German experts as well. Although there were no further categories in which the experts agreed or disagreed by a majority, some remaining statements such as H3 and H11 indicated a solid understanding of the risks of vaccination. These statements included the need for more research on vaccines (H3) and the demand for a vaccine that provides sterile immunity (H11). Despite the understanding of the risks, there were also some experts, especially in the USA, who believe that vaccines can in fact offer a solution under certain circumstances. In category H8, a large group of US experts stated that vaccination must be regarded as one option out of a more comprehensive toolkit, while at the same time, an equally large group of US experts stated in category H5 that a vaccination can be administered if an appropriate exit strategy is in place when doing so.
These results show that there was a general understanding of the risks of HPAI vaccination among all the experts. At the same time, they were still interested to certain degrees in using vaccination under certain circumstances.

There was no dedicated topic underlying category group I. Here the interviewees were given the chance to add additional remarks. As expected, this is the category group with the most singular statements. Among the statements supported by several experts, there was not a single statement agreed upon by experts from both countries. The US experts agreed by a majority that there is considerable risk of stakeholders weakening biosecurity measures again following a time without new outbreaks. This angst was not supported by German experts, who did not agree on a single statement in Category group I.
The outbreak in the USA happened two years prior to the outbreak in Germany. It is possible that experts in the USA have seen biosecurity measures weaken again since 2015, which in Germany might also potentially happen, or may never occur.

10 Conclusions

The goal of this chapter is to generate overall conclusions and specifically point out new learnings. In addition, this chapter explains possibilities for improvements in future outbreaks. The previous chapter summarized the results of each chapter and at the same time combined learnings from quantitative and qualitative analysis. This summary was done according to the four objectives of this research which were defined in chapter 1. This chapter now brings forward conclusions on each of the four objectives. In addition, this chapter points out what role the scientific community can play in the future in each of the four areas. For each of the four objectives, further research is needed to deepen the understanding of economic impacts of HPAI outbreaks.

HPAI can easily be regarded as pandemic to today's world. While HPAI events were seen as exceptional in the past, they are now reoccurring and repetitive, happening on every continent. There is a constant flow of new varieties of HPAI strains, and it is likely that this development will be an inherent part of the poultry industry in coming years. People in the coming years will not ask whether new or old HPAI strains will appear again, but when and how. This means that worldwide stakeholders will have to be prepared to deal with new outbreaks efficiently and quickly. The scientific community can support the efforts of virus mitigation by providing crucial information enabling responding workforces to act effectively. There are still important processes around HPAI that are not understood completely, such as the exact methods of proliferation of the virus on farm levels, or the international transmission of HPAI by wildfowl. Other areas such as the understanding of HPAI's economic impacts need further research as well, especially regarding idle time resulting from an outbreak. The scientific community can provide new concepts that will enable responding forces to minimize idle time and the economic impacts resulting in primary and secondary poultry industries. Additional knowledge from a virological perspective about the virus' effects, as well as veterinary insight into birds that transport and are infected with HPAI can potentially help to reduce virus progression and its consequences. The scientific community can make crucial contributions to these challenges.

10.1 Objective 1: Understanding how HPAI was able to unfold

The risk of HPAI outbreaks has been known about for years in both Germany and the USA. Germany had seen a large LPAI outbreak just a few years prior to 2017, and several neighboring European countries such as the Netherlands and France had experienced large HPAI outbreaks in the past as well. The USA on the other hand did not have a major HPAI outbreak in recent years, even though Canada and Mexico had been intensively impacted by HPAI. In addition, HPAI outbreak scenarios had become more common internationally over recent years. In addition, some months prior to the large outbreaks in the USA and Germany, positive wild bird findings and minor domestic outbreaks occurred in both countries. It is therefore fair to say that the significant risk of new HPAI introductions was strikingly obvious, most notably in those areas with very high poultry density. In general, industry authorities and stakeholders in both Germany and the USA, knowledgeable about the mechanisms of HPAI, should have been aware of the threat at the time.

Despite the above-mentioned signs, these two major outbreaks in the USA and Germany were still able to emerge. Part of the problem arising here was also a lack of biosecurity, inefficient processes in mitigation, and ignorance towards the HPAI threat potential. This was especially true for regions with a very high density of poultry production, and where the threat of economic losses was high. In Germany, flawed mitigation processes most likely caused a series of new outbreaks that eventually resulted in the largest HPAI outbreak in its recorded history of poultry production. In the USA, authorities and the industry were much less prepared for a large HPAI outbreak. When the high-density areas of Minnesota and Iowa were impacted by HPAI, a dramatic lack of coordination, resources, and personnel led to the largest HPAI outbreak in American history. Its size was so extensive that it resulted in bottlenecks in the supply of eggs and turkey meat, taking almost a year for some products to recover.

For the future it is crucial that authorities and stakeholders in the poultry production industry are aware of the ever-present HPAI threat. This will be especially true for those countries that play an important role in the international supply of poultry products, as well as countries with high-density poultry production areas. These regions will face continual threats of HPAI outbreaks. Because of this, the scientific community must support efforts to combat outbreaks by providing crucial information and helping the industry better understand the mechanisms of HPAI. The scientific community can play an important role by offering clear and concise guidance regarding questions such as HPAI's risk level, biosecurity, and mitigation improvements. In times of repetitive wild bird HPAI findings and isolated domestic outbreaks, optimal biosecurity becomes paramount to all further actions. It must be a key factor to consider at all times and stages of professional poultry production. Where high HPAI activity occurs, effective biosecurity on all levels of poultry production is the major factor that will prevent occasional HPAI occurrences from turning into local mass outbreak phenomena with long-term consequences and major economic implications. It is the task of the scientific community to provide guidance on how to improve biosecurity further; its improvement represents a significant cost factor for the poultry industry. It will have to be the primary goal of the scientific community to provide information on how to set up biosecurity measures that cost-effectively prevent outbreaks. Cost-effective biosecurity is especially important for countries with professionalized and integrated value chains and regional high-density poultry production areas. Once an outbreak is underway in a region with high-density poultry production, the effective execution of mitigation activities becomes essential. As experienced in the USA and Germany, high-density poultry production areas bear the risk of mass outbreaks. In these regions, processes of animal disease mitigation must be well-established and tested for their effectiveness. This makes the timely provision of sufficient resources and personnel adjusted to the local amount of poultry production essential. If these resources cannot be put into action at the moment of first outbreaks, or if their processes are flawed, a mass-scale outbreak will unfold in a matter of days, which in turn will be even more difficult to contain. The scientific community can actively support the optimization of local mitigation efforts by providing crucial information on the optimization of processes. It can also critically assess established processes, help to improve these, or assist in establishing new processes that will increase the overall effectiveness of mitigation efforts.

10.2 Objective 2: Spatial-temporal development

From a spatial-temporal development perspective, the outbreaks in Germany and the USA were very similar. Each virus showed ubiquitous presence in the respective country prior to its outbreak. For months there were wild bird and domestic HPAI findings in a multitude of countries. The outbreaks in the USA and Germany in other words were not single isolated incidents but rather one part of a chain of consecutive HPAI incidents as a result of the international migration of virus through wildfowl. While in Europe the virus spread without a noticeable and clear direction, the virus progressed in the USA along a clear east-to-west pattern.

Once the virus reached the high-density poultry production areas of Germany and the USA, lapses in biosecurity and other human mistakes led to massive outbreaks. In the USA, the concentrated outbreak developed around two epicenters in Minnesota and Iowa. In Minnesota, this was around Lac qui Parle County. Here, mostly turkey premises were affected, with the virus spreading in an almost circular pattern outward from the epicenter. The second epicenter emerged four weeks later in northern Iowa where large layer operations became infected; the majority of bird and economic losses occurred here. In Germany, one epicenter in the state of Lower Saxony was the site of the majority of all outbreaks. The municipality of Garrel, a key hotspot for turkey production in Germany, became the main area of bird and economic losses in Germany.

The progression of the virus around these epicenters was extremely rapid and comprehensive. The outbreaks progressed so rapidly that the authorities were simply not able to keep up. Within a couple of weeks, the majority of poultry operations in these regions were affected and had to be depopulated. But as quickly as the viruses spun out of control, equally fast was their decline. In both countries, the HPAI events began during the cold months at the beginning of the year. The weather improved significantly during the course of the outbreak, which presumably helped lessen the virus' effects.

In times of low HPAI activity, areas with highly concentrated poultry production offer some important advantages over systems that are geographically spread out. Short transportation, the agglomeration of knowledge, and the secondary industry in one nearby location allow for cost-efficient poultry production. In times of high HPAI activity however, these factors have the potential to become the perfect place for a virus to spread, as could be seen in the USA and Germany. In these regions, the higher the concentration of poultry production, the more difficult it was to contain the virus. Additionally, the higher the concentration of poultry production, the higher the negative economic impact of an outbreak. The secondary industry is most likely to also fall under quarantine or movement restriction zones, increasing the economic impact of an outbreak even further. The concentration of poultry production in Germany and USA, along with a lack of risk-adequate biosecurity measures and outbreak preparation were the main reasons for the extent of the outbreaks in 2015 and 2017.
In light of this, a key task of the scientific community will be to improve upon the understanding of regional production clusters. Despite obvious advantages in efficiency, there are disadvantages in these areas during peaks of virus activity. The scientific community must provide concepts about how to improve HPAI resiliency in high-density production areas while at the same time retaining the advantages of regionally efficient poultry production. It is conceivable that production in these areas could be reorganized to minimize HPAI outbreak risks without having to relocate it.

10.3 Objective 3: Quantitative comparison

DC were significant in both Germany and the USA. Comparing the total amount of DC to the total amount of indemnity payments in each country makes it possible to determine how effective mitigation efforts actually were. Indemnity payments are part of DC, and they are the only compensation made to farmers. It must be the goal of every country to maximize indemnity payments while at the same time reducing total DC. In Germany, indemnity payments represented 60 percent of total DC. In the USA, these were only 23 percent of total DC. This means that government spending in Germany was significantly more effective with regard to primary production. A larger portion of the money spent on mitigation in Germany actually reached the farm level, whereas in the USA, the majority of money spent on DC was used for activities that farming operations do not profit from. This indicates that processes in the USA need to be developed further so that a higher proportion of money spent on DC can be directed towards farmers.

Comparing total DC in the USA and Germany even further, it's seen that DC per bird is significantly lower in the USA. There are several reasons for this. It is possible that mitigation activities are generally more cost-effective if farming operations are large. The majority of birds in the USA were lost in very large layer operations in Iowa with more than one million birds. This can help explain why DC per bird was significantly lower in the USA. In addition, processes of euthanasia and disposal differed greatly between the two countries. In the USA, carcass disposal is commonly done directly on the farm in large piles with composting material. This is relatively cost-effective when compared to processes in Germany, where all animals and their respective contaminated material are required to be transported to local rendering plants. This comparison indicates that processes in Germany can be further improved. If on-site render and disposal are more cost-effective long-term and lead to comparable results for HPAI mitigation, German authorities and stakeholders should seriously consider a revision of current processes.

DCC occur after mitigation efforts are concluded. These costs directly impact the primary and secondary industry, and no reimbursements are made to the affected stakeholders. The primary cause of DCC is idle production facilities in the primary and secondary industries. In both the USA and Germany, DCC were significant. In first economic considerations of HPAI outbreaks, these costs are ignored because they require an in-depth economic analysis; the knowledge about these costs is not available during an outbreak scenario. DCC are typically ignored within the course of public or political discussions on outbreaks. This is problematic because not only do DCC have the potential to be much higher and therefore more detrimental to the poultry industry, they are also currently not part of any indemnity plans.

The absolute DCC number itself stands in interesting contrast to a comparison between DC and DCC. As can be expected, the amount of DCC in a country directly increases proportionally to the amount of affected farms. The absolute amount of DCC was higher in the USA compared with Germany. Contrasting DCC and DC in the USA, it shows that DCC were significantly higher in the USA, while in Germany DCC were slightly lower than DC. At the same time, the idle time of production was almost twice as long in the USA in comparison with Germany, indicating that German authorities and industry stakeholders had processes in place allowing for more time-effective measures and lower DCC costs as a result. The long-term consequences of the HPAI outbreak were more severe in the USA in comparison. Following from this, it can be said that reducing the idle time after mitigation efforts are concluded is a key factor in reducing DCC. The processes in Germany at the time of the outbreak were able to keep the idle time low enough that DCC did not exceed DC. In the USA, inefficient processes led to comparatively high DCC.

The DCC analysis also shows that in the USA, it was primarily the secondary industry that was affected with economic losses. Because mitigation efforts took longer, and because idle time after mitigation was considerably longer in the USA, the secondary industry was much more affected. Processes were relatively efficient in Germany on the other hand, so the secondary industry was not as impacted. This strongly indicates that processes in the USA have to be updated and developed further to achieve a better reduction in idle time.

These two outbreaks generally show that independent of the quickness in response and mitigation, major economic loss extends beyond DC and indemnified expenses. The primary industry is impacted long after mitigation efforts are concluded, along with the secondary industry. When considering economic outbreak effects, this factor always has to be taken into account.

10.3.1 What's needed

Once an HPAI outbreak is underway, it is important to direct activities towards two major objectives. The main goal obviously must be to control the virus as much as possible and prevent further farming operations from becoming affected. The second important goal is to help those affected with adequate indemnification to the greatest extent possible. Achieving the latter means all mitigation activities that do not pay direct reimbursements must be cost- and time-efficient. Euthanization, cleaning and disinfection, rendering of risk material, and HPAI testing must be developed further so that spending for them is reduced to a minimum. This in return will allow for improved indemnification processes, allowing maximum compensatory payments to farmers, and mitigation costs that are as low as possible. The scientific community must support the process of developing mitigation activities further, analyzing whether they reach their desired outcomes or if they need to be reorganized and/or optimized.

When it comes to DCC, a key objective will be reducing idle time as much as possible in any given situation; this is the only effective way to decrease DCC. The analysis showed that processes in Germany worked faster in comparison to the USA. The analysis further showed that the secondary industry is equally liable to be affected by HPAI outbreaks. A conceivable idea for the future would be including secondary industries in the indemnity process. The scientific community can support this approach by providing additional background analysis regarding whether such a process would be feasible and/or necessary. Whether the inclusion of secondary industries into the indemnity process will reduce overall economic costs of an HPAI outbreak will need to be determined by further research. Additional research is also needed to help guide how idle time in the primary poultry industry can be reduced. The scientific community here can support the development of new processes and concepts that reduce idle time and DCC as a result.

When political trends work against a fair assessment of an outbreak situation, these often exploit the results of economic analysis, most notably when its framework is not clear (chapter 5 described the importance of a coherent framework analysis). In general, it is crucial that the scientific community supports the poultry industry and other stakeholders such as governmental institutions in containing viruses. Critical in achieving this will be a coherent framework for the assessment of economic impacts. There are currently several different methods in use producing different results. For political assessments in particular, it is crucial that policy discourse is based on a coherent system of analysis.

10.4 Objective 4: Additional learning from the expert interviews

The results of the economic analysis were reflected in the expert interviews. The HPAI outbreak in the USA was larger in absolute numbers, relative to total production and also in terms of economic impact for the primary and secondary industries. This also was seen in the experts' assessment of the outbreak, and who classified it as emotionally demanding. In Germany, although the HPAI outbreak was also the largest HPAI outbreak in recorded history, experts here did not rank the personal and professional impact as severely as the US experts. In the USA, the HPAI outbreak clearly caused more qualitative impacts. This shows that preparation for an outbreak can happen in a two-fold matter: stakeholders can prepare for HPAI outbreaks in a technical sense, meaning sufficient resources on all levels, and provision of efficient processes. It also helps to prepare stakeholders for what an HPAI outbreak actually means. In the USA, the outbreak's effects on the people involved were so grave that a suicide hotline was set up, and many affected people had to cope with emotional stress for extended periods of time. These non-economic and non-monetary effects have the potential to be equally detrimental to the industry. It is likely that experts in Germany did not rank the HPAI outbreak as having this level of impact, because prior years saw a minor LPAI outbreak, meaning stakeholders were better prepared and knew what to expect from this kind of situation.

The scientific community will need to continue and deepen research in this regard to better understand the non-economic impacts of an HPAI outbreak. The results will help the poultry industry and authorities be better prepared and provide respective information and guidance for coming HPAI outbreaks.

Despite the grave impacts in the USA in 2015, experts there are more positive about the future of the poultry industry, and see a growing demand for poultry products internationally, while believing that the American industry will be part of this positive development. Experts in Germany are less optimistic, and do not see further growth for the industry in Germany. This is striking because the German industry and authorities were better prepared for the outbreaks, and mitigation was much smoother compared to the efforts in the USA. It is highly likely that the reasons for this difference in positivity lay outside the scope of this research. The German poultry industry has undergone significant change towards a more animal-friendly production system as a result of intense public pressure to do so. There is also considerable public opposition to the expansion of poultry production in Germany. These two factors can be a reason why German experts were less optimistic about future industry growth despite their more effective animal disease mitigation processes.

For both outbreaks, there is no exact reason as to how they began. To date it has not been fully possible to find the exact route of virus intrusion and subsequent infection. It is however likely that the first farms were affected through the presence of HPAI in the environment. It's also clear that human mistakes and misguided processes of virus elimination caused further virus spread which ultimately led to the two major outbreaks. An analysis of the experts' answers showed that this was true in both countries. The experts' answers also showed that in the USA there were problems at a basic level, whereas in Germany the established processes were in some cases poorly executed. It can generally be said that in Germany, the experts judged the processes of biosecurity and virus mitigation more effectively and professionally.

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Harm Christoph Böckmann

Harm Böckmann hat seinen Bachelor International Agribusiness and Trade in Wageningen in den Niederlanden abgeschlossen. Schon während des Studiums hat er eine Stelle bei Lohmann Tierzucht in Cuxhaven begonnen und konnte so die ersten Erfahrungen im Bereich Geflügel sammeln. Weitere Stationen im Studium führten ihn nach Schottland und China. Für das Masterstudium ging er nach Berlin an die Humboldt-Universität und studierte hier Agrarökonomie.

Nach abgeschlossenem Studium und zurück in der Heimat in Vechta hat Harm Böckmann im Jahr 2016 begonnen, bei Herrn Prof. Dr. Windhorst zu promovieren. Das Thema war eine raumzeitliche und wirtschaftliche Analyse von Geflügelpestausbrüchen. Nach begonnener Promotion vollzog sich in direkter Nachbarschaft im Landkreis Cloppenburg einer der größten Geflügelpestausbrüche, die man bis dahin kannte. Dieser Ausbruch wurde Teil der Forschung.

Zwei Jahre nach Beginn der Promotion reiste Harm Böckmann für mehrere Monate in die USA, um die Menschen und Institutionen kennenzulernen, die 2015 im größten Geflügelpestausbruch der Geschichte der USA involviert waren. Dieser Ausbruch wurde mit dem Ausbruch in Deutschland verglichen, was neue interessante Perspektiven auf die jeweiligen Ausbrüche ermöglicht hat.

Der Autor möchte sich bei allen Mitarbeiterinnen und Mitarbeitern des WING für die tatkräftige Unterstützung während der Forschung bedanken. Insbesondere Frau Lydia Buzyn und Anja Susanne Kauer, B.A. haben bei der Erstellung der Druckversion unersetzliche Hilfe geleistet. Großer Dank gilt natürlich Herrn Prof. Dr. Windhorst, der mit viel Geduld, guten Kontakten und unendlichem Hintergrundwissen wesentlich zum Gelingen der Forschung beigetragen hat.

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