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Source: Avian Diseases, 62(3):307-315.
Published By: American Association of Avian Pathologists
https://doi.org/10.1637/11814-021518-Reg.1
URL: http://www.bioone.org/doi/full/10.1637/11814-021518-Reg.1

Avian Influenza in the U.S. Commercial Upland Game Bird Industry: An Analysis of Selected Practices as Potential Exposure Pathways and Surveillance System Data Reporting

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Received 20 February 2018; Accepted 10 May 2018; Published ahead of print 16 May 2018

SUMMARY. Producing a smaller yield of higher-value birds compared to conventional poultry production, the U.S. commercial upland game bird industry deals primarily in the sale of live birds for recreational hunting. In this study, our aims were to gain insights into the occurrence of avian influenza (AI) in the U.S. commercial upland game bird industry in comparison to other poultry sectors, to identify the presence of the specific AI risk factors in the practices of raising ducks on site and having connections to live bird markets (LBMs), and to assess how AI surveillance systems may have played a role in the reporting of the presence of exposure pathway–related information. We found that 23 AI epizootics involving upland game bird premises were reported, compared to 485 epizootics in the other poultry industries, and 86% of epizootics involving upland game birds were limited to only one premises. Regarding specific AI risk factors, 70% of upland game bird epizootics involved one of the two examined practices. In assessing the impact of surveillance systems, data framed around the implementation of surveillance systems revealed that the introduction of active surveillance coincided with the more thorough reporting of both the raising of ducks on site and premises having connections to LBMs. Our results suggest the need for more thorough data collection during epizootics and the need to assess additional exposure pathways specific to the commercial raise-for-release upland game bird industry.

RESUMEN. Influenza aviar en la industria avícola recreativa de las zonas altas de Utah: Un análisis de prácticas seleccionadas como posibles vías de exposición y de reporte de datos de un sistema de vigilancia.
Con una producción menor de aves con mayor valor en comparación con la producción avícola convencional, la industria comercial de aves de con fines recreativos comercial de las tierras altas de los Estados Unidos se dedica principalmente a la venta de aves vivas para la caza recreativa. En este estudio, los objetivos fueron obtener información sobre la presentación de influenza aviar en la industria avícola comercial estadounidense de las tierras altas en comparación con otros sectores avícolas, para identificar la presencia de factores de riesgo específicos para la influenza aviar durante las prácticas de cría local de patos con conexiones con los mercados de aves vivas (LBM) y para evaluar cómo los sistemas de vigilancia de influenza aviar pueden haber desempeñado un papel en el reporte de la información relacionada con la presencia de rutas de exposición. Se descubrió que se notificaron 23 epizootias de influenza aviar que involucraban instalaciones de producción avícola recreativa en zonas altas, en comparación con 485 epizootias en las otras industrias avícolas y el 86% de las epizootias que involucraban aves de caza de zonas altas se limitaban a una sola instalación. En cuanto a los factores de riesgo específicos para la influenza aviar, el 70% de las epizootias en aves de caza de zonas altas involucraron una de las dos prácticas examinadas. Al evaluar el impacto de los sistemas de vigilancia, los datos relacionados con la instrumentación de sistemas de vigilancia revelaron que la introducción de la vigilancia activa coincidió con el informe más completo tanto de la cría local de patos, como de las instalaciones que tienen conexiones con los mercados de aves vivas. Nuestros resultados sugieren la necesidad de una recopilación más exhaustiva de datos durante las epizootias y la necesidad de evaluar vías de exposición adicionales específicas para la industria comercial de aves con fines recreativos de zonas altas que produce aves para posteriormente liberarlas.

Key words: avian influenza, upland game birds, United States, surveillance, exposure pathways

Abbreviations: AI = avian influenza; AIV = avian influenza virus; HPAI = highly pathogenic avian influenza; LBM = live bird market; LPAI = low pathogenicity avian influenza; N/A = Not available; NPIP = national poultry improvement plan

The commercial upland game bird industry started in the 1940s (47) and this small but substantial sector of commercial poultry production has grown into a niche industry of considerable value to numerous rural communities in the United States (6). In 2003, the upland game bird industry directly contributed more than $1.6 billion to the national economy (6).

The commercial upland game bird industry includes not only the production of birds for various markets such as raise-for-release markets, dog-training markets, meat markets, and, on occasion, live bird markets (LBMs), but also the operation of hunting preserves (47). Occasionally, farms work with the government to raise upland game birds for wildlife repopulation; however, this practice is not considered a commercial activity. The industry's specific production areas include breeder flocks, hatcheries, and mature bird production. The sale of mature live upland game birds to hunting preserves or for gun-dog training comprises 90% of the income-generating activities for most commercial farms (Secure Upland Gamebird Supply Plan Working Group, pers. comm.).

Various types of pheasant, quail of the *Colinus* genus, chukar partridges (*Alectoris chukar*), and wild turkey (*Meleagris gallopavo*) are the most prevalent upland game bird varieties raised in the United States (43), with the different species and subspecies within

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Declarations of interest: None.

each type having almost identical husbandry requirements and production set ups (16,47) (Secure Upland Gamebird Supply Plan Working Group, pers. comm.). Most of the upland game bird production premises in the United States are either partially or fully integrated, meaning the premises possess facilities where birds are bred, hatched, brooded, and grown to maturity by a single establishment (16,47). This integrated production activity may occur on a single site (Secure Upland Gamebird Supply Plan Working Group, pers. comm.) (47). Production of live adult birds sold for release coincides with hunting seasons, which are generally from early autumn or mid-autumn to mid-winter depending on the species and region (47). The hatching of chicks begins in mid-March and continues through mid-August with birds in brooder buildings, similar to those used in the conventional poultry industries, from April until as late as September or October (47). Following a period in the brooders, the birds are grown in large pens covered with netting. Birds selected as breeders are placed in pens to overwinter until the next production cycle in the following spring, meaning many premises typically have birds on site at all times (Secure Upland Gamebird Supply Plan Working Group, pers. comm.). The sizes of commercial upland game bird farms can vary tremendously with facilities at the upper limit producing more than 300,000 birds annually (47).

Although the production system and marketing channels in upland game bird production differ from conventional chicken and turkey industries, both industries share the threat of devastation due to one of the poultry industry's most difficult to control diseases, avian influenza (AI). Some of the first epizootics of AI in commercial upland game birds were reported in the mid-1960s in Italy (13), and in the United States, the first reported cases were in 1980 (2,27). Since these first U.S. occurrences, AI epizootics in upland game birds have continued to occur. Initially, epizootics were primarily detected via passive surveillance, in which detections are as a result of producers identifying signs of disease and voluntarily testing their birds (1,2,12,14,17,23,27, 29,34,35,37,38,40). Over time, active surveillance programs, in which birds without clinical signs are tested on a regular schedule with the intention of searching for and containing the virus, were also introduced (19) (A. Rhorer and D. Brinson, pers. comm.).

Active surveillance for AI is a recent and continuously improving tool for the upland game bird industry and all of the poultry industry. Since the 1986 low pathogenicity AI (LPAI) epizootic in Pennsylvania, numerous formal active surveillance programs have been created and sustained in an attempt to avoid further occurrences of widespread AI epizootics (4). Industry-led and state-supported active surveillance initiatives began as part of larger AI control programs such as in the surveillance protocols and recommendations within Minnesota via the Cooperative AI Control Program (19). Later, in the early 2000s, the National Poultry Improvement Plan (NPIP) instituted active AI surveillance components within its H5/H7 AI "Clean" and H5/H7 AI "Monitoring" programs. While these programs were primarily structured with commercial chicken and turkey enterprises in mind, commercial upland game birds were added to the NPIP programs in 2004 and 2009 (A. Rhorer and D. Brinson, pers. comm.).

Progress has since been made in improving active AI surveillance across all poultry sectors. In 2004, LBM producers and dealers on the East Coast, and in other states with frequent LBM activity, adopted uniform standards set up by the LBM Working Group, a group of industry, state, and federal representatives established by the U.S. Department of Agriculture Veterinary Services (7). These uniform standards included mandatory active AI surveillance, and as all the different surveillance programs evolved, so did the quality of AI epizootic documentation in poultry (7). Today, the multiple active AI surveillance programs help to monitor the AI status of the birds that the commercial upland game bird industry produces.

This study aims to establish greater insight into AI epidemiology in U.S. commercial upland game birds via three primary objectives. The first objective is to utilize the historical data of AI epizootics to assess the involvement of upland game bird premises in previous multi-premises, multi-species epizootics. The second objective is to identify the previous AI epizootics in the U.S. upland game bird industry and determine the frequency of two specific management practices reported in the literature to be risk factors for infection: premises selling to or engaging with LBMs (hereafter referred to as having "connections to LBMs") and premises raising ducks on site with upland game birds (hereafter referred to as "raising ducks on site"). The third objective is to assess the impact of the introduction of AI active surveillance systems on the documentation and reporting of epizootics in upland game birds.

METHODOLOGY

Source materials. Information about documented AI epizootics was obtained through the examination of specific literature including multi-year disease outbreak summaries and case reports published in peer-reviewed journals, conference proceedings, and annual summaries from the National Veterinary Services Laboratory published in the proceedings of the annual meetings of the U.S. Animal Health Association.

From the literature, we collected all available epizootic data of interest. Demographic information collected included year and location (by state). Additionally, production-related information fields that were captured included type of premises, types of species raised, impact of infection (recorded as number of affected premises, flocks, individual birds, *etc.*, depending on the unit reported in the literature), connections to LBMs, and the participation in the raising of ducks on site. Lastly, surveillance- and other epidemiologic-related information was extracted for the following fields: subtype of AI virus (AIV) and active or passive disease detection mechanism.

Consultation with industry experts. Personal communications were utilized to supplement information regarding specific epizootics in the literature and to build a historical timeline of active AI surveillance in the poultry industry because of limited and inconsistent literature. A primary source of industry opinion was the Secure Upland Gamebird Supply Plan Working Group, which consists of North American Gamebird Association representatives, commercial upland game bird farm owners and managers, and industry and government veterinarians. The Secure Upland Gamebird Supply Plan Working Group, in conjunction with the University of Minnesota Secure Food Systems Team, aims to develop a Secure Upland Gamebird Supply Plan that will help scientifically evaluate the risk of product movements off of commercial upland game bird farms and provide guidance to policy makers. The working group's input was typically sought when additional information for specific upland game bird epizootics was needed and to gain an understanding of the commercial upland game bird industry. Questions that aimed to provide an accurate picture of the development of active surveillance were administered to subject matter experts knowledgeable about AI surveillance programs. Specifically, clarifications were sought on the implementation of active AI surveillance systems including LBM surveillance, state-specific LPAI control programs, and NPIP AI Clean/Monitored surveillance.

Working definitions. For the purpose of this study, the following working definitions were adopted:

Upland game birds. Upland game birds are defined as the most common commercially raised types of game birds including: pheasant, bobwhite quail, and chukar. By species, these include *Phasianus colchicus* (hereafter referred to as pheasant), quail of the genus *Colinus* (hereafter referred to as quail), and *Alectoris chukar* (hereafter referred to as chukar). All of the subspecies within *Meleagris gallopavo* (hereafter referred to as wild turkey), a less commonly raised type of game bird, were also included in the study because of the appearance of outbreaks in commercially raised wild game turkey in the literature. All upland game birds referred to in this study are those that are sold as live adult birds for the primary activity of hunting or similar release activities such as dog training. Any quail outside the genus of *Colinus*, which is the primary variety known to be raised for release (16), were excluded from the study. In cases where the species or genus of quail was not reported, but was referenced as being raised for release, the quail were assumed to be a species of *Colinus* quail. Quail indicated as being raised specifically for LBMs were assumed to be outside of the *Colinus* genus. This assumption is based on the fact that *Coturnix* species of quails, such as *Coturnix japonica,* are typically raised for LBMs, not for release (Secure Upland Gamebird Supply Plan Working Group, pers. comm.). There are other minor game bird varieties raised for similar activities under similar husbandry practices such as the species of partridge, *Alectoris rufa*, also known as the red-legged partridge, but these were not encountered in the literature.

Commercial premises. A commercial premises is defined as any poultry operation that produces birds and/or poultry products for sale. This includes facilities that breed, hatch, and raise birds to adulthood/slaughter. In literature, they were determined via the use of explicit labels such as operation or game bird farm in the case of upland game birds. In cases where the above labels were not used, any premises with at least 1000 birds (regardless of species) (in accordance to the National Animal Health Monitoring System "Poultry 2004" study [49]) or not explicitly labeled as a "backyard" and/or "hobby" farm/flock was considered as a commercial premises.

Live bird market (LBM). An LBM is defined as a premises that sells varieties of domestic, exotic, and/or game poultry, birds, and/or waterfowl. Poultry for sale are typically sourced from multiple producers, dealers, and/or auctions.

Connections to LBMs. A premises that has connections to LBMs is defined as participating in the practice of selling birds to LBMs or engaging in activities that increase the likelihood of AIV exposure to LBM-sourced viruses such as locating premises within close proximity to flocks that sell directly to LBMs.

Raising ducks on site. Raising ducks on site is defined as the practice of raising ducks on the same premises as upland game birds. For the purposes of this study, husbandry practices were assumed to include standard waterfowl practices such as moving ducklings to outdoor ponds at 3 weeks of age and having feed sources exposed to open air (47). These practices are assumed to attract wild ducks to a premises, thus increasing the premises' AIV exposure risk. Other types of domestic waterfowl such as geese have a similar capacity to act as AIV exposure pathways onto upland game bird premises, but were not included in the scope of this study due to their lack of mention in the literature.

Epizootic. An epizootic is defined as the detection of one or multiple subtypes of AIV on one or more epidemiologically linked poultry premises (*i.e.*, premises that are connected via viral exposure pathways that are hypothesized to cause between-farm spread of the virus). Within the study, both a single case restricted to one premises and a widespread outbreak of multiple premises are each considered an epizootic. Due to the presentation of limited information in the literature and for purposes of uniform interpretation, if multiple commercial detections of the same AIV subtype occurred within one state or region in the same year, this study considers all of those detections as a part of one epizootic regardless of uncertain epidemiologic linkages, unless the literature stated that linkages were definitively absent. In the case of widespread epizootics, if the literature explicitly indicates that detections of an AIV subtype in multiple states or multiple years were epidemiologically linked, those detections in all states and/or years were included as one epizootic.

Scope of the study. This study encompasses documented AI epizootics that have occurred in the U.S. poultry industry since 1980, when the first AIV detection in commercial upland game birds was reported (27), up until June 2017. Only upland game bird premises that met the working definition of commercial were considered for inclusion.

The analysis includes epizootics involving commercial upland game birds as well as other commercial poultry industries including turkey (meat birds and breeders), broiler chicken (meat birds and breeders), and egg-laying chicken (layers, pullets, and breeders) to enable the comparison of AI epizootic occurrences between the commercial upland game bird industry and the other combined poultry industries.

Data analysis. A summary of the most relevant data fields is presented in Table 1, and the complete dataset is available upon request. Data were summarized in a spreadsheet in Microsoft Excel (36). If information was not available for a specific field, the field was left blank and treated as missing data in the subsequent analysis. Extracted data were examined both qualitatively and quantitatively.

For the first study objective, we compared the proportions of infected premises in AI epizootics to the total number of premises within each of the two industries, calculating the epizootic incidence proportion for each industry. Annual data from NPIP enrollment were used to determine the population denominator under the assumption that these populations were fairly constant over the 37-year period examined. While the flock number is not completely representative of the specific scope of each industry, it is the most complete information available depicting the number of poultry premises (referred to as "flocks" in the NPIP report) in the United States for commercial upland game birds and the other combined poultry commodities. A descriptive analysis of the number of multi- or single-premises epizootics within the two industries was conducted in order to compare the occurrence of multi-premises epizootics between industries. The statistical significance of the outcome of this analysis was assessed via a z-test with a significance level of 0.05.

For the second study objective, infected upland game bird premises that raised ducks on site and/or that had connections to LBMs were identified, and the frequency of each practice was utilized in assessing the occurrence of these practices on affected premises. Due to the small number of epizootics within the

Table 1. Summary of the total AI epizootics involving commercial upland game bird premises ($n = 23$) in the United States from time of first detection of AI in the commercial upland game bird industry (1980) to 2017.

Year	State	AI virus subtype	Species on premises	LBM	Ducks	Surveillance	Source
1980	Minnesota	H3N2	Pheasant, wild turkey	Unknown	Yes	Passive	2,27
1980	Minnesota	H7N3	Pheasant, wild turkey	Unknown	Yes	Passive	2,23,27,38
1983	Pennsylvania	H5[A]	Chukar	Yes	Unknown	N/A[B]	46; Secure Upland Gamebird Supply Plan Working Group, pers. comm.[C]
1986	Pennsylvania	H5N2	Chukar	Yes	Unknown	N/A	4
1986	Oregon	H9N9	Pheasant	Unknown	Yes	Passive	12
1988	Minnesota	H8N4	Pheasant	Unknown	Unknown	Passive	34
1988	Wisconsin	H9N2	Pheasant	Unknown	Unknown	N/A	34
1992	Arkansas	H5N2, H6N8, H6N2, H10N7	Quail	Unknown	Yes	Passive	35,37
1993	Maryland	H5N2, H3N2, H11N2	Pheasant	Unknown	Yes	N/A	28,37
1994	Arkansas	H7N3	Quail	Unknown	Unknown	N/A	28,37
1995	Minnesota	H5N2	Wild turkey	No	No	N/A	29; D. Halvorson, pers. comm.[D]
1998	New Jersey	H5N2	Pheasant	Unknown	Unknown	Passive	14
1998	Minnesota	H5N2	Chukar, pheasant	No	No	Passive	21,30,45; D. Halvorson, pers. comm.[DE]
2002	North Carolina	H7N2	Quail	Yes	Unknown	Active	15
2005	Washington	LPAI (subtype N/A)	Pheasant, chukar	No	Yes	Active	1
2008	Idaho	H5N8/ H4N7	Pheasant, chukar, quail	No	Yes	Passive	17,40; Secure Upland Gamebird Supply Plan Working Group, pers. comm.[G]
2009	New Jersey	H7N3	Pheasant	No	Yes	Active	25,41
2010	Washington	LPAI (subtype N/A)	Pheasant, chukar	No	Yes	Active	1
2013	Wisconsin	H5	Pheasant	No	No	Active	26; Secure Upland Gamebird Supply Plan Working Group, pers. comm.[D]
2014	Washington	LPAI (subtype N/A)	Pheasant, chukar	No	Yes	Active	1
2014	New Jersey	H7N3	Pheasant	No	Yes	Active	31,39; F. Hegngi, pers. comm.[G]
2015	Washington	H5N2[A]	Pheasant, chukar	No	Yes	Passive	1; F. Hegngi, pers. comm.[G]
2017	N/A	H5N2	Pheasant, chukar	No	Yes	Active	Secure Upland Gamebird Supply Plan Working Group, pers. comm.[F]; F. Hegngi, pers. comm.[F]

[A]Indicates a highly pathogenic strain.
[B]N/A = not available.
[C]Confirmed location, subtype, and species of outbreak and premises' connections to LBMs.
[D]Confirmed that no ducks were on site and the premises had no connections to LBMs.
[E]Confirmed surveillance system that detected outbreak.
[F]Confirmed occurrence of outbreak and subtype as reported in an unpublished report.
[G]Confirmed that ducks were on site and the premises had no connections to LBMs.

commercial upland game bird industry, only descriptive statistical analyses were performed. Number of premises was selected as the unit of interest because of the study's focus on potential implications of AI introduction and between-farm spread rather than within-farm spread. While the total number of pens (or houses) and total number of birds provide their own implications for disease transmission between farms, those implications were not explored in this study due to limited available data.

The data were framed within the timeline of the introduction of two active AI surveillance systems to explore documentation bias in relation to the reporting of the selected management practices. The prevalence of these practices was compared pre- and post-implementation of the key active surveillance programs. In order to explore documentation bias in relation to the practice of raising ducks on site, the NPIP H5/H7 AI Monitoring program introduced in 2009 was used to frame data, whereas the active surveillance program incorporated into the uniform standards for LBM producers in 2004 was used to explore potential bias in relation to the practice of having connections to LBMs.

RESULTS

Overview of AI epizootics involving upland game birds. The first recorded AI epizootics involving U.S. commercial upland game birds occurred in Minnesota in 1980. Low pathogenicity strains of H7N3 and H3N2 AIV were isolated from two epidemiologically separated pheasant premises with a total of 9000 birds (2,19,27,38). In all, 23 epizootics have involved commercial upland game bird premises since 1980. An additional 30 epizootics (information is available as Supplemental Table S1) were described in the literature as having involved upland game birds, but the information provided was insufficient to warrant inclusion of the detections in the main analysis. For example, numerous records of AI detections in upland

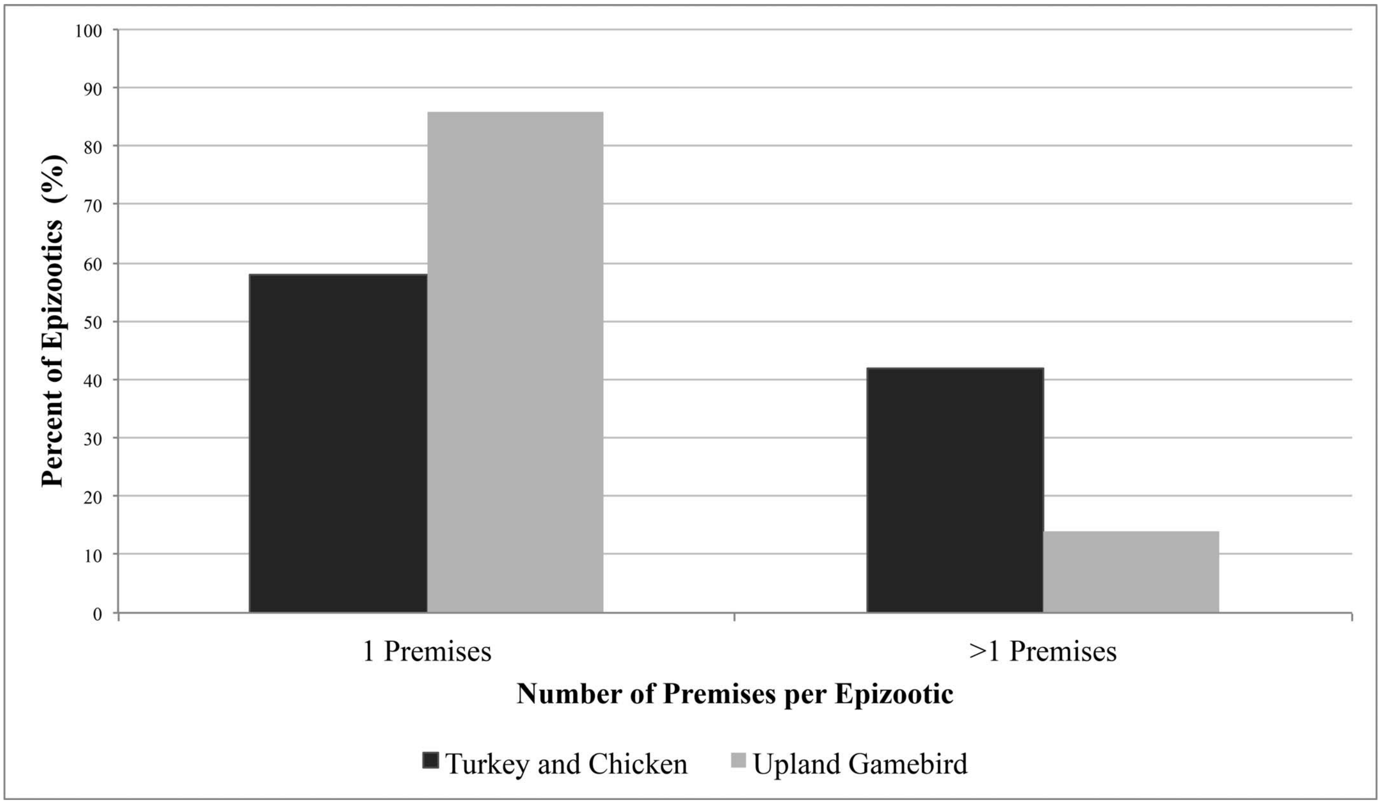

Fig. 1. Comparison of the proportion of multi- *vs.* single-premises epizootics between United States poultry industries (turkey and chicken, $n = 121$; upland game birds, $n = 22$) between 1980 and 2017. Only those epizootics for which the number of premises involved was reported in the literature are included. Summarized data for chickens and turkeys is presented in Supplemental Table S3.

game birds provided no information regarding the premises type from which the infected bird(s) originated, if any, meaning some detections could have been from backyard farms, LBMs, or wild upland game birds. The majority (86%) of epizootics involving upland game birds were limited to a single premises (see Fig. 1) with no documented spread to other premises.

Comparison of epizootics across the upland game bird industry and combined chicken and turkey industries. In total, 485 epizootics involving premises with turkeys and/or chickens were identified. Of these, 412 involved turkey (meat and breeder) premises and 84 involved broiler (meat and breeder) and/or egg-laying chicken (layer, pullet, and breeder) premises, with several epizootics involving premises of multiple industries. Details regarding epizootics in non–upland game bird species are contained in Supplemental Table S2.

According to the most recently available annual data from the NPIP report published in the U.S. Animal Health Association meeting proceedings, there are 3128 upland game bird flocks and 105,438 flocks in the combined turkey and chicken industries (32). When corrected for the total number of flocks at risk over the 37 years, we find that the adjusted epizootic incidence proportion is 0.02% of flocks becoming infected with AI per year in upland game birds and 0.01% of flocks becoming infected with AI per year in the combined turkey and chicken industries.

From Fig. 1, we observe that 42% of the epizootics involving either the chicken and/or turkey industries spread beyond a single premises and this number was significantly ($P < 0.05$) higher than the 14% reported for the upland game bird industry. The only multi-premises epizootics that involved game birds included widespread epizootics such as the 1983 highly pathogenic AI (HPAI) H5 epizootic in Pennsylvania, the 1986 LPAI H5N2 epizootic in Pennsylvania, and the 2002 H7N2 epizootic in North Carolina.

A few other epizootics illustrated potential for upland game bird premises to be involved in larger epizootics. The 2009 H7N3 epizootic in New Jersey involving a pheasant premises was reported to be epidemiologically linked to a nearby farm (41); however, the nearby farm was not confirmed as either a hobby or commercial premises, and thus the epizootic was excluded from Fig. 1. In addition, the 1980 H7N3 epizootic in Minnesota involving a pheasant and wild turkey farm involved the same subtype of H7N3 that was circulating in nearby commercial turkeys; however, based on the contemporaneous epidemiologic investigation (27), the game bird farm reportedly had no epidemiologic links to the turkey industry and the outbreak was reported as highly likely to have resulted from independent introduction caused by wild birds. Moreover, modern sequencing data show that while viruses from the pheasants (MN/917) and turkeys (MN/1200) from 1980 are related, they are not identical (52). Lastly, a case of H5 HPAI affected a single upland game bird premises in Washington State in 2015, and while there were detections in backyard flocks, there was no evidence of spread between the upland game bird farm to those backyard flocks or any nearby commercial poultry farms (1).

Overview and frequencies of selected practices on upland game bird premises. Of the 23 upland game bird epizootics, 16 (70%) involved upland game bird premises that either had connections to LBMs or raised ducks on site.

Mixed duck–upland game bird premises. Thirteen of the 23 (57%) epizootics involved premises that raised ducks on site. Of these epizootics, one involved a premises that raised quail and duck; four that raised pheasant and duck; two that raised pheasant, wild turkey, and duck; five that raised pheasant, chukar, and duck; and one that raised pheasant, chukar, quail, and duck. Minnesota and New Jersey each had two epizootics. Arkansas, Oregon, and Maryland each had one epizootic, and one premises in Washington had four separate LPAI outbreaks occur in 2005, 2010, 2014, and 2015. Epizootics occurred in 1980, 1986, 1992, 1993, 2005, 2008–10, and 2014–17 and all are listed in Table 1.

LBM connections. Three of the 23 (13%) upland game bird epizootics were confirmed to have connections to LBMs. Of the three, two included premises raising chukar and one included multiple premises raising quail. Two of these epizootics occurred in Pennsylvania in 1983 and 1986, while the other occurred in North Carolina in 2002 and all are listed in Table 1.

Surveillance system and detection of AI epizootics involving upland game bird premises. According to accessed data, surveillance system–specific information was available for 16 of the 23 documented epizootics.

Active surveillance. Of the 16 epizootics, eight involved detections through active surveillance for AIV on the premises. These epizootics occurred in North Carolina in 2002, New Jersey in 2009 and 2014, Wisconsin in 2013, Washington in 2005, 2010, and 2014, and an unpublished state in 2017 and all are listed in Table 1. The active surveillance that detected the quail premises in the 2002 North Carolina epizootic was the result of a state-level active surveillance program mandated during the widespread H7N2 epizootic in the surrounding area (15). All of the 2005, 2009, 2010, 2013, 2014, and 2017 epizootics involved premises with infections where virus was detected as a result of NPIP pre-movement AI surveillance.

Passive surveillance. Of the 16 epizootics with surveillance information, eight involved detection of AI via passive surveillance. These occurred in Minnesota in 1980, 1988, and 1998; Oregon in 1986; Arkansas in 1992; New Jersey in 1998; Idaho in 2008; and Washington in 2015. All of these are listed in Table 1. Of note, close to half of the passively detected epizootics came from premises where a spike in mortality and apparent clinical signs were the key indicators of flock infection (1,12,17,27). The subtypes of passively detected infections included: H3, H4, H5, H7, and H9.

Effect of surveillance system on reporting of epizootics. As noted in Table 2, in the 8-year period between 2009, the year of implementation of the NPIP H5/H7 Monitored active surveillance for upland game birds, and June 2017, the proportion of epizootics with premises unknown to have raised ducks on site decreased in comparison to the 29-year period prior, between 1980 and 2009. Similarly, in the 13-year period between 2004, when the active AI surveillance stemming from the LBM uniform standards was implemented, and June 2017, the proportion of epizootics involving premises unknown as to whether or not they had connections to LBMs decreased in comparison to the 24-year period between 1980 and 2004.

DISCUSSION

Our results show that there were numerically fewer AI epizootics in commercial upland game birds than there were in chickens and/or turkeys, but that there are also fewer upland game bird premises at risk. Based on these results, the epizootic incidence proportion turns out to be greater for upland game birds *vs.* chicken and turkey farms. However, to assess the real risk of introduction onto and spread between farms, one must compare the total number of individual premises affected in all of the epizootics for each industry over the study period *vs.* the total number of premises per industry. It is likely that a smaller proportion of total at-risk upland game bird flocks is affected since epizootics in this industry typically involved significantly fewer premises per epizootic, usually one premises, compared to the combined turkey and chicken industries, which often involved more than one premises per epizootic (up to 211 premises as reported in Supplemental Table S2). Unfortunately, performing this analysis would require detailed data on the total number of premises for all epizootics which is not readily available.

And although Fig. 1 demonstrates a few instances of upland game bird involvement in widespread epizootics, there are multiple examples of epizootics involving 20 or more premises in which upland game birds have not been affected (see Supplemental Table S2). Of particular interest are the extensive LPAI epizootics of numerous subtypes in Minnesota that affected hundreds of turkey premises since the 1980s (see Supplemental Table S2). The epidemiologic isolation of upland game birds during these epizootics, and many of those that occurred in Pennsylvania, stand out given that the two states are historically top producers of pheasants (33). It is highly likely that upland game birds exhibit different exposure pathways from other sectors. For example, fomite-mediated virus transmission via shared personnel, vehicles, and equipment has been hypothesized during AI epizootics in turkeys and chickens (3,10,18,20,24,38,48). Yet, on commercial upland game bird premises, sharing of equipment between farms is less likely to occur (44), although the commercial upland game bird industry is defined differently in previous literature (44).

With results indicating that over half of epizootics in upland game birds involved premises that raised ducks on site, the practice of raising game birds on the same premises with ducks for the purpose of waterfowl hunting supports assertions in the literature that the practice could qualify as an industry-specific exposure pathway (47). Wild waterfowl are well-documented reservoirs of AIVs (5,20). AIVs typically survive well in environments where ducks congregate (50). The captive ducks themselves and their associated production systems such as the use of open ponds attract potentially infected wild waterfowl to the premises (8). Consequently, both direct bird-to-bird transmission via mingling of wild and captive waterfowl and indirect transmission via fomites increases the exposure risk of birds on site. So, while our dataset is small, our limited results combined with literature assertions indicate that the practice should be considered a potentially high-risk activity for the upland game bird industry.

The results that indicated 13% of epizootics involving game birds had farms with connections to LBMs support the literature statements that LBMs act as an exposure pathway. These markets provide the ideal environment for the sustainment of AIVs as well as the opportunity for the virus to spread beyond the markets via sold and unsold birds (9,11,42,51). At the same time, these results support claims that the commercial upland game bird industry does not typically serve the LBM channel. Based on current industry subject matter expert information, only about 2% of total commercial upland game bird facilities participate in these types of markets (Secure Upland Gamebird Supply Plan Working Group, pers. comm.). Given such a low involvement of the commercial

Table 2. Number of epizootics involving commercial upland game bird premises in the United States between 1980 and 2017 that participated in, did not participate in, or were unknown to have participated in select practices (raising ducks on site and having connections to LBMs) that act as potential AIV exposure pathways, both pre- and post-implementation of active AI surveillance programs (NPIP Active AI Surveillance and LBM Uniform Standard Active Surveillance).

	Exposure pathway participation; no. of epizootics (%)					
	Raising ducks			Connections to LBMs		
Surveillance system	Yes	No	Unknown	Yes	No	Unknown
Pre-NPIP or -LBM standards surveillance (ducks: $n = 16^A$; LBM: $n = 14^B$	7 (43.8)	2 (12.5)	7 (43.8)	3 (21.4)	2 (14.3)	9 (64.3)
Post-NPIP or -LBM standards surveillance (ducks: $n = 7^A$; LBM: $n = 9^B$	6 (85.7)	1 (14.3)	0 (0)	0 (0)	9 (100.0)	0 (0)
Total ($n = 23$)	13 (56.5)	3 (13.1)	7 (30.4)	3 (13.1)	11 (47.8)	9 (39.1)

[A]Total number of upland game bird epizootics that occurred pre- or post-implementation of the NPIP H5/H7 AI Monitored surveillance program in upland game birds in 2009.
[B]Total number of upland game bird epizootics that occurred pre- or post-implementation of the uniform standards for LBM producers and dealers in 2004.

upland game bird farms in the practice of having connections to LBMs, the 13% of epizootics that involved upland game bird farms having connections to LBMs is worthy of observation and the commercial upland game bird industry should continue to avoid this practice.

Documenting the presence of both of these practices on infected upland game bird premises is important since it echoes the dangers of such practices and ultimately the need to completely minimize their prevalence on the upland game bird premises. Throughout the data collection process, it was observed that many epizootics had limited documentation of whether infected game bird farms participated in these practices. Through the framing of data based on active surveillance systems, as shown in Table 2, we noted that implementation of such surveillance programs may have enabled these practices to be identified. We note that while the data cannot prove a definitive causal relationship between reporting and program implementation, the trends observed in the data presented suggest that the apparent low frequency of premises raising ducks on site in epizootics prior to 2009, especially in epizootics that occurred around 1980, may have been due to the absence of recorded evidence rather than the absence of the practice.

These findings emphasize that active AI surveillance programs may have improved the standards of collecting premises' production-, demographic-, and epidemiologic-related data during epizootic investigations. The importance of robust data collection during epizootics has been demonstrated in literature such as in Halvorson's 2009 study (22), which assessed exposure pathways during various AI epizootics in the United States based on information from various case studies and outbreak trace-back information. Similar epidemiologic data are also needed for epizootics that occur on upland game bird farms. Such data can guide the identification and better understanding of exposure pathways and virus spread dynamics within the upland game bird industry. In addition, while some specific details of epizootics are presented at various conferences and/or meetings, or are written down in published or unpublished reports, there is no one readily available resource or surveillance program that allows for an easy analysis of the epidemiologic trends of AI in this industry.

Some of the limitations of this study include the vague nature of premises classifications in literature. Distinguishing commercial upland game bird facilities from backyard or hobby upland game bird premises was essential because these two realms of game bird production are quite different. Additionally, units of measure recorded within the literature were inconsistent, with the impact of infection per epizootic being recorded in varying units ranging from individual birds to houses, flocks, and/or premises. Such variation made determining the number of epizootics involving single or multiple premises within the combined turkey and chicken industries difficult. Further limitations relate specifically to when personal communications were used to clarify information. These include difficulties in identifying and accessing experts as well as a potential recall bias for older historical epizootics. Finally, the small number of epizootics within the upland game bird industry provided a small dataset to work with and from which to draw conclusions.

Nonetheless, we recommend that future studies should explore additional pathways of AI introduction onto commercial upland game bird farms, particularly industry-specific management, and sector, and possibly species differences that may explain the observed trends during previous recorded epizootics. Such management- or sector-related differences between commercial upland game bird production and other sectors could include the bird density on farms, total number of birds on farms, potential links to fomites, seasonality of production systems in relation to the seasonality of AI, and others. These insights will help to define transmission risks for the commercial raise-for-release upland game bird industry in comparison to hobby or ornamental upland game bird producers as well as aid in furthering our understanding of the dynamics of AI in the industry in comparison to the larger poultry industry.

Supplemental Tables S1, S2, and S3 associated with this article can be found at http://dx.doi.org//10.1637/AVIANDISEASESJOURNAL-11814-021518. Reg.1.s1; http://dx.doi.org//10.1637/AVIANDISEASESJOURNAL-11814-021518. Reg.1.s2; and http://dx.doi.org//10.1637/AVIANDISEASESJOURNAL-11814-021518. Reg.1.s3.

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ACKNOWLEDGMENTS

We extend our thanks to the Secure Upland Gamebird Supply Plan Working Group and the University of Minnesota Secure Food Systems Team for their expert elicitation. We also thank Dr. Andrew Rhorer, Dr. Denise Brinson, and Dr. Fidelis Hegngi for their contributions pertaining to active surveillance programs and additional information regarding specific epizootics. In addition, we thank Clara Brandt for her contributions to beginning stages of data collection. Amos Ssematimba is grateful to Gulu University for granting him the opportunity to work with the University of Minnesota Secure Food Systems Team. This study was funded by the U.S. Department of Agriculture Animal and Plant Health Inspection Services (USDA APHIS) Veterinary Services (grant 16-9794-2536ca) and was supported by the University of Minnesota, Center for Animal Health and Food Safety through a USDA-APHIS Center for Epidemiology and Animal Health Cooperative Agreement to Support National Preparedness Planning for Animal Health Emergencies (cooperative agreement 12–9208–0218ca). Dr. Cardona's contributions are in part supported by funding from the B. S. Pomeroy Chair of Avian Health at the University of Minnesota, College of Veterinary Medicine.