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Evidence-based Policy for Controlling HPAI in Poultry: Bio-security Revisited

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1. Abstract

There is considerable global concern over the newly emergent H5N1 strain of avian influenza that has affected millions of domestic poultry flocks and resulted in 256 human cases and 152 deaths in humans. There has been little analysis of the general assumption that smallholder backyard poultry flocks are inherently at higher risk of highly pathogenic avian influenza (HPAI) than confined and commercial scale operations. We utilized data from Thailand, collected in 2004, to test the relative risks of HPAI infection in poultry flocks, by species, type of operation, and geographic location. The results indicate that backyard flocks are at significantly lower risk of HPAI infection compared to commercial scale operations of broiler or layer chickens or quail. These results are plausible in terms of the opportunities for breach of bio-security in commercial scale operations. Both experimental and observational studies in developed country settings have demonstrated the capacity of microbes to enter and leave these larger operations despite the implementation of standard bio-security measures. The results of this study should be considered by policy makers and public health officials when developing plans to control or prevent HPAI while aiming to limit adverse effects on the livelihood of smallholder poultry producers in developing countries.

2. Introduction

Outbreaks of highly pathogenic avian influenza (HPAI) were first reported in Southeast Asia in late 2003, although the current emergence of the H5N1 virus is now considered to have occurred as early as 1996 when it was first identified in geese in Guangdong Province in southern China (1). Since then it has spread rapidly and over large distances, with outbreaks occurring in domesticated poultry and some wild bird populations in Mongolia, southern Russia, the Middle East and, in 2005, in Europe and Africa. According to WHO, as of October 2006, there have been 256 cases of laboratory confirmed human infection, with 152 deaths reported. To date, several epidemic waves have occurred in Indonesia, Thailand, Vietnam, and Laos. The widespread practice of smallholder backyard poultry keeping in many of these countries is frequently cited as one of the primary risk factors for these outbreaks, including infections in humans, and the persistence of the virus in domestic poultry populations. Based upon this assumption, some governments are considering the prohibition of unconfined poultry flocks in order to increase 'bio-security' in smallholder backyard production. Many of these measures may be prohibitively expensive for resource-poor smallholder producers and thus could force them to abandon poultry keeping. Given these likely adverse impacts of restrictive policies on smallholder poultry growers, it is important to examine the evidence base for such measures in terms of their effect on risks of HPAI.

Few of the proposed measures to enhance the biosecurity of poultry operations and to protect human populations have been rigorously tested for their effectiveness against HPAI. There is an assumption that because the majority of HPAI outbreaks have been reported in smallholder backyard flocks, these operations are inherently more risky than other types of poultry operations. We have been able to utilize available data from the HPAI epidemic and concurrent active surveillance program in Thailand to test this assumption (2). In addition we review recent studies conducted by us and others in the US and Western Europe that assess pathogen movement in and out of standard commercial poultry facilities.

3. Materials & Methods

In order to In order to examine whether backyard poultry operations are at higher risk of HPAI infection than 'commercial' scale flocks we draw on sources of unique data from Thailand on the 2004 HPAI epidemic in Thailand and from concurrent nationwide active surveillance programs (2). Overall, in the active surveillance programs, swabs were collected from around 230,000 flocks (5 birds per flock) from more than 50,000 villages (4 flocks per village) and tested for avian influenza virus. Additionally, 72,000 serum samples from birds were collected for diagnosis.

To compare the incidence of HPAI infection in 'backyard flocks' with that in commercial scale (non-backyard) flocks, we utilized the classification of the Thai Department for Livestock Development (DLD). In the case of chicken these commercial (non-backyard) flocks were further classified as 'layer' or 'broiler' flocks, while for other poultry, flocks were classified by species, namely as ‘duck’, ‘geese’ or ‘quail’ flocks. Quail flocks were evaluated using data on quail production methods (NRC) and on average flock size to impute backyard or commercial scale operations. Given the similar methods of production and nature of ducks and geese we aggregated the latter into one group in the following figures.

To examine the odds of HPAI infection among different flocks, we utilized logistic regression analysis with variable selection being based on likelihood ratio statistic. The Huber-Sandwich estimator was used to obtain adjusted coefficient estimates due to clustered data.

4. Results

In order to evaluate risks of infection, it is important to examine the standing poultry population in Thailand by both numbers of flocks and numbers of birds. As shown in Figures 1 and 2, commercial-scale enterprises of broiler or layer chickens comprise most of the standing poultry population in Thailand while backyard flocks comprise most of the flocks. Backyard flocks, which consist of 30 birds per flock on average, constitute approximately three quarters of flocks but account for only around one fifth of the standing poultry population.

Figure 1 Contribution of different ‘flock types’ to total domestic poultry population (app 280 million birds) in Thailand

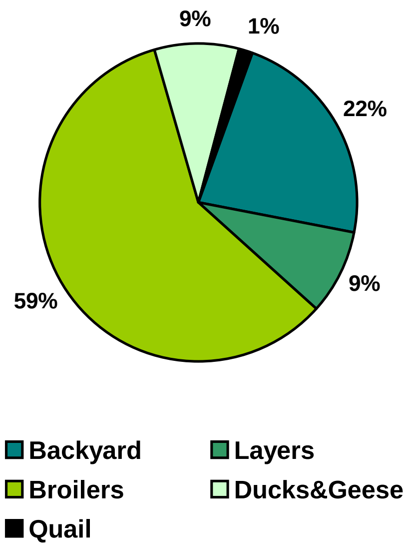
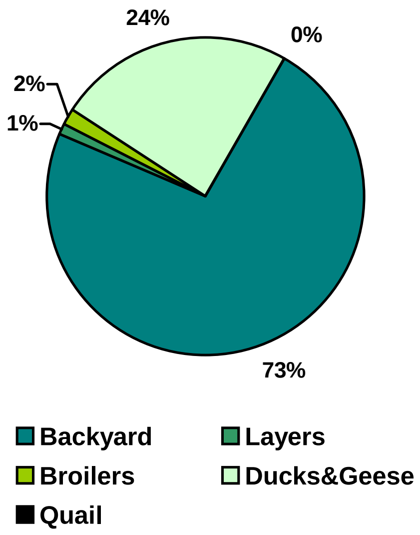


Figure 2 Contribution of different ‘flock types’ to total number of flocks (app 2.9 million flocks) in Thailand



Source: Tiensin et al., 2005, authors’ calculations

Commercial broiler enterprises (consisting of 3,500 birds per flock on average) constitute only two percent of all ‘flocks’ but account for nearly sixty percent of the standing poultry population. In the case of quail, the majority are reared in confinement as larger flocks, primarily for egg and subsequently meat production (3). Average size of quail flocks is around 1,400 birds, confirming the large proportion of commercial operations.

A total of 1,769 flocks with HPAI infection were reported to or detected by the Thai animal health authorities in 2004 (the dataset upon which we draw does not distinguish between infected flocks detected by the active surveillance programs and those detected by disease reporting). The distribution of these infections by flock type is shown in Figure 3, which indicates that over 50% of the registered infections involved backyard flocks. However, the proportional contribution of different flock types to registered infections (number of flocks affected by HPAI) is markedly different from their contribution to the total number of flocks. The crude risk of infection, expressed as a percentage of the flock type, is shown in Figure 4. Thus, for example, although layer flocks only constitute one percent of all flocks, they account for five percent of all registered infected flocks.

Figure 3 HPAI infections registered in Thailand in 2004 (n=1,769) by 'flock type'

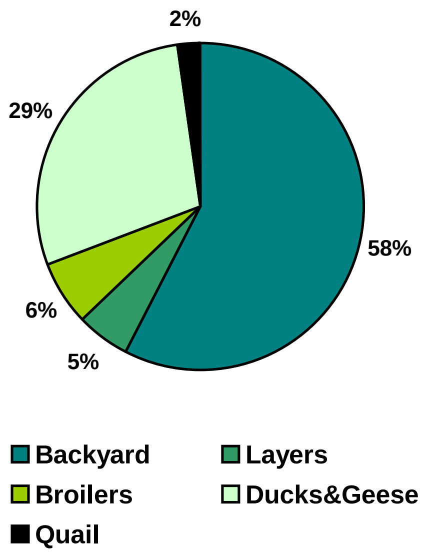
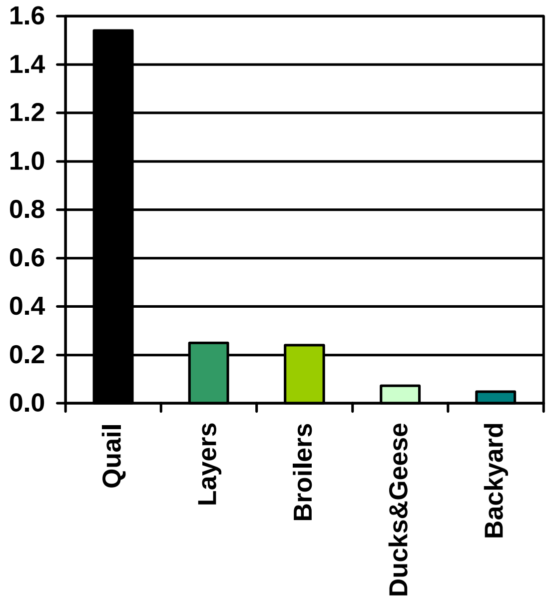


Figure 4 Risk of infection (%) with HPAI in Thailand in 2004 by 'flock type'



Quail flocks show the highest risk of detected infection, nearly reaching 1.6 percent of all quail flocks, followed by layer and broiler flocks, both with infection risks of just above 0.2 percent. Against expectations, backyard flocks show the lowest risk of detected infection with HPAI (0.05 percent), only one quarter that of layer and broiler flocks.

These results may reflect differences in ascertainment. HPAI may be more readily detectable by the personnel in large commercial operations and more likely to be brought to the attention of animal health authorities by these operators. However, these data are not based solely upon outbreak reports but also on the active surveillance programs that were in place in Thailand in

2004. Since these programs were focused on backyard operations, this potential ascertainment bias is unlikely to explain the higher risk of HPAI infection being detected in layer and broiler flocks compared to backyard operations. There are no data that permit examination of other production factors, apart from flock type (size and scale of production) and species, which might also have contributed to increasing or decreasing HPAI infection risks within and between flock types.

Another explanation for these differences may be due to other risk factors related to HPAI, such as ecological and landscape factors which might modulate transfers from wild avians and among domesticated flocks. From a temporal and a geographical perspective, HPAI outbreaks did not occur uniformly or randomly across Thailand in 2004, but were shown to be linked to certain agro-ecological factors such as the extent of wetlands and rice paddies (4). The distribution of the Thai poultry industry is not uniform throughout the country, with large-scale commercial production being particularly important in the Central and Eastern region (Figures 5 to 7). The average size of duck and geese flocks is below 50 and 5 birds respectively in the North, Northeast and South, indicating that they are mainly backyard operations, while in the Central and Eastern region average flock size is 240 and 340 respectively for ducks and 80 and 110 for geese, suggesting that in these regions they are to a large extent commercial operations. The geographic distribution of quail flocks also differs by flock type, with most of the commercial operations in the Central region.

Figure 5 Contribution of 'flock types' to total flocks by region

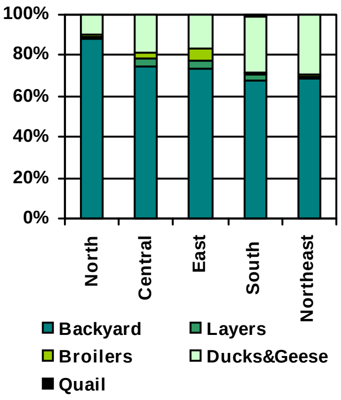


Figure 6 Average flock size by region

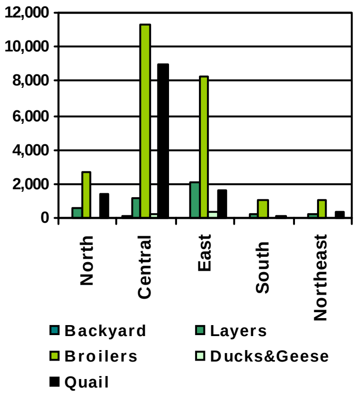
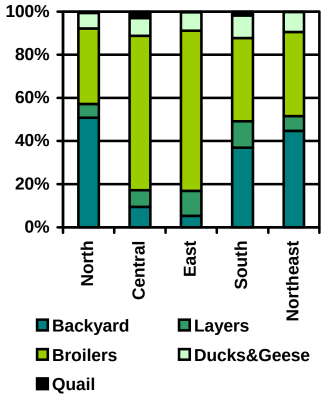


Figure 7 Contribution of 'flock types' to total birds by region



The Central region was particularly affected, followed by the Eastern region, while the Northern, Northeastern and Southern regions only experienced minor epidemics. Given that these different regions also have different mixtures of flock types, the data was subjected to statistical multivariate analysis to control for potential confounding and describe potential interactions between region and flock type specific risks within region and species category. Table 1 displays the adjusted odds ratios (and their 95% confidence intervals) for the selected risk factors, taking backyard operations in the Northeastern region (lowest crude risk) as the reference group (odds ratio = 1).

Table 1: Odds ratios, 95% confidence intervals and levels of statistical significance for selected risk factors for HPAI infection in Thailand in 2004.

Region	Flock type	OR	95%CI
Northeast	Backyard	1.0	
	Layers	5.04	2.3-11.5
	Broilers	1.07	0.3-4.4
	Ducks	0.33	0.2-0.6
	Quail	57.0	7.9-410.8
	Geese	1.6	0.2-11.2
North	Backyard	10.8	8.7-13.5
	Layers	83.1	54.7-126.1
	Broilers	115.9	80.9-166.0
	Ducks	17.4	13.0-23.3
	Quail	1064.1	570.1-1986.1
	Geese	29.1	10.7-79.2
Central	Backyard	27.1	19.6-31.1
	Layers	79.1	55.0-113.9
	Broilers	104.5	74.7-146.1
	Ducks	127.8	101.8-160.5
	Quail	1044.4	666.7-1636.2
	Geese	54.4	25.0-106.0
East	Backyard	19.5	11.9-20.7
	Layers	42.7	24.3-74.9
	Broilers	14.7	7.2-30.3
	Ducks	19.4	12.8-29.4
	Quail	-	
	Geese	39.0	12.3-123.4
South	Backyard	2.1	1.02-2.3
	Layers	1.6	0.2-11.2
	Broilers	5.8	1.8-18.4
	Ducks	1.1	0.6-2.2
	Quail	6.7	0.9-47.8
	Geese	-	

This table demonstrates that in most regions, backyard flocks had the lowest risks of HPAI, as compared to commercial flocks of broilers, layers, or quail. The multivariate statistical analysis shows that there was an interaction between region and species, such that within the North and Central regions, amongst the flock types backyard flocks had the lowest odds of outbreak occurrence relative to backyard flocks in the Northeast. In the East, there was relatively little difference between flock types, but layers and geese had the highest odds. In the South, the odds of infection were not different from backyard flocks in the Northeast for layers, ducks and quail, but they were higher for broiler flocks. In the Northeast, layers and quail had higher odds than backyard flocks, whereas they were reduced in ducks, layers, broilers, ducks and geese in the South and Northeast. Across regions, the odds of HPAI infection in quail flocks infection are by far the highest. These results are similar, to the geographical pattern of the 2004 HPAI outbreaks, most of which occurred in the central region of the country, and the lowest number in the South. Taken together, the data do not support the assumption that backyard poultry production in Thailand is more risky, in terms of HPAI infection, than larger and confined commercial poultry operations (that is, either layer, broiler chickens or quail).

5. Discussion

Our finding of increased risks of HPAI infection among commercial scale poultry flocks, as compared to backyard operations, is the first analysis of comparative data. It is consistent with two studies conducted in connection with outbreaks of H5N1 in Hong Kong and of H7N7 in the Netherlands (5, 6). While neither of these studies directly compared risks between commercial and backyard scale operations, both of these investigations reported increased risks of sero-positivity to avian influenza among persons contacting live poultry in commercial operations as compared to referent groups. A more recent report from Vietnam (7) did not find an association with employment in commercial poultry production but only 3 persons in the case:control study (1 case and 2 controls) reported this activity.

In interpreting these results, we have reexamined the evidence from studies of other pathogens, to test assumption that the standard operations of large-scale commercial poultry producers are highly bio-secure. Bio-security is defined as any practice or system that prevents the spread of infectious agents from infected to susceptible animals, or prevents the introduction of infected animals into a herd, region, or country in which the infection has not yet occurred (8). Another, more strict definition has been proposed, which states that bio-security is the outcome of all activities undertaken by an entity to preclude the introduction of disease agents into an area that one is trying to protect (9). Although it is assumed that backyard flocks are inherently less bio-secure, in fact large-scale poultry operations pose significant challenges to ensuring bio-security. The confinement of large numbers of birds (as many as 50,000 in each modern broiler house in the US and Thailand) imposes the need to supply these large populations kept at high densities with feed, water and air. It is important to note that because confinement of thousands of animals requires controls to reduce heat and regulate humidity, poultry and swine houses require high volume ventilation which results in considerable movement of materials from and into the external environment (10). A recent article on bio-security in duck production in Thailand included photographs of these high volume ventilations systems in confined operations (11). The other major challenge to bio-security arises through the need to dispose of large amounts of animal waste from these large populations – each broiler chicken is estimated to produce about 1.7 kg waste over its 6-7 week lifespan.

The challenge to bio-security on poultry farms can be discussed using two poultry diseases of global significance, campylobacteriosis and Newcastle disease, as examples. Inferences are relevant to understand the opportunities for pathogen transfers in and out of confined poultry operations, and not necessarily to risks of human disease, since Newcastle disease is not a human pathogen although Campylobacter spp are leading causes of both food and water borne gastroenteritis in humans. Newcastle disease is transmitted among poultry via contaminated faeces and probably via inhalation of aerosols, which is similar to HPAI. The specific mechanisms for spread between farms are also similar to HPAI, ie movement of poultry, poultry products, humans, contaminated feed and water. The availability of vaccines for Newcastle disease, not bio-security, effectively controls the incidence of disease in commercial poultry populations in developing countries.

Studies of Campylobacter, an avian commensal and human pathogenic bacteria, are also relevant to consider. Like avian influenzas, wild birds are the natural vertebrate reservoirs of Campylobacter spp, and they can serve as vectors for transmission to domestic avians and other vertebrates (12-18). We have found that poultry workers in commercial broiler houses are at increased risk of exposure to Campylobacter (19), consistent with a report from Thailand (20). Campylobacter spp move among avian host species, both domesticated (21) and wild (22-24) and in both directions (25, 26). In confined poultry houses, broiler poultry are readily colonized by Campylobacter, and the external environment (which may be contaminated in large part from wild avians) appears to be a major source of colonization. The inability of conventional bio-security measures to prevent the movement of Campylobacter in and out of modern broiler facilities was clearly demonstrated in a recent study of Campylobacter-free broiler flocks, housed in sanitized facilities, using standard bio-security measures, and fed Campylobacter-free feed and water. Seven out of ten of these flocks became colonized with Campylobacter by the time of slaughter and two flocks were colonized by Campylobacter strains genetically indistinguishable from strains isolated from puddles outside of the facility prior to flock placement (27). Although the route of entry was not determined, this study clearly showed the capacity for microbes to enter broiler facilities despite the implementation of standard bio-security measures. Once a poultry flock is colonized with Campylobacter, the food, water and air within the house quickly becomes contaminated with the bacterium (27). Contaminated air exiting the house via ventilation systems becomes a source of Campylobacter to the external environment. Microbes may be carried great distances by wind and surface water transport. Campylobacter strains with identical DNA fingerprints to those colonizing broilers have been measured in air up to 30 m downwind of broiler facilities housing colonized flocks (27).

There are additional mechanisms by which Campylobacter and other microbes enter and leave ‘bio-secure’ poultry houses. For example, insects may carry microbes in and out of facilities through ventilation systems and small openings. This was demonstrated in a study in Denmark which found that Campylobacter carriage was common among flies surrounding the broiler facilities and that as many as 30,000 flies may enter a broiler facility during a single flock rotation in the summer months (28). House flies captured within broiler facilities and other food environments can also carry multi-drug resistant bacteria (29) as well as avian influenza virus (30). Recent studies at Johns Hopkins laboratory confirm these findings.

Animal house wastes constitute another pathway for pathogens to exit poultry houses. In large scale operations, with few exceptions poultry wastes are managed by land disposal. Some pathogens, including viruses, can survive in poultry wastes for considerable amounts of time (31). No data are available on avian influenzas, but Newcastle disease virus can be spread by poultry house wastes (32). Land-disposed poultry house wastes are attractive to wild birds due to the presence of spilled feed in these wastes. These then may become infected and contaminate water supplies of other poultry operations. In addition, poultry house wastes are used in aquaculture as “bedding” in many countries around the world (33, 34). This practice provides an opportunity for direct contact by wild water fowl. While no studies have examined the presence of viruses in bedding wastes of aquaculture ponds, this practice results in the spread of antimicrobial resistant pathogens in situations where the ‘bedding’ wastes are from poultry provided feed with antimicrobial additives (35). This method of waste recycling has been supported in the past by FAO (36, 37). The shipment of poultry wastes for this purpose has been suggested by some as one mechanism for the transfers of HPAI from Asia to Central Europe (38).

6. Conclusions

This is the first analysis of data to test the hypothesis that smallholder backyard poultry flocks are at greater risk of HPAI, and potentially exposing human populations to HPAI, as compared to commercial scale and confined poultry flocks. The analysis utilized the most extensive and least biased data set available, which included information from extensive national active surveillance programs carried out by the Thai Department of Livestock Development in 2004. The results indicate that, contrary to general assumptions, the odds of HPAI infection are higher in confined and large scale flocks – layer and broiler chickens and quail – than in backyard poultry flocks. The Thai data suggests that production methods utilized in many non-backyard / commercial poultry operations, with less than perfect bio-security, apparently increase risks of HPAI infection, at the farm or flock level, above those experienced by subsistence backyard producers. Although the majority of reported HPAI outbreaks in Thailand in 2004 occurred in the latter, this increased cumulative risk of HPAI in the smallholder sector is primarily due to their relatively greater numbers rather than more risky production practices.

These findings have important implications for current strategies to minimize and prevent outbreaks of HPAI and protect human health. First, the results demonstrate that commercial poultry operations are far from risk-free. Although a combination of measures may significantly reduce the risk of pathogen introduction and spread, for a variety of pathogens ‘zero’ risk is virtually impossible to achieve in farmed livestock populations, even in highly developed settings. In the present state of uncertainty it is premature to rule out attention to any circumstance that may promote the emergence and transmission of an important disease such as HPAI. Second, some of the measures being considered to make subsistence poultry production ‘safer’, eg forced housing or confinement of poultry, will impose very high costs, particularly upon a marginal group of entrepreneurs and household producers. This may lead to an overall reduction of HPAI outbreaks, but more as a result of the loss of household production flocks than as a result of enhanced bio-security.

In developing strategies and policies to mitigate disease risk for livestock as well as human populations it is important to ensure that the practical implementation of bio-security measures are tailored to the pathogen(s) which constitute(s) the threat as well as to the production practices of the farming system at risk. This requires identification of the main pathways of pathogen transmission, quantification of risks and assessment of efficacy and cost of proposed risk mitigation measures. The imposition of measures which do not significantly reduce the risk of pathogen introduction and spread but place severe economic burdens on society or groups thereof may be politically opportune but are unjustifiable and unlikely to contribute to public health protection.

7. References

1 Sims, L.D., Domenech, J., Benigno, C., Kahn, S., Kamata, A., Lubroth, J., Martin, V., Roeder, P. (2005). The origins and evolution of H5N1 highly pathogenic avian influenza in Asia. Vet. Rec.;157: 159-164.

2 Tiensin, T., Chaitaweesub, P., Songserm, T., Chaising, A., Hoonsuwan, W., Buranathai, C., Parakamawongsa, T., Premashthira, S., Amonsin, A., Gilbert, M., Nielen, M. and Stegman, A. (2005). Highly pathogenic avian influenza H5N1, Thailand, 2004. Emerging Infectious Diseases;11:1664-1672.

3 National Research Council, Panel on Microlivestock (1991). Microlivestock: Little-known Animals with a Promising Economic Future, Washington: NAS Press

4 Gilbert M., Wint, W. and J. Slingenbergh (2004). The ecology of Highly Pathogenic Avian Influenza in East and Southeast Asia: outbreak distribution, risk factors and policy implications, Food and Agriculture Organization of the United Nations.

5 Bridges, C.B., Lim, W., Hu-Primmer, J., Sims, L., Fukuda, K., Mak, K.H., Rowe, T., Thompson,

W.W., Conn, L., Lu, X., Cox, N.J., Katz, J.M. (2002). Risk of influenza A (H5N1) infection among poultry workers, Hong Kong, 1997-1998. J Infect Dis; 185:1005-1010.

6 Koopmans, M., Wilbrink, B., Conyn, M., Natrop, G., van der NH, Vennema, H., Meijer, A., van SJ, Fouchier, R., Osterhaus, A., Bosman, A. (2004). Transmission of H7N7 avian influenza A virus to human beings during a large outbreak in commercial poultry farms in the Netherlands. Lancet; 363:587-593.

7 Dinh PN, Long HT, Tien NTK, Hien NT, Mai LTQ, Phong LH, Tan HV, Nguyen NB, Tu PV, Phuong NTM et al (2006). Risk factors for human infection with avian influenza H5N1, Vietnam 2004. Emerg Infec Dis 12(12): 1841-1847.

8 Radostits O.M. (2001). Control of infectious diseases of food-producing animals, in: Herd Health: Food animal production medicine, 3rd Edition, Saunders Company.

9 Dargatz D.A., Garry F.B., Traub-Dargatz J.L. (2002). An introduction to biosecurity of cattle operations. Vet. Clin. North Am. Food Anim. Pract.;18:1-5.

10 Jones T, Donnelly C, Stamp Dawkins M. (2005). Environmental and management factors affecting the welfare of chickens on commercial farms in the United Kingdom and Denmark stocked at five densities. Poultry Sci;84:1155-1165.

11 Songserm, T., Jam-On, R., Sae-Heng, N., Meemak, N., Hulse-Post, D.J., Sturm-Ramirez, K.M., Webster, R.G. (2006). Domestic ducks and H5N1 influenza epidemic, Thailand. Emerg Infect Dis;12:575-581.

12 Cabrita J, Rodrigues J, Braganca F, Morgado C, Pires I, Goncalves A. (1992). Prevalence, biotypes, plasmid profile and antimicrobial resistance of Campylobacter isolated from wild and domestic animals from northeast Portugal. J Appl Bacteriol;73:279-285.

13 Yogasundram K, Shane S, Harrington K. (1989). Prevalence of Campylobacter jejuni in selected domestic and wild birds in Louisiana. Avian Dis;33:664-667.

14 Fernandez H, Gesche W, Montefusco A, Schlatter R. (1996). Wild birds as reservoir of thermophilic enteropathogenic Campylobacter species in southern Chile. Mem Inst Oswaldo Cruz;91:699-700.

15 Stern N, Myszewski M, Barnhart H, Dreesen D. (1997). Flagellin A gene restriction fragment length polymorphism patterns of Campylobacter spp. isolates from broiler production sources. Avian Dis;41:899-905.

16 Southern J, Smith R, Palmer S. (1990). Bird attack on milk bottles: possible mode of transmission of Campylobacter jejuni to man. Lancet;336:1425-1427.

17 Altekruse S, Swerdlow D, Stern N. (1998). Microbial food borne pathogens. Campylobacter jejuni. Vet Clin North Am Food Anim Pract;14:31-40.

18 Hanninen M, Perko-Makela P, Pitkala A, Rautelin H. (2000). A three-year study of Campylobacter jejuni genotypes in humans with domestically acquired infections and in chicken samples from the Helsinki area. J Clin Microbiol;38:1998-2000.

19 Price L (2006). Microbial risks associated with industrial poultry production. PhD Thesis submitted to the Johns Hopkins University Bloomberg School of Public Health, Baltimore MD.

20 Meeyam T, Padungtod P, and Kaneen JB (2004). Molecular characterization of *Campylobacter* isolated from chickens and humans in Northern Thailand. Southeast Asian J Trop Med Public Health 35(3): 834-843.

21 van den Bogaard A, Stobberingh E. (2000). Epidemiology of resistance to antibiotics. Links between animals and humans. Int J Antimicrob Agents;14:327-335.

22 Broman T, Waldenstrom J, Dahlgren D, Carlsson I, Eliasson I, Olsen B. (2004). Diversities and similarities in PFGE profiles of Campylobacter jejuni isolated from migrating birds and humans. J Appl Microbiol;96:834-843.

23 Petersen L, Nielsen E, Engberg J, On S, Dietz H. (2001). Comparison of genotypes and serotypes of Campylobacter jejuni isolated from Danish wild mammals and birds and from broiler flocks and humans. Appl Environ Microbiol;67:3115-3121.

24 Stanley K, Jones K. (1998). High frequency of metronidazole resistance among strains of Campylobacter jejuni isolated from birds. Lett Appl Microbiol;27:247-250.

24 Craven S, Stern N, Line E, Bailey J, Cox N, Fedorka-Cray P. (2000). Determination of the incidence of Salmonella spp., Campylobacter jejuni, and Clostridium perfringens in wild birds near broiler chicken houses by sampling intestinal droppings. Avian Dis;44:715-720.

26 Lee M, Sanchez S, Zimmer M, Idris U, Berrang M, McDermott P. (2002). Class 1 integron-associated tobramycin-gentamicin resistance in Campylobacter jejuni isolated from the broiler chicken house environment. Antimicrob Agents Chemother;46(11):3660-3664.

27 Bull S, Allen V, Domingue G, Jorgensen F, Frost J, Ure R, et al. (2006). Sources of Campylobacter spp. colonizing housed broiler flocks during rearing. Appl Env Microbiol;72:645-652.

28 Hald B, Skovgard H, Bang D, Pedersen K, Dybdahl J, Jespersen J, et al. (2004). Flies and Campylobacter infection of broiler flocks. Emerg Infect Dis;10:1490-1492.

29 Macovei L and Zurek L (2006). Ecology of antibiotic resistance genes: characterization of enterococci from houseflies collected in food settings. Arch Environ Microbiol; 72: 4028-4035

30 Bean W, Kawaoka Y, Wood J, Pearson J, Webster R. (1985). Characterization of virulent and avirulent A/chicken/Pennsylvania/83 influenza A viruses: Potential role of defective interfering RNAs in nature. J Virol;54:151-160.

31 Gerba C and Smith JE (2005). Sources of pathogenic microorganisms and their fate during land application of wastes. J Environ Qual;34: 42-48.

32 Guittet M, LeCoq H, and Picault JP (1997). Risk for transmission of Newcastle disease by contaminated poultry products. Rev Sci Tech 16(1): 79-82

33 Perdue ML and Swayne DE (2005). Public health risk from avian influenza viruses. Avian Dis 49(3): 317-327.

34 Sehqal HS and Sehqal GK (2002). Aquacultural and socio-economic aspects of processing carps into some value-added products. Bioresource Technol 82(3) 291-293.

35 Petersen A, Andersen JS, Kaewmak T, Somsiri T, Dalsgaard A (2002) Appl Environ Microbiol 68(12) 6036-6042.

36 FAO (2001). Integrated agriculture-aquaculture. A primer. FAO Fisheries Technical paper No. 407. FAO, Rome. http://www.fao.org/docrep/005/y1187e/y1187e00.htm

37 FAO (2003). Recycling of animal waste as a source of nutrients for freshwater fish culture within an integrated livestock system. http://www.fao.org/docrep/field/003/ac526e/AC526e00.htm

38 Butler D (2006). Doubts hang over source of bird flu spread. Nature 439(7078): 772

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