PART 2

Risks and Challenges for Poultry Production

Risks associated with poultry production systems

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SUMMARY

Every poultry farm has its own risk profile for the introduction of pathogens, subsequent development of disease, and spread of pathogens to other farms. This risk profile is determined by a complex interaction between the levels of infection in an area, the measures implemented on the farm to prevent disease, and other factors including the density of farms in the area and linkages with other farms and markets. Farm biosecurity measures reduce, but do not eliminate, the risk of introduction or onward transmission of pathogens; they include factors such as the location of farms, the physical facilities, and the operational procedures implemented. Investments in these measures are subject to the law of diminishing returns. The Food and Agriculture Organization of the United Nations (FAO) has defined four production systems based partly on the biosecurity measures implemented. Distinguishing between farms on the basis of the measures practised is important, as not all intensive poultry production units apply biosecurity measures appropriate to the level of risk of virus incursion. Experiences with highly pathogenic avian influenza viruses of the H5N1 subtype have shown that farms in all production systems have experienced outbreaks, of highly pathogenic avian influenza, and that it is not possible to blame one particular system for the genesis or spread of the disease. Nevertheless, farms that rear ducks outdoors or where poultry are sold through poorly regulated live poultry markets appear to be high-risk enterprises, especially in countries where infection is present. Enhancement of biosecurity measures is generally agreed to be the best way to minimize this risk, but not all farms are in a position to implement stringent biosecurity, especially those that rely on rearing poultry outdoors. Formal risk analysis has rarely been applied to individual farms, but would assist in determining the benefits of existing and proposed on-farm biosecurity measures and in highlighting gaps in our knowledge regarding the levels of hazard for farms.

Key words: poultry, production, systems, risks, H5N1

1 INTRODUCTION

Many different methods are used for rearing poultry. Production systems range from small, village-level scavenging poultry flocks (Kitalyi, in FAO, 1998) from which few poultry enter the formal market system, to integrated intensive operations in which large companies control all aspects of the production and marketing chain upstream and downstream from production units (see, for example, Tyson Foods, 2006). Between lies a range of systems

– from individual farms practising industrial-type production (Sims *et al.*, 2003) to flocks of ducks reared on paddy fields (Gilbert *et al.*, 2006) which are often transported long distances to graze on recently harvested fields.

Each of these systems, and each individual farm or flock, has its own risk profile for the introduction of pathogens, subsequent development of disease, and spread of disease to other farms. This is influenced by a number of factors, including: the density of farms (Marangon *et al.,* 2004), especially for agents in which rate of transmission is density dependent (e.g. airborne spread) (Truscott *et al.,* 2007); and the linkages between different farms through production and market chains, which may lead to disease transmission that is density independent (e.g. spread via fomites) (ibid.).

This review examines the various production systems, discussing the risks they face and the risk they pose with regard to animal diseases, focusing on highly pathogenic avian influenza (HPAI) caused by viruses of the H5N1 subtype. It considers the systems' key weaknesses and strengths in relation to disease prevention and spread, with special emphasis on biosecurity measures employed on farms. It reviews the interaction between the threat of infection and the different production systems, how the former varies over time, and the influence of this and other factors, such as farm density, on the overall risk of disease in different production systems. It also considers how these risks can be assessed and managed.

1.1 Production systems and biosecurity – some background and definitions

In 2004, the Food and Agriculture Organization of the United Nations (FAO) defined four production systems (originally referred to as "sectors", but the term "system" is now preferred) based on the characteristics of the production methods, especially the biosecurity measures implemented, and the extent of involvement of the farm in the formal market chain (FAO, 2004b). The features of this classification system have been reviewed elsewhere (Sims and Narrod, in FAO, 2008) and are summarized in Table 1.

The term "biosecurity" has been used widely in the debate on avian influenza (FAO, 2004a; Thieme, in FAO, 2007a; Otte *et al.,* in FAO, 2007b). In essence, it describes the sum of the measures taken to prevent incursion and spread of disease. In this paper, this term is applied specifically to farms, and refers to the hygiene and management measures taken to minimize the risk of incursion of pathogens onto individual farms (sometimes referred to as "bioexclusion") and to minimize the risk of onward transmission to other farms if infection occurs (often referred to as "biocontainment"). Farm biosecurity practices cover a broad range of measures. These have been divided into three categories (Shane, 1997):

i) conceptual, including the choice of location for farms;
ii) structural, covering the physical facilities, such as netting to protect against entry of wild birds; and
iii) operational, covering the work procedures that farm staff and visitors are expected to follow.

Field experience suggests that breakdowns in biosecurity can occur if attention is not paid to any one of these three elements.

Farm biosecurity, in its broad sense, covers all measures used to prevent disease. There-

TABLE 1
Summary of FAO production systems

Production system	Main characteristics
System 1	Integrated, industrialized enterprise with sophisticated, high-level farm biosecurity measures. Full control over all farm inputs and outputs (e.g. breeding stock, feed mill, slaughterhouse, processing, distribution, animal health services).
System 2	Commercial, intensive poultry production involving largely independent enterprises or contractors, practising moderate to high-level biosecurity. Distribution of poultry to slaughterhouses and/or to live poultry markets.
System 3	Commercial farms with relatively poor biosecurity. Sales are more likely to be through live poultry markets or to traders who on-sell through live bird markets. This system covers ducks and other poultry. Production may be intensive or extensive.
System 4	Village-level, scavenging chickens for local consumption. These small flocks are reared in village households. An occasional bird is sold locally, bartered, used as a gift or, occasionally, sold to a poultry trader for cash[1].

fore, other measures applied to individual poultry, such as vaccination, that reduce the risk of infection following virus incursion into a flock of poultry and the likelihood of onward transmission to other farms can also be regarded as biosecurity measures. However, as these are often treated separately, under the category of disease control and preventive measures (see, for example, FAO, 2004b), and are considered in detail in many other papers, they are not covered in depth here. The focus in this paper is worker behaviour and physical facilities (including farm location), which form the basis of most farm biosecurity plans and activities.

As with other measures used to control and prevent disease in poultry, farm biosecurity measures reduce, but do not eliminate, the risk of infection and disease. As a United Kingdom leaflet (DEFRA, 2006) on poultry-farm biosecurity states:

> *"Biosecurity means taking steps to ensure good hygiene practices are in place so that the risk of a disease occurring or spreading is minimized".*

Despite utilizing sophisticated biosecurity measures, the defences of some well-managed farms are sometimes breached by horizontally transmitted pathogens (East *et al.*, 2006; Otte *et al.*, in FAO, 2007b), including avian influenza viruses. This reaffirms that reliance on biosecurity measures alone will not prevent all cases of infection and disease.

In fact, there is no such thing as a totally biosecure farm – the investment required to achieve this would never make economic sense. Total biosecurity is restricted to high-

[1] Village-level flocks from which poultry or products are sold regularly into markets outside the local district should be classified as system 3 farms.

security laboratories (and even these have, at times, failed to contain viruses).

The likelihood of incursion of a particular pathogen depends on the properties of the agent, including its means of spread and survival in the environment. This means that some agents can be kept out of farms more readily than others. For example, biosecurity measures to prevent campylobacter infections have a high failure rate (see Otte *et al*., in FAO, 2007b), which is probably linked to the agent's biology and its high prevalence in nature. Other agents, especially certain parasites and agents that require close contact between infected animals for transmission, can be readily excluded.

1.2 Biosecurity and farm density

Modelling studies of outbreaks of H5N1 HPAI in Great Britain suggest that infection is likely to be extinguished if infected farms are relatively isolated, but can cause large clusters of disease in areas with high density of poultry flocks (Truscott *et al*., 2007). This matches field observations in earlier cases of HPAI in the United Kingdom, in which the disease was restricted to single farms or small clusters of neighbouring farms (Sims and Narrod, in FAO, 2008), and recent experiences in Italy, Canada and the Netherlands, where there was considerable local spread once virus gained access to a farm in areas with dense populations of poultry farms (Capua *et al*., 2003; Stegeman *et al*., 2004; Power, 2005).

Many of the areas with dense poultry production (so-called densely populated poultry areas) have developed without an overall master plan (Capua *et al*., 2003). Expansion of the poultry industry in specific locations usually occurred as a result of some economic or production advantage (such as easy access to markets, or ready availability of a supply of feed, land, etc), which then attracted other farm operators and increased the concentration of farms. A number of countries are contemplating the establishment of new livestock production zones. If designed and planned properly, these could reduce the likelihood of the spread of disease. However, it is also possible that they could increase risk if they lead to excessively high concentrations of farms (which may also emit excessive air, land and water pollutants if too concentrated and improperly regulated).

2 PRODUCTION SYSTEMS AND RISKS OF H5N1 HPAI

The current panzootic of H5N1 HPAI has focused attention on the risks associated with, and posed by, different poultry production systems. It has provided an opportunity to reflect on their role in the genesis, spread and prevention of HPAI, and has drawn a remarkably broad range of responses regarding the apparent contribution of the different production systems.

For example, many veterinarians and other poultry-industry experts regard enhancement of commercial farm biosecurity measures as the most appropriate response to this panzootic and to avian influenza generally (see, for example, TAES, 1995). Some have called for greater intensification of poultry production, or at least moves to enclosed production (Martin *et al*., in FAO/OIE, 2006), with a few countries even calling for the virtual elimination of "backyard" and free grazing poultry production (see, for example, MARD, 2006, cited by ACI, 2006). Others have proffered alternative, almost diametrically opposed, views suggesting that this disease is largely the result of industrialization of poultry production (see, for example, Grain, 2006; Greger, 2006). This view has also been promoted by those opposed to so-called "factory farming" on welfare and environmental grounds (see, for example, Beyond Factory Farming, 2006).

In fact, blame for the current H5N1 HPAI panzootic cannot be attributed to any one production system, as farms in all systems have been affected and played some role in the persistence and spread of this disease (Sims and Narrod, in FAO, 2008). All production systems have their strengths and weaknesses, which are described below, although some specific production and marketing methods, notably free range rearing of commercial ducks and sale of poultry through poorly regulated live poultry markets, appear to have played a particularly important role in the genesis of this particular panzootic (Sims *et al*., 2005).

Despite calls by some for elimination of certain production methods, all of the current production systems are expected to persist for the foreseeable future. Even if there is an increase in intensification (as planned in some countries and likely to occur by evolution in others), smallholder and village/backyard flocks will still be present; although, based on experiences in developed countries, the proportion of poultry reared in such systems will likely diminish over time.

These flocks are most likely to persist in poorer countries, especially in places where they help to ensure financial stability for vulnerable groups and increase diversity of sources of income. In some countries, measures taken to control HPAI have already resulted in exclusion of some smaller producers from formal market chains (FAO/MARD, 2007). These households will need assistance to develop appropriate methods to prevent avian influenza and other diseases, and in some cases to retain or restore access to markets. The methods used to do this will probably differ from those used in larger-scale commercial farms, given the marked differences in production methods between the two. Small non-commercial flocks will also persist in rich countries, with some people choosing to rear poultry as a hobby, or to meet particular cultural or social needs and preferences such as rearing of game birds or desire to use freshly laid eggs.

Industrial production will also continue, although production methods will likely continue to evolve over time. Current trends suggest that this type of production will probably grow as long as demand for cheap and affordable poultry and traceability of food products increases. Free-range commercial production will also increase in places where consumers are prepared to pay a premium for poultry or eggs produced using these methods.

2.1 Biosecurity and intensive production

The use of intensive production methods does not mean that farms necessarily implement biosecurity measures appropriate to the level of risk. The outbreak of HPAI in western Canada in 2004 revealed many flaws in biosecurity practices in farms that were infected (Power, 2005). Outbreaks of HPAI in the Lao People's Democratic Republic in 2004 were reported in commercial farms around Vientiane, but not in backyard flocks located away from the city. Several papers and articles (e.g. Grain, 2006) have suggested that this showed that intensive poultry rearing represents a higher risk than the rearing of scavenging poultry. However, such statements did not take into consideration the low level biosecurity measures practised on these commercial farms, which were deemed to be system 3 farms by several independent observers (see, for example, Rushton *et al*., in FAO, 2005a) and the possible occurrence of unreported disease in the village flocks.

Classifying all industrialized poultry farms together, without regard to the biosecurity measures implemented, is unhelpful and provides no indication of the likelihood of disease outbreaks on individual farms. This varies depending on the measures used to reduce the risk of infection on the farm, as well as other factors such as the presence of the agent in the area around the farm, the density of farms in the area and the measures taken to prevent infection by other farms.

For example, the risk of HPAI virus incursion into a farm is likely to be lower in infected areas where well-managed vaccine campaigns are implemented than in places where vaccination is not used. This occurs because vaccination, when applied correctly, reduces the levels of excretion in infected birds, therefore reducing the overall levels of virus in an area, and also increases the resistance of poultry to infection (van der Goot *et al*., 2005; Ellis *et al*., 2006).

2.2 Farm biosecurity and H5N1 HPAI

If a farm becomes infected with an H5N1 HPAI virus, it is an indication of a mismatch between the measures implemented and the risk of incursion. This does not necessarily indicate that the farmer has failed to implement appropriate biosecurity measures, as infection can sometimes occur even with well-designed and properly operated systems. However, in some outbreaks of H5N1 HPAI, specific deficiencies in biosecurity measures were identified (see for example DEFRA, 2007) which, had they been implemented properly, may have prevented viral entry. In others, the reason for the incursion of virus remains unknown.

Unfortunately, few field investigations of H5N1 HPAI in Asia provide sufficient detail on the biosecurity measures practised on infected farms to assess whether disease occurred as a result of poor management or whether the level of infection around the farm was such that it overwhelmed otherwise "reasonable" measures. If gains are to be made in understanding the role of different production systems with respect to this disease, future investigations should include better information on biosecurity measures, similar to that provided in investigations of the February 2007 outbreak in turkeys in the United Kingdom (DEFRA, 2007).

Only one small case-control study on H5N1 HPAI has been published (Kung *et al*., 2007), involving an outbreak in Hong Kong SAR. This study concluded that links to retail markets were a key factor in the outbreak, although the sample size was small and many of the cases were probably the result of local secondary spread due to proximity to infected premises. Biosecurity measures implemented at the time of this outbreak were deficient on all but a few farms (Sims, unpublished).

A study of outbreaks of HPAI in Israel in 2006 provided some general information on the biosecurity measures on infected farms. All had open sheds, but two of the affected farms (breeder farms) otherwise implemented higher-level biosecurity measures than the others. The precise means of introduction of infection to these farms was not determined, although close interactions between personnel and shared vehicles for deliveries may have played a role. The possibility of the introduction of virus by wild birds could not be ruled out (Balicer *et al*., 2007).

Results of case-control studies for other avian influenza viruses are also pertinent. A study to evaluate risk factors for spread of low pathogenicity H7N2 avian influenza among commercial poultry in the United States of America (McQuiston *et al*., 2005) found that disposal of dead birds off-farm for rendering was a significant risk factor. Wild birds are well established as a source of avian influenza viruses, and a number of farms have been exposed due to inadequate bird-proofing, use of untreated drinking water, or contaminated feed and litter.

Studies in which an attempt was made to compare the number of cases of H5N1 HPAI in different farm types have not conclusively demonstrated relationships between the overall risk of infection with H5N1 viruses and specific farm production systems – due largely to problems of ascertainment bias. One study in Thailand (Tiensin *et al*., 2005) which suggested broiler farms may have been more likely to be infected acknowledged this possibility; when the study was conducted there was considerable under-reporting and non-recognition of infection, especially in subclinically infected ducks.

Recently, reported outbreaks in Viet Nam and Thailand have all been in small flocks reared under conditions of minimal biosecurity (therefore, largely production system 3), but, again, it is not known whether other outbreaks have occurred and gone unreported in farms in other systems.

Virtually all veterinarians working in the poultry industry and international agencies agree that farms practising high-level biosecurity are less likely to be infected than those with poor biosecurity, at least at the beginning of an outbreak in a particular area. Despite the larger number of inputs to industrial-style farms, the concurrent implementation of biosecurity measures can reduce the risk associated with these. There are exceptions to this rule. Minimally biosecure farms in remote locations, away from known sources of infection, are at low risk of being infected, whereas farms that purport to practise high-level biosecurity, but still engage in high-risk practices, such as sale of poultry through poorly controlled live poultry markets, are at a higher risk than would appear if only the farm facilities and management practices were examined. The rule is also less relevant in infected areas with a high density of farms – due to the potential for local transmission of virus over short distances. This can lead to the spread of infection to farms that otherwise implement appropriate biosecurity measures.

The following notes provide information on the biosecurity measures implemented in the different production systems, and factors affecting their vulnerability.

System 1

By definition, system 1 farms practise high-level biosecurity (if they don't they should not be classified as system 1 farms).

System 1 operations are often large multifarm, multibarn enterprises, and as a consequence of their size, have more inputs (and outputs) than smaller farms (Otte *et al*., in FAO, 2007b). In addition, ownership of these farms is largely concentrated in the hands of a few large transnational companies. This allows greater control over inputs, and as these enterprises invest considerable sums in facilities and poultry, it is likely that appropriate biosecurity measures will be implemented to protect this investment.

Many of the companies operating system 1 farms work in multiple countries, and this can result in transborder movement of poultry, poultry products or equipment, which may involve movement from infected countries to uninfected countries. The outbreak of H5N1 HPAI in a turkey flock in Sussex, United Kingdom, in 2007 (although not strictly a system 1 enterprise based on the biosecurity systems in use) demonstrated the extent of transborder trade in poultry meat through this one large company –and the risks that this can create if strict biosecurity measures are not maintained.

Risks to system 1 farms are offset by the biosecurity procedures in place and the controls these enterprises have over the source of inputs, many of which are derived from suppliers that form part of the integrated company.

System 1 farms have on occasions become infected with HPAI, but it has not always been possible to determine the reason for this. In one case, it is presumed that a combination of a high level of virus in the area around the farm and climatic conditions that facilitated dispersal of contaminated material may have played a role (Sims, unpublished).

In some countries, owners of integrated system 1 farms have strong political connections and it has been suggested (although not proven) that this may have led to collusion between government and industry and covering up of disease outbreaks (Davis, 2006). Regardless of the truth of these allegations, there is a segment of the community that remains suspicious of the motives of these companies and has lost faith in them, fearing that outbreaks in company farms may go unreported.

The only way to overcome this is to have independent, well-resourced veterinary services backed by appropriate legal powers to take action in the event of an outbreak of a disease such as HPAI. This must be coupled with strong open links between the private and public sectors.

Integrated farming operations often choose to locate their operations away from other farms, especially from farms at higher risk of infection. However, if another farmer also chooses to establish similar poultry operations in the same area, the benefits to both from isolation will be diminished. Some system 1 farms have also attempted to improve the biosecurity of system 3 and 4 flocks in the vicinity of their enterprises, to minimize the level of hazard in the area around their poultry houses.

System 2

Biosecurity measures for system 2 farms vary considerably, in line with the broad definition of this system (i.e. farms that practice "medium to high-level" biosecurity). Well-managed farms will have a similar risk profile to system 1 farms, whereas those at the lower end of the classification are likely to represent a greater risk. This is compounded if the farm sells poultry to multiple traders, does not practise all-in all-out management, or has direct links with poorly managed live poultry markets. The location of these farms plays an important role in the risk of infection.

Many supposed system 2 farms have been affected in the current panzootic of H5N1 HPAI. In some cases, breaches in biosecurity measures implemented on these farms contributed to the outbreaks, as was seen in outbreaks in Hong Kong SAR in 2002 where some farms had links to live poultry markets.

System 3

System 3 farms are generally considered to be the most vulnerable to virus incursion, especially large system 3 farms. Not only do these farms employ minimal biosecurity measures, they are also most likely to encounter virus through the marketing chain or potentially via contact with wild birds (e.g. grazing ducks in Asia).

Some of these farmers only rear poultry when they deem that it is likely to be profitable to do so or when they have surplus funds to invest. It appears that they are willing to take the risk that their flock may get infected (or do not have sufficient resources), and therefore invest less in facilities and biosecurity measures. In other cases, they do not own the building in which their poultry are housed and are, therefore, unwilling to invest in structural alterations that would enhance biosecurity (Pagani and Kilany, in FAO, 2007c). In so doing they potentially increase the risk for surrounding farms and those linked to the farm via the same marketing and supply chains.

Wild birds are recognized as a potential source of avian influenza viruses including H5N1 HPAI viruses. If poorly biosecure (system 3) farms are located in places that attract wild birds, the level of hazard is greater than for farms located elsewhere. This was the basis for interventions in Russia, in which poorly biosecure flocks near sites of congregation of wild water fowl were vaccinated after analysis of information from outbreaks in such farms in 2005/2006 (Irza, 2006).

System 3 farms are found in many locations – urban, peri-urban and rural. Some of these have developed from small, system 4 backyard flocks, and occupy the same site and use the same inappropriate facilities as the original flock. Often, these are located near to other poultry. In system 3 farms where poultry are allowed to range freely, the concentration of other poultry and wild birds in the area is an important factor that is likely to determine the risk of exposure.

Many outbreaks have occurred in system 3 farms, including grazing duck flocks, but a lack of denominator data prevents assessment of the relative susceptibility of these compared to farms using other production systems (Morris and Jackson, in FAO, 2005b).

System 4

System 4 farms differ little from system 3 farms except for the scale of the enterprises and the limited commercial sale of poultry in the former, most of which is conducted locally.

Although system 4 farms often implement few formal biosecurity measures, isolated system 4 farms can operate almost as a closed system, with few contacts with the commercial industry. Inputs are derived locally with minimal contact with traders. This means they can remain free from infection despite not implementing specific measures to prevent infection.

This was the case with backyard poultry in Hong Kong SAR in 1997 – very few, if any, of these birds were sold through commercial markets. This has also been described in isolated communities in Viet Nam (Edan *et al*., 2006). In HPAI outbreaks in the Netherlands and Canada very few "backyard" flocks were found to be infected (Halvorson and Hueston, 2006), suggesting that links between farms may be more important than proximity (unless airborne spread occurs).

Major risks for system 4 producers include human traffic in villages, wandering poultry and wild birds.

2.3 Combinations of farming systems

The mix of different farm types in a particular area is probably a more important factor than the concentration of farms in determining the overall risk for these farms. If all farms in an area practise high-level biosecurity, the risk of infection is reduced. However, if one or more farms in the area persist with high-risk practices, then the risk to all farms in the area is increased.

3 WHY DO FARMERS IMPLEMENT BIOSECURITY MEASURES?

For most large farms, commercial interest dictates that the farm owners implement biosecurity measures to reduce the risk of disease, especially if they believe that their flock is in danger of being infected and that the cost of outbreaks will outweigh the investment in biosecurity measures. To make informed decisions, farmers must understand the risks posed by their farming practices, the type of measures to implement, and the likely effectiveness of the biosecurity measures they implement. These are difficult to quantify, even for those with considerable animal health expertise.

Ultimately, the amount spent on biosecurity measures by individual farmers is an economic decision similar to other decisions relating to purchase of insurance. As with other similar decisions, it is subject to the law of diminishing returns. In addition, some farmers will choose to accept the risk of a disease outbreak and continue to engage in high-risk practices that provide few impediments to the incursion and subsequent onward spread of H5N1 HPAI viruses. This can occur if the farm owner does not have the resources to invest or cannot obtain credit, if there is no disincentive or regulation forcing biosecurity measures, or if the farmer perceives the overall risk (or cost of infection) as being low. By choosing not to invest in biosecurity measures, farmers make short-term savings, but these can be easily lost through poorer productivity resulting from the introduction and persistence of other pathogens and diseases. It can also lead to loss of entire flocks if an outbreak of H5N1 HPAI occurs.

In Australia, implementation of biosecurity measures is linked to co-funding agreements between government and industry for support in handling emergency animal diseases. This provides a strong incentive for farms to put in place appropriate measures and is supported by the various producer/poultry industry groups. Recent surveys suggest that this may be having a positive effect on farm management practices, with most commercial farms implementing the required biosecurity measures (East, 2007).

In other places, such as Hong Kong SAR, farm owners are not licensed to keep poultry unless they implement certain biosecurity measures such as bird-proofing. This is coupled with enforcement of these licence conditions.

For village-level producers, the incentives to implement biosecurity measures may differ from those of large producers. These may relate more to public health issues than to concerns about production, especially given that poultry die-offs occur regularly and in many communities are accepted as the norm in low-input systems. This is an area that warrants further research.

4 RISK ANALYSIS – RISK ASSESSMENT AND RISK MANAGEMENT RELATING TO FARMS AND FARM SYSTEMS

Most biosecurity programmes are based on some form of risk analysis, which involves identifying hazards, the pathways for their entry into farms, and the effect of existing measures taken at or outside the farm to reduce (or increase) these risks. However, most of these assessments, when they occur, are informal and probably not even identified as risk analyses by farm managers when developing and implementing farm procedures.

Generic biosecurity plans and guidelines are also available for farmers through government animal health services, universities and poultry industry associations, which are then adapted by farmers to local farm conditions (see for example University of Minnesota[2], University of California[3]).

So far, there has been little use of formal risk analysis on farms, but if this technique were to be applied it could provide better information on the likelihood of breakdowns, based on existing or proposed practices. This would give farm operators and animal health authorities clear indications as to whether additional measures need to be taken to prevent disease, especially if the analysis suggests that existing procedures are associated with a high probability of disease breakdowns and spread.

The overall risk of incursion of H5N1 HPAI viruses (or other pathogens) into a specific farm is determined by a complex interaction between the levels of infection in the area (the level of hazard), which varies over time, and the likelihood of carriage of the virus into the farm.

The risk of virus incursion depends on the number of "contacts" with the world outside the farm, and the probability of each of these "contacts" involving infected or contaminated material. For example, larger farms tend to have more inputs (greater amounts of feed and greater movement of people such as catching crews and vaccination teams). However, these risks are modified by the biosecurity measures practised on-farm relating to these inputs.

Risk analysis for incursion of specific pathogens (such as H5N1 viruses) into farms in different production systems, if performed, should employ the same principles and techniques used by individual countries or states when performing import risk analysis – see OIE (2007) for details on import risk analyses. In these assessments, the farm can be considered as the "importing country" with the risk of "importing" virus depending on the level of infection in the area around the farm and the probability of virus entering the farm via each of the potential infection pathways – which in this case include animal feed, traders, wild birds, farm workers, water, day-old chicks, other items that are brought onto a farm, and direct spread of virus via dust and wind.

The risk analysis process includes hazard identification, risk assessment and risk management. The fourth component, risk communication, is used to inform farmers and workers of the need to implement appropriate biosecurity measures.

As a formal risk analysis can be costly, most enterprises would not normally opt to use this technique, even if available. The only exceptions would be large system 1 farms set-

2 http://www.ansci.umn.edu/poultry/resources/biosecurity.htm

3 http://www.vetmed.ucdavis.edu/vetext/INF-PO_Forum/checklist-2pp.pdf

ting up compartments for export, in which case importing countries would almost certainly demand a thorough and transparent risk analysis before accepting produce from the compartment. However, governments and industry groups would benefit from obtaining this type of information when devising control and preventive programmes.

Most veterinarians servicing the poultry industry have not been formally trained in risk analysis (Halvorson and Hueston, 2006), although they utilize the same scientific principles when developing biosecurity plans. To overcome this deficiency, and simplify the process of assessing risks, an exposure risk index has been developed that allows some comparison of the level of risk posed by different events and activities. This is based around the quantity of the hazardous material, the amount of pathogen in the hazardous material, the amount of this that is available (e.g. a mound of contaminated faeces versus faeces that is spread out over a field), the survival of the pathogen in the hazardous material, and the proximity of the material to susceptible poultry (ibid.). Use of this system correlates well with perceptions of veterinarians regarding the relative risk posed by various hazards, and could be an alternative to formal risk assessment.

4.1 Issues relating to hazard identification

Hazard identification is the process by which the potential threats to the area of interest (in this case, individual farms) are assessed. This is usually applied to specific pathogens, such as H5N1 HPAI viruses.

The best way to understand and identify hazards is to review the pathways that farms use for the introduction of items or people, and to assess where these come from and the likelihood of their being or becoming contaminated (fomites) or infected (poultry) along the supply chain. This assessment should also examine activities in the vicinity of the farm that might add to the risk, such as the presence of other farms or flocks of poultry, slaughter plants, processing plants or markets; the management procedures in place in these enterprises; and their sources of poultry or poultry meat. Market value chain analyses help to provide this information by identifying high-risk practices; this helps to overcome some of the constraints associated with disease surveillance discussed below.

Hazard identification for H5N1 HPAI in many infected developing countries is hampered by the limited availability of surveillance data. Generally speaking, these data do not provide accurate information on the infection status in any given place or area. Disease reports provide some indication of the levels of infection. However, active surveillance studies, when performed, have shown that "passive" disease reports underestimate the prevalence of infection, as clinically silent infection can occur (e.g. in ducks) and not all cases of disease suggestive of HPAI are reported to authorities. Even when active surveillance is done, it usually only gives an indication of presence of virus (if, in fact, virus is detected) in certain areas at a particular point in time.

Even when surveillance studies are undertaken, negative results do not necessarily prove the absence of infection. For example, serological studies in unvaccinated chickens are of limited value for detecting past exposure to H5N1 HPAI in a flock, due to the high case-fatality rate in infected poultry (Sims *et al.*, 2003), and virological surveillance on apparently healthy chickens on farms is insensitive due to the limits on the number of samples that can be processed. Wild-bird surveillance on healthy live birds has failed to detect virus in most places where this has been done, even in places where wild birds are known to have played a role in virus transmission. As a consequence, low-level infection, such as might occur in the early stages of an outbreak in a farm or in a flock of wild birds, can remain undetected.

Seasonal effects also need to be considered in assessing surveillance data. The levels of circulating virus can vary depending on the weather conditions (e.g. longer survival of virus in cool weather) and other factors such as the number of susceptible poultry being reared in the vicinity. Poultry numbers can increase prior to festivals as producers rear more poultry to take advantage of increased demand and prices. They can also increase dramatically just prior to rice harvests when additional ducks are bred to graze harvested rice paddies. Periods of wild-bird migration can also be associated with increased levels of influenza viruses in a given area.

The location and species affected are also crucial. If infection with influenza viruses is confined to wild birds, then those farms that prevent or limit direct and indirect contact between wild birds and poultry are less likely to become infected than those that do not practise these preventive measures. However, once infection is established in poultry, it is generally accepted that spread of virus is more likely to occur by contacts within the poultry industry.

In conducting a hazard analysis it needs to be recognized that infection with H5N1 HPAI will not normally persist in a flock of chickens for an extended period of time unless there is regular replenishment of susceptible poultry to the flock during the period it is infected. If there are no populations of birds in which the virus can persist, then the disease is relatively easy to contain and may even self-extinguish (at least until the next virus incursion to the area).

By contrast, live-poultry markets, where there is a constant inflow of poultry, and where a transient population of poultry is kept for more than 24 hours, provide ideal sites for perpetuation of avian influenza viruses (Kung *et al.*, 2003). Similarly, duck flocks can probably remain infected for an extended period of time. Experimental studies suggest that individual ducks probably only excrete virus for several weeks (Hulse-Post *et al.*, 2005), but the virus would likely take longer to transmit through an entire flock. Longevity of infection in a duck flock is also expected to increase if there is regular introduction of new susceptible birds.

As the level of threat varies over time, a two-level biosecurity system has been promoted in some places. This involves the use of a standard set of biosecurity measures under normal conditions, but enhanced biosecurity measures (in which farm inputs and visits are severely curtailed) when the threat increases, such as when new cases of infection have recently been diagnosed in the area around the farm (see, for example, OMAFRA, 2005). This works well when a disease is notified early, but in a number of cases in Asia, disease was already widespread before it was detected or reported, somewhat reducing the value of such a system.

4.2 Risk assessment

Risk assessment applied to farms should comprise a release assessment (i.e. what is the likelihood that virus outside the farm will get in to the farm?) and an exposure assessment (what is the likelihood that virus once inside the farm will actually infect and cause disease in poultry?). Both are influenced by management systems employed on farms to reduce these risks. These are combined with an assessment of consequences to provide an overall assessment of risk. In the case of H5N1 HPAI in fully susceptible chickens, the consequences of infection are extremely serious due to the high rates of mortality produced and the losses arising from culling affected and in-contact poultry by veterinary authorities when the disease is reported.

The risk assessment should take account of existing risk-reduction measures as well as any proposed measures.

4.3 Release assessment

The main pathways that can lead to incursion of avian viruses into farms are well known (Halvorson and Hueston, 2006), and include: visitors, such as traders and work crews; manure haulage; dead-bird pick-up; off-farm labour; egg collection; allowing free ranging of poultry if this results in sharing areas with other poultry or wild birds; use of untreated water from ponds or rivers for drinking, cleaning or cooling; use of raw (not heat treated) animal feed and poor handling of feed; poor rodent control; introduction of new stock without appropriate quarantine and hygiene measures; and access of wild birds to poultry sheds, feed or water supplies.

Although it may not be possible to quantify all of these risks, several important principles apply. First, the level of risk is determined by the frequency of the event. Therefore, high-risk daily activities are often of greater consequence than similar activities that occur only a few times a year. In addition, the risks posed by these activities are influenced by the measures put in place to address them and the degree of compliance with these measures.

For example, if farm workers live off-site then they should be required to change their clothing and possibly shower when entering the farm. If this is done properly, the risk associated with this activity is lowered.

Another point to note is that the results of one survey, involving self-assessment of biosecurity measures and subsequent cross-checking by field observations, demonstrated marked differences between the perceptions of farmers regarding the biosecurity measures on farms, as recorded in a survey, and the situation on the ground (Nespeca *et al*., 1997). This suggests that independent audits of biosecurity procedures are valuable in ensuring that measures are being implemented.

A hazard profile can be developed for each individual farm (as shown in the hypothetical example in Table 2) based on the source of the inputs and the likelihood that these are contaminated. This uses a qualitative assessment of risk, but if appropriate data are available, a quantitative assessment should be conducted.

4.4 Exposure assessment

The effect of incursion of H5N1 HPAI virus into a flock of poultry depends on the susceptibility of the species reared (e.g. turkeys have been shown to be more susceptible than chickens), the method of rearing and the mode of introduction. For example, in the case of virus introduced to a poultry house on footwear, birds on litter are generally at higher risk of exposure to the pathogen than those in cages.

TABLE 2
Hypothetical hazard profile for a poultry farm

Pathway	Factors affecting level of hazard	Release assessment
Day-old chicks	No known infection in the province where the farm sources day-old chicks. All chicks are delivered in new cardboard containers. The vehicle used to transport the day-old chicks is fumigated daily and goes through a disinfectant bath before entering the farm.	Negligible
Animal feed	Bulk heat-treated feed from a single company. No feed vehicle enters the premises – transfer of feed over boundary fence.	Negligible
Wild birds	A few starlings and sparrows have been found within sheds two weeks previously. Repairs have been made to bird proofing. No major bodies of water on the farm to attract wild birds. Nearest permanent watercourse 2 km away.	Low
Water	Drinking and cooling water from a bore.	Negligible
Tradespeople	Farm staff conduct all repairs.	Negligible
Catching crews	All birds in one shed are sent to slaughter on a single day using own staff.	Negligible
Vaccinators	No outside workers vaccinate.	Negligible
Traders	All trading done by telephone. No company representatives allowed on premises.	Negligible
Local spread	No farms within 1 km.	Negligible
Dead bird disposal	Composted on site.	
Links to live poultry markets	All sales direct to slaughterhouse in farm vehicles.	Negligible
Farm workers	Farm workers are not allowed to keep poultry or visit places where poultry are kept. All staff must change clothing on entry to the farm.	Low
Veterinarian	One routine visit per month. Must change clothes and shower on entry. No contact with other poultry allowed within the previous 24 hours.	Low
Faeces	Composted on site.	Negligible
Fencing/security	Farm securely fenced and entry gate locked at all times.	Negligible
Rodents	Regular programme of rodent baiting. Grass kept low around barns.	Negligible
Neighbouring farm	Nearest chicken farm is 3 km away. Village 1.5 km away with several non-commercial flocks of chickens.	Negligible
Other (markets roads, slaughterhouses, etc.)	One major road used by poultry vehicles approximately 1 km away. Nearest slaughterhouse 7 km away. No live poultry markets within 50 km.	Negligible

Consequences of exposure are modified by the use of vaccines, which can increase resistance to infection and also reduce Ro (case reproduction number) below 1 (van der Goot *et al*., 2005), preventing onward transmission in a flock. Vaccination has been the main method used in a number of places, including Hong Kong SAR, to increase resistance and reduce the effects if virus enters a farm, (Sims, 2007).

The stocking density of poultry in a farm can also influence the size of the outbreak. Infection can be self-limiting in scavenging poultry flocks kept at low density, and may not affect all poultry in the flock, especially if these are not housed close together at night.

Airborne spread (if it occurs) or introduction of virus via feed or water could result in a more rapid increase in the levels of disease if multiple poultry are exposed simultaneously compared with the slow onset associated with exposure of a single bird or small number of birds.

4.5 Risk management

Once the risk assessment is completed, the risk of infection is established, and the implications of various measures are determined, farmers and veterinarians should then make appropriate changes to existing biosecurity systems.

For some farms, the risk of virus incursion in the current location will be deemed to be so high that the only alternatives are to relocate the farm or to use other measures such as prophylactic vaccination to minimize the risk associated with exposure to virus once it enters the flock.

4.6 Farm biosecurity and Hazard Analysis and Critical Control Points (HACCP)-type procedures

Farm biosecurity measures lend themselves to methods based on HACCP-type management. HACCP is based around identification of key hazards, and determining critical control points along the production pathway, at which these hazards are monitored and corrective action taken if problems are detected (see, for example, Grimes and Jackson, 2001). Use of HACCP-type procedures when developing individual farm-biosecurity plans, also facilitates auditing by independent parties.

All commercial farms should have a biosecurity plan. This can range from a very simple plan for a system 3 farm to a full manual of procedures for a system 1 integrated operation.

5 BIOCONTAINMENT

So far, this paper has concentrated on measures used to limit the entry of pathogens onto farms, which reflects the view of most farmers when it comes to disease prevention. This focus on preventing pathogens from gaining entry to farms is probably based on the belief that there is more benefit to individual farmers in reducing the risk of introduction than in trying to deal with the consequences after it has occurred.

There is a public-good element in biocontainment which owners of individual units may choose to ignore. Once infection occurs on a farm, little direct benefit accrues to individual farm operators if they implement biocontainment measures. This benefit is a collective one distributed to all players in the industry (see the discussion on the Nash equilibrium presented by Otte *et al*., in FAO, 2007b).

Biocontainment is also imposed on farms by animal health authorities once disease is reported. This is usually achieved through combinations of movement restrictions and culling affected poultry.

Larger multi-barn farms are more likely to consider issues relating to biocontainment, as the effects of the transmission of infection from one shed to the other sheds can be significant. However, geographical and financial constraints and land-tenure issues often dictate the location and degree of separation of individual barns on farms, and distance from other farms, leading to compromises in biosecurity.

A study of poultry farms in Australia found that one of the key risk factors for seropositivity for Newcastle disease virus was proximity to other farms. This suggested that airborne spread may have been involved, although other horizontal links between these farms could not be ruled out (East *et al.*, 2006).

Many modern enclosed poultry houses require forced ventilation to ensure the welfare of the housed poultry. The large extraction fans used can blow plumes of dust from inside sheds over considerable distances. It is still not clear whether avian influenza viruses survive in dispersed dust from farms, but this potential risk needs to be considered especially when farms are located close together (Power, 2005). Local spread of HPAI has been reported in some outbreaks (Brugh and Johnson 1986) even though avian influenza viruses are not normally considered to be spread over more than a few metres by air. Whether this local spread is due to airborne particles, flies, transfer by small birds (e.g. starlings) or local movement of people involved in control operations is yet to be determined.

When dealing with agents that can be spread by air, careful choice of the site of farms is required. Airborne spread cannot be prevented through adjustments to management on existing farms in areas with high concentrations of poultry farms (Shane, 1997).

Biocontainment depends on early diagnosis and action on infected farms. However, infection with H5N1 HPAI viruses can be present for seven days or more before being recognized in unvaccinated flocks (and possibly longer in vaccinated flocks, assuming only partial flock immunity) due to the lag phase between virus introduction and spread to sufficient numbers of poultry to cause a significant increase in mortality. This can lead to inadvertent transmission of infection if these poultry or products from them are sold. This is compounded by some farmers deliberately selling flocks that are known to be infected during the early stages of outbreaks (the short window between the first few fatal cases of disease and high rates of mortality has been exploited by observant farmers who, on detecting a slight increase in mortality, sell poultry before the disease spreads within their flock).

To overcome these problems, preventive biocontainment measures should be in place before infection occurs. This should cover issues such as farm density, direction of ventilation outputs, manure handling and dead-bird disposal. However, as these preventive measures may not be implemented voluntarily, it may be necessary to drive their implementation through the use of appropriate, enforceable regulations controlling density of farms (perhaps through a moratorium on building new farms within a certain distance of existing farms and closure (with compensation) of existing farms to reduce density) and rules for the disposal of waste material and carcases.

In areas where the risk of incursion and subsequent transmission is high, it is reasonable to use prophylactic vaccination both to reduce the likelihood of infection and to reduce excretion of virus if infection occurs. This approach has been applied in Italy and Hong Kong SAR.

Not surprisingly, larger farms have more outputs than smaller ones, including quantities of poultry and manure/litter (Otte *et al*., in FAO, 2007b). Therefore, large farms that do not implement appropriate biocontainment measures, such as on-site composting of manure before removal from the farm, can pose a high risk to other farms in the area, if they become infected.

6 METHODS FOR MINIMIZING RISK OF INFECTION INTO AND OUT OF FARMS

The general consensus, emerging from a UN technical workshop held in Rome in June 2007 (FAO, 2007d) was that many high-risk commercial practices, involving both marketing and production of poultry, exist in countries enzootically infected with H5N1 HPAI, and also in those at risk of becoming so. These practices are not restricted to any one production system.

When developing disease-control programmes, high-risk practices in all production systems should be identified and, where appropriate and feasible, modified over time. However, consideration should be given to the potential adverse effects (environmental, social, gender and economic) of any proposed changes before any significant modifications are made. Support should be provided to vulnerable members of communities disadvantaged by enforced changes. If changes to production and marketing practices are impractical, alternative disease-control measures will need to be implemented.

None of the above implies that all poultry must be housed or reared under intensive, industrial conditions.

The following section provides some suggestions on ways to enhance biosecurity in farms in each production system.

System 1

The best way to minimize risk to and from system 1 farms is to locate these away from other farms and to have clear, audited working procedures for ensuring high-level biosecurity.

Some biosecurity guides provide general guidance on appropriate separation for poultry farms and individual barns on farms (see Millar, 2004). These are of limited value for places with pre-existing farms, where the only way to apply these guidelines is through closing some of these farms. Nevertheless, if certain areas appear to have excessively high concentrations of poultry, bans on new farms in these areas are warranted, and provision of incentives for existing farms to close or relocate may be justified.

By definition, these farms already implement high-level biosecurity measures. However, these can be strengthened through compartmentalization, in which all inputs are tightly controlled and contacts with farms and suppliers outside the compartment are largely severed, so that all farms and related downstream and upstream units, such as feed suppliers and slaughterhouses in the compartment, can be defined as discrete epidemiological units.

To ensure biosecurity systems are operating properly, regular independent audits, daily compliance checks and implementation of HACCP systems will provide greater assurance of the measures implemented.

Most system 1 farms sell poultry through slaughterhouses rather than through live poultry markets; this reduces the risk of infection especially if the slaughterhouse does not receive poultry from other farms.

System 1 farms should implement regular targeted surveillance to demonstrate ongoing freedom from infection.

Often these farms self-regulate, and it is better for some overseeing of biosecurity measures to be provided by official veterinary services.

System 2

System 2 farms vary in the quality of their biosecurity measures. One option to strengthen these is to put in place specific standards that have to be met through farm licenses or permits, as is used in Hong Kong SAR. This must be backed by appropriate enforcement.

This can also be done through restrictions placed on access to markets, so as to only include farms meeting certain conditions, such as biosecurity standards.

Use of schemes such as that operating in Australia, where application of specific biosecurity measures is a requirement for participation in government cost-sharing arrangements in the event of serious disease outbreaks, also warrants consideration.

In places where system 2 farms sell poultry through poorly regulated live-poultry markets, attention should be paid to reducing the risk posed by these markets through improving management and hygiene and enhancing traceability and certification for poultry entering these markets (however, conditions for issuance of certificates must be scientifically sound and properly designed so as to actually reduce risk – this is not the case with much of the current certification in Asia).

As with system 1 farms, relocation may be required if the farm is located in an area where there are many other farms and the risk of infection is high. Independent biosecurity audits should be conducted to assess compliance with biosecurity plans and standards.

System 3

This paper has argued that system 3 farms are considered to be at high risk of virus incursion because of the lack of biosecurity measures and, in many cases, their links to poorly controlled live-bird market systems.

These farms often do not incorporate biosecurity measures appropriate to the level of risk of a breakdown. This raises a number of questions about these practices. First, increasing the size of a poultry flock from (system 4) backyard production to small-scale commercial production has allowed many disadvantaged people (especially women) to move out of poverty by taking advantage of the high returns potentially available from poultry rearing. However, this creates an externality if there is no regulation of biosecurity standards for these farms.

One solution is to modify production and biosecurity systems on these system 3 farms so that they become system 2 farms. However, this requires changes in management systems (full dependence on purchased feed) and, possibly, changes in the breed(s) reared to those amenable to intensive production. It also requires considerable investment in facilities. For many this is not economically or technically feasible.

This process can be driven by urban markets that demand "clean" certified produce.

At present this reduces opportunities for smallholders in system 3 to market their produce through legitimate channels. Small, independent system 3 farms will probably struggle to meet these market demands. Nevertheless, there is potential to develop "clean" villages or communes if all poultry-rearing households in these locations agree to restrictions on the entry of poultry and middlemen, and on methods of marketing; other disease control and preventive measures (such as vaccination); and submit to regular surveillance testing. This would require full cooperation from all poultry rearing households and community animal health workers in the commune as well as traders and others who visit. This is a relatively new concept that warrants further exploration.

Other options available for those farms that cannot upgrade are segregation of species (a major challenge in many rural areas), vaccination, small behavioural changes by poultry rearers (e.g. changing footwear before entering poultry enclosures, and not allowing visitors to enter premises) and indirect measures that reduce levels of infection in markets through better management, which reduces the likelihood of poultry traders inadvertently transporting virus from markets to farms.

Where changes to management cannot be implemented (e.g. grazing ducks in Viet Nam) there will likely be ongoing reliance on vaccination, coupled with movement controls.

System 4

Similar measures to those proposed for system 3 can also be adopted for system 4 flocks, in particular the behavioural changes that do not require investment in facilities. There has been a push towards confinement of scavenging poultry, but this may not be feasible for flocks in which the main advantage is the "free" feed obtained through scavenging.

Again, if husbandry methods can't be changed, then other means to protect these poultry must be found, such as vaccination or better control of disease in production systems 1, 2, and 3, which will reduce the risk to these flocks (except in places where wild birds are playing a significant role in the spread of disease).

7 CONCLUSIONS

This paper has demonstrated that our knowledge of the role of different production systems in the persistence and spread of H5N1 HPAI viruses remains poor, due to a lack of detailed studies and investigations of outbreaks. This could be improved through use of formal risk assessments on a selection of farms in different production systems, and better case investigations.

Farms in all production systems have been affected by H5N1 HPAI, and appropriate measures need to be taken in all four systems to prevent infection and onward transmission of these viruses.

System 1 farms face risks because of their size, and sometimes their international trading practices, but these are mitigated by implementation of high-level biosecurity measures. System 2 farms vary markedly in their susceptibility to infection, depending on their location, the quality of their biosecurity measures and the method they use to sell poultry. Some lower-level system 2 farms represent a significant risk. If system 1 or system 2 farms are infected, there is a high probability of subsequent local spread of infection, depending on the density of farms in the vicinity. System 3 production is deemed to represent the highest risk for incursion of H5N1 viruses, because in many parts of the world most sales from these farms are through live-poultry markets, and farm biosecurity measures are poor. System 3 production also includes grazing ducks, which are believed to have played a critical role in the genesis of the H5N1 HPAI panzootic. System 4 flocks are small and in some cases may already be largely segregated from the commercial sector – which offers some protection from infection.

If HPAI caused by Asian lineage viruses of the H5N1 subtype is to be contained, and perhaps even eliminated, all farms will be required to implement appropriate measures to minimize the risk of virus incursions and subsequent spread to other farms. This will require concerted efforts by animal health authorities and the private sector.

In many farms there is still a mismatch between the risk of infection and the biosecurity measures in place. This can be overcome by enhancing the biosecurity of farms using measures appropriate to the production system and/or by increasing resistance of poultry through vaccination and other control measures. Ultimately, this is a decision that has to be made by individual farm owners, but it can be guided by government regulations and quality information about the risks associated with different production systems and ways to overcome them.

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Poultry production and the environment – a review

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SUMMARY

Over the past decades, the poultry sector's growth and trends towards intensification and concentration have given rise to a number of environmental concerns. A direct consequence of these structural changes (industrialization, geographical concentration and intensification) in poultry production is that far more waste than can be managed by land disposal is produced, resulting in environmental problems. This paper analyses the environmental impacts arising from intensive poultry production, evaluating such impacts across the food chain and all environmental media. The paper also presents technical options to mitigate environmental impacts, such as improvements to farm management, animal-waste management and nutrition management, along with options to reduce the impacts of intensive feed production.

Key words: poultry, intensification, future, climate

1 INTRODUCTION

Over recent decades the poultry industry has made tremendous adjustments to meet the increasing demand for inexpensive and safe supply of meat and eggs. Over the past three decades, the poultry sector has been growing at more than 5 percent *per annum* (compared to 3 percent for pig meat and 1.5 percent for bovine meat) and its share in world meat production increased from 15 percent three decades ago to 30 percent currently (FAO, 2006a).

This growth has been accompanied by structural changes within the sector, characterized by the emergence and growth of "land-independent" (industrial) farming establishments, and the intensification and concentration of poultry operations. Pressure to lower production costs and increase supply has led to more efficient operations, made possible through the shift to larger, specialized and more integrated facilities, and through improvements in the use of animal genetics, optimized nutrition and new production technologies. The driving forces behind structural change in poultry production are no different than those that affect other livestock commodities: market pull, innovation and economies of scale. Innovation and economies of size that characterize the livestock sector have also served to separate animal production from crop production. Large, specialized facilities today focus on producing animals, and purchase most of their feed. This often means that there is limited access to land on which to spread manure.

The use of large facilities associated with higher concentrations of poultry, has given rise to environmental concerns that are not only limited to the local production settings, but extend to environmental problems at regional and global scales. The obvious, and often limited, impacts observed at production-site level, thus, tend to obscure much larger impacts on the regional and global environment. In this paper we therefore analyse the sector's impacts by zooming out across the three spatial scales. Furthermore, the use of a scale approach is a useful structure for the analysis of environmental impacts because it directly links the outcomes of the review to the policy interventions that are required at the various levels (farm to international).

This paper also adopts the food-chain approach, analysing the environmental impacts arising from poultry production, and evaluating such impacts all the way from feed production to animal production and slaughtering. It considers impacts on all environmental media – air, water and land, at local, regional and global scales. The issue of disease transmission from/to wildlife populations is, however, omitted as other papers in these proceedings discuss this topic.

The next section will give an overview of environmental issues at the level of production and processing (Section 2). We then present an in-depth analysis of the impacts of poultry production as the sector intensifies in certain preferred areas (Section 3). Section 4 deals with global environmental issues associated with the poultry sector. We then briefly present technical options (Section 5), followed by conclusions (Section 6).

2 ISSUES AT THE LEVEL OF PRODUCTION AND PROCESSING UNITS

This section provides an overview of environmental concerns at the local level, arising from two point sources: the animal production site and the abattoir. At this level, impacts are usually directly observed by farmers, neighbours and policy-makers.

2.1 Animal production units

Local disturbances (e.g. odour, flies and rodents) and landscape degradation are typical local negative amenities in the surroundings of poultry farms. Pollution of soil and water with nutrients, pathogens and heavy metals is generally caused by poor manure-management and occurs where manure is stored. Water and soil pollution related to poultry litter is, however, generally not an issue at the production site, as poultry manure is only directly discharged into the environment in exceptional conditions. Indeed, the high nutrient content and low water content of poultry litter make it a valuable input to agriculture. Manure is either recycled on cropland belonging to the animal farm or marketed. In the usual set-up, an intermediary or a processor collects manure from poultry farms. Manure is either resold rough or processed into compost or pellets. Manure products are used as fertilizer, or as animal feed especially for fish and cattle.

In south Viet Nam, the authors observed that end users may be located as far as 300 km from the animal farm where manure is produced. An intermediary will sell manure to the group of users with highest willingness to pay, which can change throughout the year, and from year to year, according to the cropping calendar and the economic conditions. Manure price at the animal-farm gate varies with its pureness (presence of litter) and water content and with the season (demand). On average, 20 kg bags of fresh chicken manure without litter are sold for VND4 000 to 6 000 while 20 kg bags of manure with litter are sold for VND1 500 to 2 000.[1]

Local disturbances

Poultry facilities are a source of odour and attract flies, rodents and other pests that create local nuisances and carry disease. Odour emissions from poultry farms adversely affect the life of people living in the vicinity. Odour associated with poultry operations comes from fresh and decomposing waste products such as manure, carcasses, feathers and bedding/litter (Kolominskas *et al*., 2002; Ferket *et al*., 2002). On-farm odour is mainly emitted from poultry buildings, and manure and storage facilities. Odour from animal feeding operations is not caused by a single compound, but is rather the result of a large number of contributing compounds including ammonia (NH_3), volatile organic compounds (VOCs), and hydrogen sulphide (H_2S) (IEEP, 2005). Of the several manure-based compounds which produce odour, the most commonly reported is ammonia. Ammonia gas has a sharp and pungent odour and can act as an irritant when present in elevated concentrations.

Odour is a local issue, which is hardly quantifiable; the impact greatly depends on the subjective perception of populations neighbouring the farm. It is, therefore, difficult to evaluate the maximum distance over which odorous gas travels; however, odour problems are generally concentrated within 500 metres of the farm. Although generally not causing any public-health concern, odours can represent a strong local problem that is frequently reported by farms' neighbours as the most disturbing environmental impact. The emission of odours mostly depends on the frequency of animal-house cleaning, on the temperature and humidity of the manure, on the type of manure storage, and on air movements. For these reasons it is generally higher in waterfowl farms than in chicken farms.

Flies are an additional concern for residents living near poultry facilities. Research conducted by the Ohio Department of Health indicated that residences that were located in close proximity to poultry facilities (within half a mile[2]) had 83 times the average number of flies. In addition to the nuisance they cause, flies and mosquitoes can transmit diseases, such as cholera, dysentery, typhoid, malaria, filaria and dengue fever. Although less often reported than flies and mosquitoes, rats and similar pests are also a local nuisance associated with poultry production. As with flies and mosquitoes, they can be a vector for disease transmission. Their presence is mainly related to animal-feed management and especially to storage and losses from feeding systems.

Pesticides used to control pests (e.g. parasites and disease vectors) and predators have been reported to cause pollution when they enter groundwater and surface water. Active molecules or their degradation products enter ecosystems in solution, in emulsion or bound to soil particles, and may, in some instances, impair the uses of surface waters and groundwater (World Bank, 2007).

Land use and landscape

The trend to larger production units, and their regional concentration, certainly has the potential to adversely affect surrounding land use and the appearance of the landscape.

[1] VND = Vientamese dong.

[2] Approximately 800m.

Massive industrial poultry installations can create an adverse aesthetic impact. Impact on land use in highly concentrated areas is manifested through conflict with development needs and in some areas with rural tourism.

Poultry carcass disposal

Improper disposal of poultry carcasses can contribute to water-quality problems especially in areas prone to flooding or where there is a shallow water table. Methods for the disposal of poultry carcasses include burial, incineration, composting and rendering. In the case of recent highly pathogenic avian influenza (HPAI) outbreaks, the disposal of large numbers of infected birds has presented new and complex problems associated with environmental contamination. Large volumes of carcasses can generate excessive amounts of leachate and other pollutants, increasing the potential for environmental contamination.

Buried birds undergo a decomposition process. During this process, nutrients, pathogens and other components of the carcass are released into the environment. As these substances enter the surrounding soil, they may be broken down, transformed, lost to the air, or otherwise immobilized so that they pose no environmental threat. However, there is a possibility that some constituents may eventually contaminate soil, groundwater and surface water (Freedman and Fleming, 2003). Another related problem is the removal of manure from houses that contain infected birds.

Ritter *et al.* (1988) examined the impact of dead-bird disposal on groundwater quality. They monitored groundwater quality around six disposal pits in Delaware. Producers in Delaware were using open-bottomed pits for their day-to-day mortality disposal. These pits are not strictly the same as burial pits, though there are some similarities. Most of these

BOX 1:

Pollution issues resulting from culling campaigns

There is no clear overview of environmental issues associated with culling campaigns. Punctual observations, however, hint that they may be substantial. In Egypt, about 13 millions birds were culled and buried as part of the control measures implemented in response to the HPAI outbreak. We assume an average weight of 1 kg per bird, and estimate that this amounts to the burial of 13 million kg of fresh organic matter. Water resources are particularly at risk as the animals were buried in areas of shallow water and high human population (310 inhabitants/km^2 on average).

Following the recent avian influenza outbreak in Viet Nam, birds were culled and buried next to land used for human food production. The culling site itself was over a kilometre from the affected farm.

In Nigeria, a UNDP study (2006) found there was no adherence to any standard with regard to the location or the depth of the pits dug for the burial of carcasses. In some villages, the carcasses were thrown randomly into nearby bushes or open dump sites.

pits were located in sandy soils with high seasonal water tables. The potential for pollution of groundwater is high with this method of disposal. After selecting the sites, two to three monitoring wells were placed around each pit to a depth of 4.5 metres. Ammonia concentrations were high in two of the wells. Three of the disposal pits caused an increase in ammonia concentrations in the groundwater. Total dissolved solids concentrations were high in all monitoring wells for most dates. Bacterial contamination of groundwater by the disposal pits was low.

2.2 Slaughterhouse

The most significant environmental issue resulting from slaughterhouse operations is the discharge of wastewater into the environment. Like many other food-processing activities, the necessity for hygiene and quality control in meat processing results in high water usage and consequently high levels of wastewater generation (IEEP, 2005). Poultry processing activities require large amounts of high-quality water for process cleaning and cooling. Typical water usage in poultry slaughterhouses ranges between 6 and 30 cubic metres per tonne of product. Large quantities of water are consumed in poultry slaughterhouses for evisceration, cleaning and washing operations (EU, 2003).

Process wastewater generated during these activities typically has high biochemical and chemical oxygen demand (BOD and COD[3]) due to the presence of organic materials such as blood, fat, flesh, and excreta. In addition, process wastewater may contain high levels of nitrogen, phosphorus, and residues of chemicals such as chlorine used for washing and disinfection, as well as various pathogens including *Salmonella* and *Campylobacter* (World Bank, 2007). Poultry by-products and waste may contain up to 100 different species of micro-organisms, including pathogens, in contaminated feathers, feet and intestinal contents (Arvanitoyannis and Ladas, 2007). Typical values for wastewater produced from poultry processing are 6.8 kg BOD per ton live weight killed (LWK) and 3.5 kg suspended solids per ton of LWK (de Haan *et al*., 1997).

Poultry slaughterhouses release large amounts of waste into the environment, polluting land and surface waters as well as posing a serious human-health risk. The discharge of biodegradable organic compounds may cause a strong reduction of the amount of dissolved oxygen in surface waters, which in turn may lead to reduced levels of activity or even death of aquatic life. Macronutrients (nitrogen, phosphorus) may cause eutrophication of the affected water bodies. Excessive algal growth and subsequent dying off and mineralization of these algae may lead to the death of aquatic life because of oxygen depletion (Verheijen, *et al*., 1996).

Slaughterhouses are usually located in urban or peri-urban locations, where transport costs to markets are minimized and where there is abundant labour supply. This situation increases the risk of environmental impacts: first, because slaughterhouses often lack the land required to set up waste-management facilities; second, because the pollutants that

[3] The Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are parameters that give an indication of the concentration of organic compounds in wastewater. Their calculation is based on standardized chemical procedures for determining how fast biological organisms use up oxygen in a body of water. The concentration of suspended solids represents the amount of insoluble organic and inorganic particles in the wastewater (Verheijen *et al.*, 1996).

are emitted add to those emitted by other human activities; and third, because neighbouring communities are directly affected by surface-water and groundwater contamination.

3 WATERSHED-LEVEL POLLUTION ASSOCIATED WITH WASTE MANAGEMENT

Intensification of production and the geographical concentration of production units often results in environmental concerns. The decoupling of crop and livestock production through the migration of livestock production away from crop activities into areas with little or no agricultural land leads to high levels of environmental impact – mainly related to manure mismanagement and nutrient overloads (Naylor *et al*., 2005).

3.1 Poultry manure

Poultry manure contains considerable amounts of nutrients such as nitrogen, phosphorus, and other excreted substances such as hormones, antibiotics, pathogens and heavy metals which are introduced through feed (Steinfeld *et al*., in FAO, 2006b). Leaching and runoff of these substances has the potential to result in contamination of surface water and groundwater resources.

Nutrients

Animals reared in intensive production systems consume a considerable amount of protein and other nitrogen-containing substances in their diets. The conversion of dietary nitrogen to animal products is relatively inefficient; 50 to 80 percent of the nitrogen is excreted (Arogo *et al*., 2001). Nitrogen is excreted in both organic and inorganic compounds. Nitrogen emissions from manure take four main forms: ammonia (NH_3), dinitrogen (N_2), nitrous oxide (N_2O) and nitrate (NO_3^-).

Phosphorus is an essential element for animal growth. Unlike nitrogen, phosphorus is relatively stable once attached to soil particles and does not leach through the soil into groundwater. It does not pose any environmental risks except as a nutrient; it limits biological activity in water resources and builds up in soil when applied in excess. Phosphorus emissions from manure occur in one main form: phosphate (P_2O_5).

Heavy metals

Manure contains appreciable quantities of potentially toxic metals such as arsenic, copper and zinc (Bolan *et al*., 2004). In excess, these elements can become toxic to plants, can adversely affect organisms that feed on these plants, and can enter water systems through surface run-off and leaching (Gupta and Charles, 1999). Trace elements are introduced into poultry diets either involuntarily through contaminated feedstuffs or voluntarily, as feed additives used to supply animals' requirements or – in much greater proportions – as veterinary medicines or growth promoters.

Drug residues

Antimicrobial agents are administered to poultry for therapeutic reasons or to prevent illness (prophylaxis). At much lower doses (subtherapeutic doses) antimicrobial agents are used as feed additives to increase the rate of growth and to improve feed efficiency (Campagnolo *et al*., 2002; Steinfeld *et al*., in FAO, 2006b). Irrespective of dosage, an estimated 75 percent of antimicrobial agents administered to confined poultry may be excreted back into the environment (Addison, 1984). Recent evidence suggests that the interaction between bacterial organisms and antimicrobials in the environment may contribute to the development of antimicrobial-resistant bacterial strains (Chee-Stanford *et al*., 2001). Campagnolo *et al*. (2002), in a study that evaluated the presence of antimicrobial compounds in surface water and groundwater resources proximal to intensive poultry operations in Ohio, found antimicrobial residues to be prevalent – present in 12 water samples (67 percent) collected proximal to poultry farms.

In the United States of America, overall use of antimicrobials for non-therapeutic purposes in animals rose by about 50 percent between 1985 and 2001. This was primarily driven by increased use in the poultry industry, where non-therapeutic antibiotic use increased from 2 million to 10.5 million pounds (907 185 kg to 4 762 720 kg) between the 1980s and 2001 – which amounted to a dramatic 307 percent increase on a per-bird basis (Mellon *et al*., 2001).

Pathogens

Manure also contains pathogens which may potentially affect soil and water resources, particularly if poorly managed. Parasites such as *Cryptosporidium* and *Giardia* spp. can easily spread from manure to water supplies and can remain viable in the environment for long periods of time (Bowman *et al*., 2000).

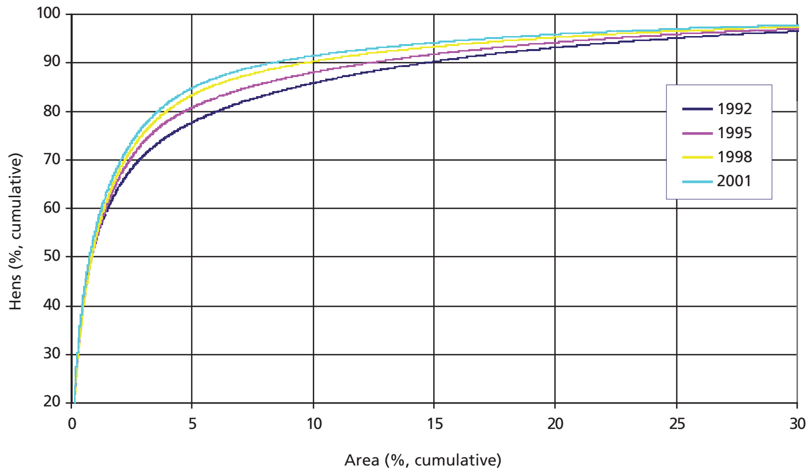
3.2 Regional concentration of production

The trend toward clustering of poultry production in certain preferred locations is ongoing in developed as well as developing economies. An analysis of hen populations at municipio level in Brazil, for example, shows an increasing concentration during the period 1992 to 2001 (see Figure 1). In 1992, 5 percent of the country's total area hosted 78 percent of the chicken population, while in 2001 the same area was home to 85 percent of the population.

Clustering is a process of geographic concentration of production units. This gives rise to groups of interconnected producers, feed mills, slaughterhouses and processing units. Clustering is driven by economies of agglomeration – the benefits that individual units obtain when they locate close to one another. Basically, the more related units clustered together, the lower the unit cost of production and the larger the market that individual units can sell into. In the livestock sector, lower production costs are achieved through competition among suppliers of inputs (e.g. feed mills, veterinary and other services), and specialization and division of labour among producers (e.g. breeding operations, fattening operations and contract farming). If a well-developed transport infrastructure supports this set-up, supply to urban and export markets is often very competitive.

Intensive production, therefore, concentrates in areas favoured by cheap inputs (particularly feed) and services, and by good market outlets for livestock products. Such conditions are found in the vicinity of cities, feed processors and large slaughterhouses, as well as harbours trading feed and animal products. The geographical location of intensive poultry activity is, thus, less and less linked to agricultural and land-use parameters. In other words,

FIGURE 1
Changes in the geographical concentration of chickens in Brazil from 1992 to 2001



poultry production is shifting from agricultural use of the land, based on biophysical criteria (e.g. soil quality, climate, length of growing period) towards industrial use of the land.

3.3 Environmental issues

Gerber *et al*. (2005) summarize some of the major potential impacts of intensive livestock production on land and water resources:

- eutrophication of surface waters, caused by the input of organic substances and nutrients either through wastewater from production, runoff or leakages from storage and handling facilities – affecting aquatic ecosystems and drinking water quality;
- leaching of nitrate, and possible pathogen transfers to groundwater – affecting the quality of drinking water;
- accumulation of nutrients and other elements in soil due to continuous application of excess quantities of manure; and
- impacts of pollution on nutrient-sensitive ecosystems resulting in biodiversity losses.

In most cases, structural changes in the production system have a rather negative impact on manure management practices. In particular, growth in the scale of production and geographical concentration in the vicinity of urban areas, cause dramatic land–livestock imbalances, hampering manure recycling options. Indeed, in such conditions, transport costs associated with carrying manure back to the field are prohibitive.

Contribution to regional-level nutrient overloads

As mentioned above, poultry manure is generally recycled. Despite this apparently safe handling, it often contributes to nutrient-based pollution at regional level. First, areas where poultry production concentrates are also often characterized by high populations of other livestock species, pigs in particular. Poultry manure, thus, contributes to the structural nutrient overload in these areas. Secondly, the manure may be applied to crops or fish ponds in excess or in addition to chemical fertilizers or fish feed, resulting in an over-supply of nutrients. Such saturated systems will release excessive nutrients into the environment.

Excessive levels of nitrogen in the environment lead to a cascade of effects, including (Erisman *et al*., 2001; De Vries *et al*., 2003):

- decreased species diversity and acidification of non-agricultural soils, due to nitrogen deposition related to ammonia and nitrous oxide emission;
- eutrophication of surface waters, including excess algal growth and a decrease in natural diversity due to runoff of nitrogen from agricultural soils;
- pollution of groundwater due to nitrate leaching from agricultural soils and non-agricultural soils; and
- greenhouse gas emissions in the form of nitrous oxide.

Nitrogen pollution has been identified as posing a risk to the quality of soil and water. These risks relate to high levels of nitrates, which can be leached to the groundwater table or to surface water causing eutrophication. In its nitrate form, nitrogen is very mobile in soil solution and can easily be leached below the rooting zone and into groundwater.

The rapid growth of intensive poultry production in many parts of the world has created regional and local phosphorus imbalances (Gerber *et al*., 2005). The application of manure has resulted in more phosphorus being applied than crops require, and increased potential for phosphorus losses in surface runoff. This situation is exacerbated by manure management being nitrogen based. When manure is applied to meet the nitrogen needs of most crops, a substantial build-up of phosphorus occurs in the soil (Burton and Turner, 2003; Sharpley, 1998). Environmental problems associated with phosphorus losses from soils can have significant off-farm impacts on water quality. In some cases, these impacts are manifested many miles from the site where the phosphorus losses in soil erosion and runoff originally occurred (Sharpley, 1998). Too much phosphorus input into a body of water leads to plant overgrowth, shifts in plant varieties, discolouration, shifts in pH, and depletion of oxygen as a result of plant decomposition. A drop in the level of dissolved oxygen in surface water has deleterious effects on fish populations (Ferket *et al*., 2002). Thus, increased outputs of phosphorus to fresh water can accelerate eutrophication, which impairs water use and can lead to fish kills and toxic algal blooms. In general, 80 percent of the phosphorus contained in animal feed is subsequently excreted (Burton and Turner, 2003).

Food- and water-borne diseases are another major issue associated with manure management. Pathogens are mostly transmitted through untreated animal waste. Recycling manure is a cost-effective way to reduce discharge into the environment and contamination of water systems. However, recycling must be controlled carefully in order to avoid transferring pathogens to the human food chain. Nonetheless, manure is usually not treated, even if limited composting may take place when manure is stored over several weeks (on farm or in a middleman’s barn) and crop residues are added.

Soil contamination with heavy metals

With increasing use of metals not only as growth promoters, but also as feed additives to combat diseases in intensive poultry production, manure application has emerged as an important source of environmental contamination with some of these metals. Metals such as arsenic, cobalt, copper, iron, manganese, selenium and zinc are added to feeds as a means to prevent disease, improve weight gain and feed conversion, and increase egg production (Bolan *et al*., 2004; Jackson *et al*., 2003). Typically, animals can absorb only 5–15 percent of the metals they ingest. The majority is therefore excreted in manure. Part is absorbed by the soil, but heavy metals can also end up in water bodies where they become more concentrated.

The environmental risk associated with heavy metals is largely dependent on the soil's ability to adsorb and to desorb these elements, and the potential for leaching or soil-loss to water by erosion. The spreading of animal manure contaminated with heavy metals can lead to an accumulation of these elements in agricultural soils and water bodies. Unlike excess nitrogen and phosphorus applied to land, heavy metals such as zinc and copper remain bound to soil and do not migrate to water supplies except during soil erosion (Ferket *et al*., 2002). The concentrations of copper and zinc needed by animals are moderately low – 8 parts per million (ppm) for copper and 40 ppm for zinc (National Research Council, 1994). Yet, throughout the United States of America, most broiler diets contain levels of 125 to 250 ppm of copper in order to improve feed efficiency. The U.S. Geological Survey has reported that intensive poultry production units in the Delaware–Maryland–Virginia (Delmarva) Peninsula, on the eastern shore of the United States of America are introducing between 20 and 50 tonnes of arsenic into the environment annually (Christen, 2001) (Box 2).

Ecosystem contamination with drug residues and hormones

The excretion of hormones from poultry has been cited as a possible cause of endocrine disruption in wildlife. Endocrine disruptors are a class of compounds (either synthesized or naturally occurring), which are suspected to have adverse effects in animals. They affect organisms primarily by binding to hormone receptors and disrupting the endocrine system. Endocrine disrupting chemicals (EDCs) include pesticides, herbicides and other chemicals that interact with endocrine systems (University of Maryland, 2006).

In poultry production, EDCs can both enter and leave the production cycle. Sources of EDCs during the production phase include contaminants in litter and from grains used as feed. Poultry can also produce EDCs in the form of steroid hormones that are excreted in manure. The steroids of greatest concern are estrone and 17-ß-estradiol. Research has shown that poultry litter contains estrogen (17-ß-estradiol), estrone and testosterone in measurable concentrations, and that these EDCs persist in the litter (Nichols *et al*., 1997; Shore and Shemesh, 2003; Fisher *et al*., 2005). Degradation of steroids in poultry litter during storage is minimal. However, once steroids have reached waterways their degradation is rapid. Research into the endocrine disruption impact of naturally occurring steroids on fish suggests that on runoff from fields where poultry manure has been applied steroid levels are high enough to cause endocrine disruption resulting in reproductive disorders in a variety of wildlife. Endocrine disruption resulting from intensive poultry production has been well documented in the Delmarva Peninsula in the United States of America (Box 3).

BOX 2:

Arsenic use in intensive poultry production in the United States of America

In the United States of America, arsenic is used in poultry production for growth promotion and for controlling intestinal parasites. According to estimates, at least 70 percent of the broiler chickens raised annually in the United States of America (8.7 billion in 2005) are fed arsenic – typically a compound called roxarsone (3-nitro-4-hydroxyphenylarsonic acid). Up to three-quarters of arsenic in feed will pass through chickens into the estimated 26 to 55 billion pounds* of chicken litter or waste created in the United States of America annually. With around 90 percent of chicken waste being currently applied to fields and cropland as "fertilizer", the U.S. Geological Survey has calculated, based on arsenic concentrations in poultry waste, that between 250 000 and 350 000 kg of arsenic is annually applied to land in the United States of America (Rutherford *et al.,* 2003). Because 70–90 percent of arsenic in poultry litter becomes water soluble, it can readily migrate through soils and into underlying groundwater. While soluble or dissolved arsenic poses the greatest risk for environmental contamination, wind or water erosion can transport contaminated soil particles into water bodies (Bellows, 2005). Garbarino *et al.* (2003) estimated that 2 billion pounds of arsenic are annually introduced into the environment from poultry operations in the United States of America. According to the U.S. Environmental Protection Agency (US-EPA, 2007) (http://www.epa.gov/safewater) 13 million Americans drink water contaminated with arsenic beyond the safety standard of 10 parts per billion.

Arsenic as an obstacle to manure management

Apart from its role in the contamination of water and soil resources, arsenic used in poultry production has also become an obstacle to animal waste management. Today, the production of bioenergy and pelletization of animal waste are two important options being explored for poultry waste management. Existing incinerators in the United States of America burn about 680 million kg of poultry litter each year, and the ash from the incineration process is sold as fertilizer. The other new disposal technology is to produce fertilizer pellets directly from poultry waste by drying and pelletizing it. This is currently being implemented in Delaware, where about 55 million kg of pellets are produced annually. Although these two technologies have the potential to reduce or eliminate harmful pathogens in poultry waste, neither can destroy or detoxify arsenic. Preliminary measurements of arsenic concentrations in pelletized waste sold as fertilizer have shown levels between 18 and 22 mg/kg – levels similar to those reported in unprocessed poultry waste. There is, therefore, concern about increased exposure to arsenic through air emissions from energy plants, and contamination of soils and water.

*1 pound = 0.45 kg

Source: Nachman *et al*. (2005)

BOX 3:

Effects of endocrine disruptors from intensive poultry on fish

The Delmarva Peninsula, consisting of eastern Maryland, most of Delaware, and the portion of Virginia east of the Chesapeake Bay, is one of the most densely concentrated poultry producing areas in the United States of America. The region generates 600 million birds and 1.6 billion pounds (726 million kg) of manure (or litter) annually. Excessive land application of poultry wastes has precipitated severe water quality problems in surface waters and groundwaters throughout the region. Impacts include harmful algal blooms, decreases in water clarity, widespread anoxia, and declines in submerged aquatic vegetation. Pollutants and pathogens in poultry litter traditionally linked to environmental degradation include nutrients and protozoan, bacterial and viral agents. In addition, recent attention has turned toward various non-traditional poultry litter-associated contaminants. These include feed additives (e.g. trace metals and antibiotics), poultry house/bedding material impurities (e.g. metals and pesticides) and faecal/urinary steroids (e.g. estrogenic and androgenic hormones). In most vertebrates, sex steroids, specifically 17-ß estradiol (E2) and testosterone, are responsible for gender differentiation, development of reproductive structures and stimulation of breeding behaviours. They are released naturally in poultry urine and faeces and persist at high concentrations and for prolonged durations (more than two years) in litter. Studies conducted on the Delmarva Peninsula and elsewhere have demonstrated the transport of E2 from poultry litter-amended fields to surface waters and groundwaters at levels sufficient to warrant environmental concern. The studies have also confirmed that these contaminants are capable of causing endocrine disruption in aquatic animals.

Source: Fisher *et al*. (2005).

Ecosystem contamination through ammonia deposition

Atmospheric ammonia (NH_3) is increasingly being recognized as a major air pollutant because of its role in regional-scale tropospheric chemistry and its effects when deposited into ecosystems. Ammonia is a soluble and reactive gas. This means that it dissolves, for example in water, and that it will react with other chemicals to form ammonia-containing compounds. The concentrations of ammonia in the air are greatest in areas where there is intensive livestock farming. Agricultural land receiving large inputs of nitrogen from manures normally acts as a source of ammonia, but it may also act as a "sink" and absorb ammonia from the atmosphere. There is little deposition of ammonia gas to intensively managed farmland, which is largely a net source of ammonia (Sutton and Fowler, 1995). Ammonia in the atmosphere can be absorbed by land, water and vegetation (known as dry deposition). It can also be removed from the atmosphere by rain or snow (wet deposition). Impacts of ammonia deposition include; soil and water acidification, eutrophication caused by nitrogen enrichment with consequent species loss, vegetation damage, and increases in emissions of the greenhouse gases such as nitrous oxide.

4 IMPACTS ON THE GLOBAL ENVIRONMENT

Environmental impacts of poultry production are not always confined to specific areas; they also include impacts of a global dimension. Two issues are of relevance: the production of concentrate feed and greenhouse gas production related to energy use in animal production processes and in the transport of processed products. This section analyses these two issues in the context of poultry production and the sector's impacts on the environment.

4.1 Feed production

Overview on feed consumption

The extraordinary performance of the poultry sector over the past three decades has partially been achieved through soaring use of concentrate feed, particularly cereals and soybean meal (FAO, 2006a). We estimate that in 2004 the poultry sector utilized a total of 294 million tonnes of feed, of which approximately 190 million tonnes were cereals, 103 million tonnes soybean meal and 1.6 million tonnes fishmeal.

Estimates put the global use of cereals for feed (all species included) at 666 million tonnes, or about 35 percent of total world cereal use (FAO, 2006a). This implies that in 2004 cereal utilization as feed by the poultry sector represented about 28 percent of the cereal and 75 percent of soybean meal used by the livestock sector.

The estimates for feed utilization by the intensive poultry sector were obtained by applying a two-step approach. The first step estimates total feed use in poultry systems by applying a "utilization approach", i.e. total feed utilization is obtained by multiplying total production (for poultry meat and eggs) by the corresponding feed conversion ratio which reflects both the intensity and efficiency of the livestock system.

The second step involves apportioning the total feed obtained per region based on the concept of "feed baskets". Feed baskets represent the different components that make up a feed ration in any given country. The major elements of feed baskets in intensive poultry systems are usually cereals, oilseeds and fishmeal (Steinfeld *et al*., in FAO, 2006b), while those in mixed systems are to a greater extent made up of agro-industrial by-products (oilmeals, fishmeal) and crop residues, and contain less cereal. In calculating feed use the following assumptions were made.

1. Cereals make up the bulk of the feed baskets in intensive poultry production – an estimated 60 percent. The rest is shared between oilseeds (mainly soybean) and fishmeal (ibid.). However, cereal use for poultry production differs across countries, with maize dominating in Brazil, China and the United States of America, and wheat in the European Union (EU). In mixed systems, we estimate that cereals make up about 30 percent of the feed basket, with the remainder comprising crop residues and agro-industrial by-products.
2. This estimate also assumes homogeneity of poultry production across countries and regions and, therefore, applies an average feed conversion ratio across all regions. For poultry-meat products, an average was taken based on the feed conversion ratios for broilers, turkeys and ducks. For eggs, the feed conversion ratio average was based on the feed conversion ratio for brown-shelled and white-shelled layers. Poultry reared in landless systems are considered efficient users of feed and therefore have lower feed conversion ratios than those in mixed systems.

Demand for feed by the livestock sector has been a trigger for three major global trends: the intensification of feed production, agricultural expansion and erosion of biodiversity. The production of feed has an impact on the environment at various stages of crop production. In terms of the environment, these three trends have had a number of global impacts, which include land and water pollution, air pollution, greenhouse gas emissions, land-use change through deforestation and habitat change, and overexploitation of non-renewable resources.

Environmental impacts related to feed production

Intensive agriculture. Intensification of feed production affects land and water resources through pollution caused by the intensive use of mineral fertilizer, pesticides and herbicides to maintain high crop yields. It is estimated that only 30–50 percent of applied nitrogen fertilizer (Smil, 1999) and approximately 45 percent of phosphorus fertilizer (Smil, 2000) is taken up by crops. Steinfeld *et al*. (2006) estimated that about 20 million tonnes of nitrogen fertilizer were used in feed production for the livestock sector. Based on the estimation that the poultry sector utilizes 36 percent of feed concentrates (cereals and soybean), we can attribute about 7.2 million tonnes of nitrogen fertilizer use to feed production for the sector.

Intensive feed production also contributes to air pollution. The application of nitrogen fertilizer to cropland is a major source of air pollution through the volatilization of ammonia. Assuming an average mineral fertilizer ammonia volatilization loss rate of 14 percent, it has been estimated that global livestock production can be considered responsible for a global ammonia volatilization from mineral fertilizer of 3.1 million tonnes of NH3-N (nitrogen in ammonia form) per year (Steinfeld *et al*., in FAO, 2006b). Based on these same assumptions, the poultry sector can be considered responsible for about 1.1 million tonnes of ammonia volatilization from mineral fertilizer per year.

Intrusion into natural habitats. Increases in feed production, have to some extent been related to the expansion of cropland dedicated to feed. Feed production to satisfy the feed demand of intensive systems indirectly affects the global land base through changes in land use. Area expansion is in most cases at the expense of forested land (deforestation) cleared for crop production. For example, the land area for soybean production in Brazil increased from 1 million hectares in 1970 to 24 million hectares in 2004 – half of this growth came after 1996, most of it in the Cerrado, with the remainder in the Amazon Basin (Brown, 2005). According to Brazil's National Institute of Space Research (Bickel and Dros, 2003), just over 2.5 million hectares of forest in the Amazon disappeared in 2002, with about 70 percent of the 1.1 million hectare expansion of the agricultural frontier in the Amazon region alone attributed to soybeans. Wassenaar *et al*. (2007) project large hotspots of deforestation in the Brazilian Amazon forest related to the expansion of cropland, mainly for soybean. Changes in land use can have profound impacts on carbon fluxes, leading to increased carbon release and fuelling climate change. In addition to changes in carbon fluxes, deforestation also has an impact on water cycles and increases runoff and consequently soil erosion. WWF (2003) estimates that a soy field in the Cerrado loses approximately 8 tonnes of soil per hectare per year.

Erosion of biodiversity. Feed production is also driving biodiversity erosion through the conversion of natural habitats and the overexploitation of non-renewable resources for feed production. Intensive feed production contributes to biodiversity loss through land use and land-use change, and modification of natural ecosystems and habitats. The demand for feed has triggered increased production and exports from countries such as Brazil. Between 1994 and 2004, land devoted to soybean production in Latin America more than doubled to 39 million hectares (FAOSTAT, 2006).

The clearing of vast areas of the biologically rich Amazon rainforest and the Cerrado to produce maize and soybeans for feed has led to the loss of plant and animal species (Box 4).

Overexploitation of natural resources. The production of fishmeal for the poultry sector is an important factor contributing to the overexploitation of fisheries. The world's fish stocks are facing serious threats to their biodiversity. The principle source of this pressure is overexploitation, which has affected the size and viability of the fish populations (Steinfeld *et al.*, in FAO, 2006b). FAO (2005) estimates that 52 percent of the world's fish stocks are fully exploited, and are therefore producing catches that are already at or very close to their maximum sustainable yield. Current estimates are that around 40 percent of global fishmeal production is used for the livestock sector of which 13 percent is used by the poultry sector (Figure 2) (Jackson, 2007).

The expansion of the aquaculture sector and its demand for fishmeal as a feed ingredient has led to a reduction in the use of fishmeal by the poultry sector (as illustrated in

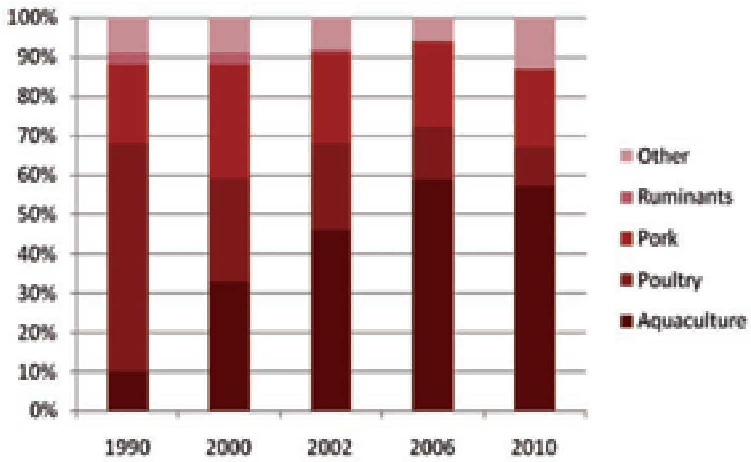
BOX 4:
Soybean production in the Cerrado

The Cerrado is one of the world's biodiversity hotspots. It has an area of 200 million ha and covers a quarter of Brazil, making it the country's second biggest ecosystem after the Amazon. It is regarded as the world's most species-rich savannah. Having approximately 4 400 endemic species in a total of 10 000 species of plants, it is classified as one of the earth's 25 biodiversity "hot spots". However, the areas designated as protected – barely 1.5 percent – are far fewer and smaller than in the Amazon. The Cerrado, Brazil's second major biome, is suffering severe clear-cutting and irreversible losses of its original vegetation and biodiversity. Numerous animal and plant species are threatened with extinction as a result of the expansion of the agricultural frontier, and an estimated 20 percent of threatened and endemic species do not occur in protected areas.

The extent of the destruction of the Cerrado is now evident. Two-thirds of its original vegetation has already been destroyed or severely degraded. Cultivation of soybeans in the Cerrado has since 1970 risen from 20 000 to 29 million tonnes – an increase in Brazilian soybean production from 1.4 percent to 58 percent. As state planning on land use – determining where and how much primary vegetation should be converted to land for agricultural use – exists only in a rudimentary form, soybean expansion is one of the main factors threatening the Cerrado ecosystem.

Sources: Bickel (2005); Klink and Machado, (2005).

FIGURE 2
Past and projected trends in global use of fishmeal by sector



Sources: Marine Aquaculture Task Force (2007); Jackson (2007).

Figure 2). Between 1990 and 2006, the share of fishmeal consumed by the poultry industry decreased drastically from about 58 percent to 13 percent. The poultry sector compensated for this loss by increasing the amount of soybean meal used in feed rations. Despite current and projected decline in the sector's use of fishmeal as a feed input, the role of the industrial poultry sector in the overexploitation and depletion of fisheries can not be ignored.

4.2 Climate change

The relatively high energy input in intensive livestock systems has given rise to concerns regarding greenhouse gas emissions and climate change. The energy consumption of industrially produced poultry is relevant because of the production of carbon dioxide (CO_2) along the production chain. Carbon dioxide emissions are produced by the burning of fossil fuels during animal production and slaughter, and transport of processed and refrigerated products, but importantly also through land use and land-use change, and the use of inputs for the production of feed.

On-farm energy consumption

On-farm energy consumption includes direct and indirect energy input – direct energy refers to fossil energy used for the production process (e.g. energy input for poultry housing systems), and indirect energy to that used as an integral part of the production process (e.g. feed processing). Due to a lack of information on energy use for processing, this estimation of on-farm fossil fuel consumption is limited to quantifying energy use associated with poultry housing.

The energy used for heating, ventilation and air conditioning systems typically accounts for the largest quantity of energy used in intensive poultry operations. Animal housing

TABLE 1
Energy consumption in poultry production

Activity	Estimated energy consumption		
	Broilers[a]	Layers[a]	Turkeys[c]
Local heating	13–20		
Feeding	0.4–0.6	0.5–0.8	
Ventilation	0.10–0.14	0.13–0.45	1.4–1.5
Lighting		0.15–0.40	
Egg preservationb		0.30 –0.35	

Notes: a – Wh (watt hour)/bird/day; b – Wh/egg/day; c – kWh/bird/year.
Sources: World Bank (2007); EU (2003).

facilities are therefore potential sources of carbon dioxide emissions from intensive poultry farms. Other sources of carbon dioxide emissions include energy used for feed preparation, on-farm transport and burning of waste (EU, 2003). Generally, on layer farms, artificial heating of housing is not commonly applied, due to the low temperature needs of birds and the high stocking density. The activities that require energy are ventilation, feed distribution, lighting, and egg collection, sorting and preservation. On broiler farms, the main energy consumption is related to local heating, feed distribution and housing ventilation. Quantification of the energy consumption of intensive poultry farms is a complex undertaking because systems are not homogeneous. The amount of energy consumed varies with the technologies applied, the production characteristics of the farms, and climatic conditions. Table 1 shows energy requirements of some essential activities on broiler, layer and turkey farms in the EU.

A rough indication of the fossil fuel related emissions from intensive poultry systems can be obtained by applying the energy requirements given in Table 1, assuming that the energy consumption for heating during the winter in higher latitude countries is equivalent to the high energy use for ventilation in lower latitudes. By applying these estimates to the global total for intensively produced poultry, it is estimated that about 52 million tonnes of carbon dioxide are emitted per year.

Carbon dioxide emissions from slaughtering

Poultry processing facilities use energy to heat water and produce steam for process applications and cleaning, and for the operation of mechanical and electrical equipment, refrigeration and air compressors. In poultry abattoirs, fossil fuel is mainly used for process heat, while electricity is used for the operation of machinery and for refrigeration, ventilation, lighting and the production of compressed air. Ramírez *et al*. (2004) in an analysis of energy consumption in the EU meat industry found poultry slaughtering to be more energy intensive (3 096 MJ/tonne dress carcass weight) than other meat sectors (1 390 MJ/tonne dress carcass weight for beef and 2 097 MJ/tonne dress carcass weight for pork).

Using the Ramírez *et al*. (2004) estimates of energy consumption values for poultry, we estimate that carbon dioxide emissions from poultry slaughtering facilities amount to 18 million tonnes. This estimate is obtained by applying the energy consumption data to total poultry meat production and multiplying by the respective carbon dioxide emission factors for both electricity and natural gas.

Carbon dioxide emissions from international trade

International trade in poultry meat contributes significant carbon dioxide emissions – induced by fossil fuel use for the shipping of poultry meat. Steinfeld *et al*. (in FAO, 2006b) estimated carbon dioxide emissions by combining traded volumes with respective distances, vessel capacities and speeds, fuel use of main and auxiliary power generators for refrigeration, and their respective emission factors. Based on this analysis, trade in poultry meat was found to contribute an estimated 256 000 tonnes of carbon dioxide (representing about 51 percent of the total carbon dioxide emissions induced by meat-trade ocean transport). The addition of transportation within national boundaries, involving shorter distances, but much larger quantities and less efficient vehicles, would certainly increase significantly the sector's greenhouse gas emissions related to transportation.

Greenhouse gases emissions from feed production

Emissions of greenhouse gases such as carbon dioxide and nitrous oxide are influenced in an indirect way by intensification of feed production, which requires energy input for the production of mineral fertilizer and the subsequent use of this fertilizer in the feed production process.

Carbon dioxide (CO_2). This greenhouse gas is produced by the burning of fossil fuels during the manufacture of fertilizer. By applying energy use per tonne of nitrogen fertilizer (estimated at 40 GJ per tonne) and the IPCC (Intergovernmental Panel on Climate Change) emission factor for natural gas (17 tonnes of carbon per terajoule) to total nitrogen fertilizer use in the production of feed for poultry production (estimated at 7.2 million tonnes) and applying the ratio of the molecular weight of carbon dioxide to the molecular weight of carbon (44/12) results in an estimated annual carbon dioxide emission of 18 million tonnes – about 44 percent of that ascribed to the livestock sector.

Nitrous oxide (N_2O). Poultry production is indirectly associated with the greenhouse gas nitrous oxide because of the sector's high concentrate-feed requirements and the related emissions from arable land due to the use of nitrogen fertilizer. FAO–IFA (2001) reported a 1 percent N_2O-N (nitrogen in nitrous oxide) loss rate from nitrogen mineral fertilizer applied to arable land. By applying this loss rate to the total nitrogen fertilizer attributed to the poultry sector, we estimate that nitrous oxide emissions from poultry feed related fertilizer to be 0.07 million tonnes of N_2O-N per year – about 35 percent of the global nitrous oxide emissions attributed to the livestock sector from mineral fertilizer application.

Overall, intensive poultry production (indirectly and directly) contributes an estimated 3 percent of the total anthropogenic greenhouse gas and is responsible for about 2 percent of the total greenhouse gas emissions from the livestock sector. This estimate however does not include emissions from land use and land-use change associated with feed production or emissions related to transport of feed.

TABLE 1
Summary of greenhouse gas emissions related to poultry production

	Million tonnes carbon dioxide equivalent
Carbon dioxide	
Nitrogen fertilizer production for feed	18
On-farm energy consumption	52
Slaughtering	18
International trade (transport)	0.3
Nitrous oxide	
Indirect fertilizer emissions	0.02
Total	88.3
Share of the livestock sector	2%
Share of anthropogenic emissions	0.3%

Note: These estimates do not include emissions related to land use and land-use change, nor intra-national transportation.

5 TECHNICAL MITIGATION OPTIONS

The magnitude of environmental impacts is highly dependent on production practices and especially on manure management practices. We introduce here a number of techniques and management practices that are available to control the environmental issues described above. Lack of awareness and capital are often cited as the two factors hampering the implementation of such practices.

5.1 Farm management

Taking environmental issues into account in all management strategies at the farm level can reduce the impacts felt at the level of production.

Odour emissions can be controlled by:

- minimizing the surface of manure in contact with air – frequent collection of litter (once a week in dry seasons and twice a week in rainy seasons), closed storage (bags or closed sheds);
- cooling animal manure, achieved as a positive side effect of cooling the animal houses – cooling systems can be equipped with biofilters and air scrubbers that trap odours from the ventilation airflow;
- lowering litter's water content – achieved by the incorporation of hydrophilic products such as hashes, rice husk, peanut husk, dust or sawdust;
- applying deodorant products to feed or directly to animal houses; and
- building wind protection structures.

The proliferation of flies and mosquitoes can be controlled by:

- minimizing the surface of manure in contact with air – frequent collection of litter (once a week in dry seasons and twice in rainy seasons, i.e. at shorter intervals than the length of the larvae development cycle), closed storage (bags or closed sheds);
- lowering litter's water content – achieved by the incorporation of hydrophilic prod-

ucts such as hashes, rice husks, peanut husks, dust, sawdust or available dry crop residues;
- applying insecticides (this practice may however have significant public health-related side effects);
- building wind protection structures;
- positioning nets around the farm.

Rat proliferation can be controlled by:
- minimizing feed losses during storage and feeding;
- raising cats or keeping snakes in cages close to the poultry barn to scare rats; and
- use of poison or traps.

Visual impact and landscaping can be improved by:
- use of screening trees around the farm facility to reduce the visual impact of farm infrastructure and of noise, dust, light and odour;
- use of the natural topography and terrain of the site and the existing vegetative cover to maximize visual screening; and
- use of construction materials that minimize visual impact.

5.2 Animal waste management

Soil and water pollution is controlled through the implementation of good fertilization practices. In brief: environmental risks are reduced when manure is applied in amounts and at times that correspond to crop or fish-pond uptake. Water pollution is often an acute problem in waterfowl production, especially when the flock is concentrated on relatively small ponds. There is currently a lack of information with regard to the effects of waterfowl production on surface water and groundwater resources.

Water- and food-borne disease propagation can be prevented by:
- storing manure in closed buildings or bags – a storage system allows producers to hold manure until a convenient and optimum time for use; storing poultry manure in closed buildings reduces the emissions of gaseous compounds to the air, and the risk of environmental contamination as compared to the risk associated with leaving manure exposed;
- storing the manure for one to two months before its application on land or fish ponds;
- composting manure – potentially reduces or even eliminates certain pathogens and fly larvae, and improves the handling characteristics of manure and other residues by reducing their volume, weight and moisture content (most manure and other organic residues usually contain high nitrogen content and are, therefore, subject to nitrogen loss during composting);
- drying (with machine or by spreading out) – minimizes the moisture content of manure, inhibits chemical reactions, and thus reduces emissions (the best way to prevent ammonia emissions from poultry litter and manure is to reduce microbial decomposition, which can be accomplished by drying the freshly produced manure as soon as possible and keeping it dry);

- timing and rate of manure application – this is a critical management factor; manure must be applied at the correct time of year to prevent losses to surface water, groundwater and the atmosphere, and to optimize the utilization of manure nutrients by growing plants; proper timing is a function of several variables, including weather, soil conditions and stage of crop growth; and
- dead-bird management and disposal, which must comply with legally accepted practices including rendering, composing, incineration and burial; a contingency plan should be in place for disposal of large numbers of dead birds in the event of disease outbreaks; in addition, consideration should be given to impacts on the physical environment – e.g. burial pits should be at least 3 metres above the maximum groundwater table.

5.3 Nutrition management

Nutritional management aims to reduce pollution load by limiting excess nutrient intake and/or improving the nutrient utilization efficacy of the animal. It not only affects the quantity of mineral outputs from animals and the characteristics of manure, but also has cross-media effects – reducing the pollution load of soil, water and air. Nutrition management can also allow improvement to feed conversion ratios through optimal diet balancing and feeding regimes, and improvement to feed digestibility. This reduces the amount of feed used per unit of livestock product. Relevant measures include:

- formulating feeds that closely match the nutritional requirements of birds in their different production and growth stages to reduce the amount of nutrients excreted; options in this category include phase feeding, split-sex feeding or feed formulation on an available-nutrient basis;
- use of low-protein diets supplemented with amino acids, and low-phosphorus diets with highly digestible inorganic phosphates;
- improving feed digestibility and nutrient bioavailability through the use of dietary supplementary enzymes such as phytase, highly digestible genetically modified feedstuffs such as low-phytate maize, and highly digestible synthetic amino acids and trace minerals; and
- using good quality, uncontaminated feed (e.g. in which concentrations of pesticides and dioxins are known and do not exceed acceptable levels) which contains no more copper, zinc, and other additives than is necessary for animal health.

5.4 Feed production

The key to reducing the negative environmental impacts associated with intensive agriculture for feed production lies in increasing efficiency, i.e. increasing production while reducing the use of inputs that adversely affect the environment. The negative effects of feed production can be greatly reduced with appropriate cultivation (e.g. minimum tillage), integrated pest management (IPM) and targeted fertilizer inputs. Technologies are available for many different environments to conserve soil and water resources and to minimize the use and impact of inorganic fertilizers and pesticides.

Good agricultural practices require the application of available knowledge to the utilization of the natural resource base in a sustainable way for the production of safe and healthy food. Management of resources such as soil and water by minimizing losses of soil, nutrients and agrochemicals through erosion, runoff and leaching into surface water or groundwater is a criterion for good agricultural practice. Good agricultural practice will maintain or improve soil organic matter through the use of appropriate mechanical and conservation tillage practices; will use soil cover to minimize erosion loss by wind or water; and will ensure that agrochemicals and organic and inorganic fertilizers are applied in amounts, at times and using methods, appropriate to agronomic and environmental requirements.

IPM uses an understanding of the life cycle of pests and their interactions with the environment, in combination with available pest control methods, to keep pests at a level that is within an acceptable threshold in terms of economic impact, while giving rise to minimum adverse environmental and human health effects. Recommended IPM approaches include: use of biological controls such as predators, parasites and pathogens to control pests; use of pest-resistant varieties; mechanical and biological controls; and, as a last resort, chemical controls including synthetic and botanical pesticides. Other IPM approaches encompass pesticide application techniques that aim to increase the efficiency of chemical applications.

Minimal tillage practices in agronomic crops such as soybean and maize reduce the loss of nutrients from the field, they also improve the water-stability of soils and reduce soil erosion; this often results in higher levels of soil organic carbon and reduces carbon emissions.

Enhancing the efficiency of water use in feed production by improving irrigation efficiency and water productivity is a further method of reducing adverse environmental impacts. Water productivity can be improved by methods including selection of appropriate crops and cultivars, better planting methods, minimum tillage, timely irrigation that matches water application with the most sensitive growing periods, nutrient management and drip irrigation.

6 CONCLUSIONS

This paper has focused on poultry production in intensive systems and its impacts on the environment. The assessment captures most of the issues associated with poultry production, as environmental impacts related to backyard or mixed extensive systems are marginal because of the limited concentration of wastes and reliance on locally available sources of feed, such as food residues, crop residues or feed collected by free-ranging birds. The review has also demonstrated the need to look beyond the farm level in order to understand the sector's impacts on the environment, as many of the impacts of production are felt beyond the point of production.

Generally, the environmental impacts of the sector are substantial. Poultry production is associated with a variety of pollutants, including oxygen-demanding substances, ammonia, solids, nutrients (specifically nitrogen and phosphorus), pathogens, trace elements, antibiotics, pesticides, hormones, and odour and other airborne emissions. These pollutants have been shown to produce impacts across multiple media. These impacts can be summarized as follows.

Surface water impacts. Impacts are associated with waste spills, as well as surface runoff and subsurface flow. The oxygen demand and ammonia content of the waste can result in fish kills and reduced biodiversity. Nutrients contribute to eutrophication and associated blooms of toxic algae and other toxic micro-organisms. Human and animal health impacts are associated with drinking contaminated water (pathogens and nitrates) and contact with contaminated water (pathogens and Pfiesteria). Trace elements (e.g. arsenic, copper, selenium and zinc) may also present human health and ecological risks. Antibiotics, pesticides and hormones may have low-level but long-term ecosystem effects.

Groundwater impacts. Impacts associated with pathogens and nitrates in drinking water may cause underlying groundwater to become unsuitable for human consumption.

Air/atmosphere impacts. Impacts include those on human health (caused by ammonia, hydrogen sulfide, other odour-causing compounds, and particulates), and contribution to global warming (due to carbon dioxide and nitrous oxide emissions from the production process and other related activities such as feed production and transport of finished products). Additionally, volatilized ammonia can be re-deposited and contribute to eutrophication, acidification and damage to vegetation and sensitive ecosystems.

Soil impacts. Nutrients and trace elements in animal manure can accumulate in the soil and become toxic to plants.

Other indirect impacts include ecosystem destruction and biodiversity erosion associated with the expansion of feedcrop production into natural habitats and the overexploitation of non-renewable resources for feed production.

Compared to other livestock species, however, poultry performs well from an environmental perspective. A substantial comparative advantage that poultry has over other animal sectors relates to its efficiency in feed conversion. Poultry's feed conversion ratio represents a major contribution to the profitability of the industry in terms of reduced feed inputs as well as in waste output. For cattle in feedlots, it takes roughly 7 kg of grain to produce a 1 kg gain in live weight. For pork, the figure is close to 4 kg per kg of weight gain, for poultry it is just over 2 kg, and for herbivorous species of farmed fish, such as carp, tilapia, and catfish, it is less than 2 kg (Brown, 2005). Another comparative advantage lies in the low water content and high nutrient content of poultry manure. It is, thus, often handled with more care than manure from other species – especially pigs – as recycling is generally economically profitable.

Technologies exist that have the potential to produce substantial reductions in environmental impacts. The problem is one of cost, corresponding incentives/disincentives and awareness. Given the strong reactivity of the sector (large companies, foreign direct investment, demand growth), getting economic incentives and disincentives right within a framework of market forces should be sufficient to minimize environmental impacts.

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Do old and new forms of poultry go together?

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SUMMARY

Given conflicting zoosanitary regimes, the question arises whether or not old and new forms of poultry production may peacefully co-exist in the face of highly pathogenic avian influenza (HPAI) and other biological threats. Here, we argue that commercial poultry plants and associated distribution and marketing channels may have to step-up biosecurity and sanitation efforts in order to halt the evolution of further pathogens that thrive on mass-rearing of birds in quasi-biosecure conditions. Scavenging poultry, on the other hand, may be more capable of resisting parasites and infectious disease agents, but it should be noted that there are a growing number of exceptions, including HPAI and other, mainly RNA, viruses. Mostly, these pathogens first emerge as virulent agents in large poultry plants. Conversely, there is evidence that commercial poultry chains are forced progressively to invest in health protection because the poultry plants are under increasing threat from microbes circulating freely in nearby village or backyard poultry. Given the rapid evolution of medium-size systems and live-bird markets, meeting points between old and new forms of poultry husbandry are on the rise and so are the options for mutually destructive pathogen transmissions. Hence, structural reforms are necessary in order to address the growing health threats present in today's far too complex poultry circuitries.

Key words: old, new, production, systems

1 INTRODUCTION

Large-scale commercial poultry production plays an important role in feeding a rapidly growing urban middle class worldwide. Modern poultry chains provide quality protein which is safe, nutritious and relatively cheap. At the same time, different forms of backyard poultry continue to play an important role in providing food and income to mainly rural societies. The co-existence of large-scale commercial and low-input systems cause conflicts because of contrasting zoosanitary regimes. For example, the switch from low to highly pathogenic avian influenza (HPAI) typically takes place upon the entry of a wild-bird carried virus into a large flock of domestic birds (Duan *et al*., 2007; Campitelli *et al*., 2004). Following the propagation of virus in commercial premises, village or backyard poultry also may become infected (Alexander, 2007a). When commercial holdings have restored freedom from HPAI, backyard systems may still be experiencing infection (Sims, 2007).

One of the lessons learned with HPAI H5N1 is that free-ranging ducks in rice–duck agricultural systems may end up as a virus reservoir and a supply source of HPAI virus, which poses a risk to susceptible terrestrial poultry (Gilbert *et al*., 2006). A growing number of live-bird markets (LBM) act as meeting points for poultry of all sorts. LBMs constitute important nodes in the viral contact network structure (Ellis *et al*., 2004). The combination of LBMs, village or backyard poultry, medium-sized holdings, large duck populations in irrigated-rice areas, migratory birds, peri-urban poultry industries and associated input-supply, processing, distribution and marketing networks, including international trade and traffic, has led to entrenchment of the HPAI H5N1 virus in three continents. Hence, disease-prevention efforts should encompass measures that go beyond the veterinary realm, and consider reforming the poultry environments.

2 HPAI H5N1 BIOCOMPARTMENTS

HPAI has over the past five or so decades become increasingly more common in poultry industries across the globe (Alexander, 2007a). Along with the increasing number of outbreaks, the duration of individual HPAI episodes and the number of infections in humans also gradually increased. The surge of HPAI H5N1 in Asia has amplified this trend. Asia today remains the geographical focus of HPAI. The genesis, spread, persistence and continuous evolution of the H5N1 virus in this region brings us to consider the distinct biocompartments sustaining the virus transmission cycles.

First, we consider the wild water-bird reservoir which constitutes the natural ecology for all existing avian influenza viruses (Webster *et al*., 1992). A highly diverse gene pool of continually re-assorting virus genetic segments secures the virus subtype diversity that fits myriad ecological settings across the Palearctic and Nearctic bio-geographical regions. The foremost avian host is the mallard duck, but other dabbing duck species, anseriform birds, shore birds, waders, passerines and other species, including birds of prey, may also be found infected, albeit in decreasing order of virus prevalence and subtype diversity.

Poultry encroachment by avian influenza virus mostly involves opportunistic H7 and H5 subtypes (Alexander, 2007b). Presumably, terrestrial poultry triggered the initial switch from low to highly pathogenic avian influenza H5N1 virus (Duan *et al*., 2007). The strong affinity of this virus to aquatic poultry became clear when, during the 1990s, a diversity of H5N1 genotypes started circulating in healthy, domestic ducks distributed in southern and coastal areas of China (Chen *et al*., 2004). Duck production in China had accelerated since the mid-1980s, and exponential-scale growth continued through the 1990s (FAO, 2007a). While H5N1 prevalence was initially prominent in ducks and geese, infection rates in chickens increased gradually (Chen *et al*., 2006). The spread of the H5N1 virus in poultry assumed subcontinental proportions in 2003–2004 (Li *et al*., 2004). Inter-continental panzootic waves followed during 2005–2007 (Kilpatrick *et al*., 2006). In the process, the H5N1 had spilled back to migratory waterfowl, which occasionally vectored the virus over large distances (Gilbert *et al*., 2006). The virus had also infected commercial poultry chains operating internationally, mainly through trade and traffic of day-old chickens.

The most important biocompartment is the LBM, which acts as an amplifying node for viral traffic, indirectly linking commercial networks and village or backyard poultry (Ellis *et al*., 2004; Sims, 2007). Village poultry may not contribute much to the bulk of live birds supplied to the markets, but given the readiness with which open systems attract infection, and given also that sales of village poultry go through intermediaries linked to the urban demand centres, village poultry also constitutes a relevant biocompartment.

Free-range duck populations in rice paddies in river deltas, plains and other wetlands of East and Southeast Asia act as another major biocompartment (Gilbert *et al*., 2006). Free-ranging ducks are linked to wild water birds, to village poultry and occasionally also to LBMs, and thus form a supply source for virus dispersal into wider areas (Hulse-Post *et al*., 2005; Gilbert *et al*., 2006). The countries where the H5N1 virus has become entrenched include Bangladesh, China, Indonesia and Viet Nam in Asia, and Egypt and Nigeria in Africa. Today (late 2007) most countries in Asia with important duck populations experience a persisting H5N1 problem. India and the Philippines are among the exceptions. Egypt also reportedly holds 45 million ducks, mainly in the Nile delta. Ducks do not normally show major clinical symptoms (Brown *et al*., 2006; Sturm-Ramirez *et al*., 2005). Kept near or mixed with terrestrial poultry, ducks act as virus supply source while susceptible chickens and other birds support the active spread of disease, particularly when this also involves live-bird markets. Geographic amplification may occur through commercial networks or wild-bird vectoring of virus (Kilpatrick *et al*., 2006).

Transmission cycles are collectively sustained through wild birds, ducks, backyard/village poultry, LBMs, commercial chains and associated distribution networks. These compartments form the component parts of a system of global disease spread and persistence. Mammals, including humans, are also sometimes infected with HPAI H5N1, but these are spill-over infections or short, dead-end infection chains. Humans and other mammals do not form a separate biocompartment sustaining the global transmission cycle.

3 REFORMING BIOCOMPARTMENTS

Arguably, the best prospects for freeing any one biocompartment from HPAI are in the commercial systems. Here, terrestrial poultry is kept in full confinement and input supplies are closely integrated – from grandparent stock to feed mills, hatcheries, production plants, slaughterhouses and processing units, including the product-related distribution and marketing chains. However, in most countries in Asia, and also in Africa, birds produced in biosecure production plants are also supplied to LBMs. Intermediary vendors may also form an important source of infection for commercial plants. Additional risks for H5N1 infection are associated with wild birds and scavenging poultry around premises. Still, these risks may be readily contained; most enterprises producing broiler meat, and those producing hen eggs, succeed in securing HPAI-free production environments even in affected areas. Partially open plants, such as those involving turkeys, quails and domestic waterfowl, pose a higher risk. Theoretically, these risks may be minimized through the creation of clusters of licensed producers, certified HPAI-free, which only supply the LBM allocated to them. No other suppliers would obtain access to these closed LBM systems. Provided such an exercise is supported by proper risk assessment, city councils may assist in creating an expanding HPAI-free poultry production and marketing environment. Once major urban LBMs turn HPAI free, opportunities would arise also for the smaller LBMs and producer associations. Instead of introducing policing and law enforcement, stakeholders may be actively encouraged to take matters in their own hand. If more producers would start supplying exclusively local markets, a progressive disruption of the transmission cycle could result. It would be necessary to act in cohesion and on the basis of well-defined risk-management schemes.

In situations where LBMs become free from virus and turn HPAI-proof, there would still be virus persistence in more remote rural poultry, particularly in the wetland-associated duck reservoirs. However, given the scattered nature of village flocks and free-ranging ducks populations, this could present a next target for step-wise, progressive HPAI control. In the absence of such progressive, coordinated control, it is unlikely that H5N1 or other HPAI viruses will ever disappear. Periodic epidemic waves would continue, as is observed in the case of the velogene Newcastle Disease viruses which bring severe mortality to village poultry in Asia and Africa, mostly at the onset of the rainy season. HPAI in Southeast Asia could turn increasingly seasonal in areas with a high density of smallholders and/or medium-size, mixed poultry plants. The presence of free-ranging duck virus reservoirs may readily kick-start an epidemic wave, even in the absence of HPAI-infected LBMs or commercial chains. There is also the possibility that wild ducks and other waterfowl will play an increasingly prominent role in vectoring H5N1 viruses across Eurasia (Duan *et al*., 2007).

4 REFORMING OLD AND NEW FORMS OF POULTRY PRODUCTION

The answer to the question of whether old and new forms of poultry go together is mostly negative. The rationale for this goes back to the principles of disease ecology. Progressive intensification of poultry production kicked-off during the 1950s and early 1960s, starting in the United States of America and other developed countries where the market provided the incentive and technologies had become available to apply economies of scale. A global poultry wave followed, with rapid expansion and peak growth in Europe during the 1970s, in Latin America during the 1980s, and in Asia during the 1990s. Industrial production of eggs became an economically viable undertaking almost everywhere on the planet, as long as a sufficiently large demand centre was within reach. Global broiler production became much less evenly distributed in geographical terms because of focal chicken-feed supply sources and energy and transport-related market forces (FAO, 2007). Nonetheless, even in places where poultry-meat production has become concentrated in relatively small areas, there is confidence that specified-pathogen-free environments and a steady supply of high-quality products – nutritious, safe and relatively cheap – can be secured also in the future. However, this may not be achieved in some countries.

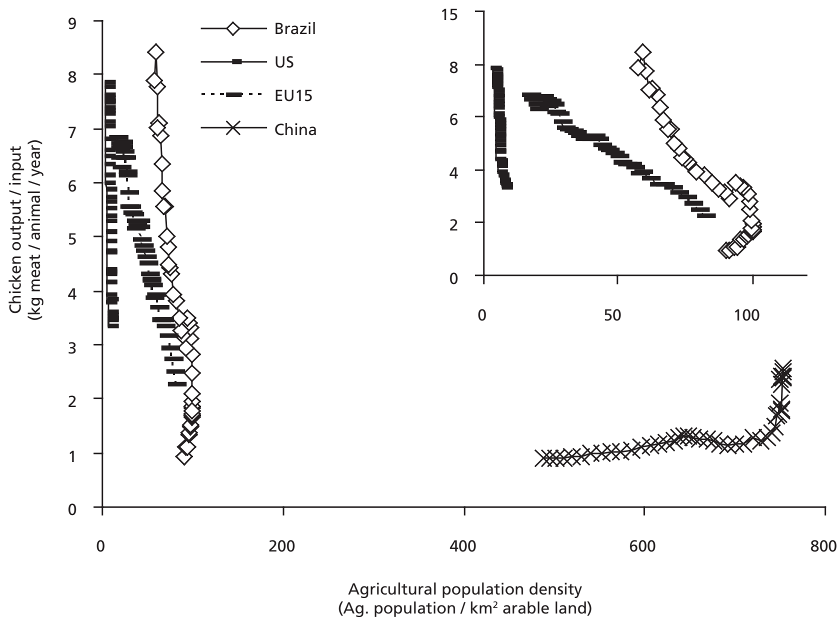
Figure 1 displays the trajectories of poultry intensification as experienced in Brazil, China, the European Union (EU15[3]), and the United States of America. Each trajectory is given by the line connecting poultry intensification scores for consecutive years starting from 1960 to 2005. Intensification is measured in terms of the output–input ratio (chicken produce relative to the standing population) held against farmer density. China has only recently started to intensify poultry production on a large, industrial scale and will for a long period of time continue to rely also on smallholders supplying local markets. This could provide a breeding ground for avian pathogens. A growing number of virulent infectious disease agents are finding their way from large to medium to small poultry units and vice versa. Aggressive pathogens thrive well on mass-rearing of birds kept in permanent confinement

[3] The 15 countries that were members of the European Union prior to expansion in 2004.

and in high concentrations, of the same age and sex, immuno-susceptible, and which are genetically selected for production traits rather than for any resistance against disease agents. While scavenging poultry better resist parasites and infectious disease agents, there are a growing number of exceptions, including HPAI viruses (Alexander, 2007a), velogene Newcastle disease virus (Wan *et al.*, 2004), gumboro disease (Gottdenker *et al.*, 2005), and infectious bronchitis viruses (Gutierrez-Ruiz *et al.*, 2000). Mostly, these pathogens first emerge as virulent agents in large poultry plants. At the same time, there is evidence that commercial poultry production chains are forced to progressively invest in health protection because their poultry plants are under increasing threat from microbes circulating freely in adjacent village or backyard poultry.

Given the rapid evolution of mixed, quasi-biosecure systems and of live-bird markets, the number of meeting points between old and new forms of poultry husbandry is on the rise and, unfortunately, so are the options for mutually destructive pathogen transmissions. Segregation of old and new forms of production, not just in terms of biological compartmentalization, but also in geospatial and land-use terms may be the answer. Due attention should be given to the fact that the rationale for pathogens evolving into virulent forms and engaging in species jumps goes back to disease ecology. Wherever a host ecological vacuum emerges, opportunistic and intrusive disease agents will explore whether this alien

FIGURE 1
Poultry intensification trajectories as observed in Brazil, China, the European Union (EU15) and the United States of America, from 1960 to 2005



Note: The insert in the top-right corner shows further detail of just the United States of America, EU15 and Brazil (from left to right) host resource may be worthwhile exploiting. RNA viruses are particularly flexible in this regard, capable of blending invasive behaviour and genetic host-range adjustment into a single ecological strategy, securing pathogen fitness in a dynamic host environment. Evidently, poultry production, being highly dynamic, provides the right incentive to drive such developments.

Reforms may even be necessary beyond the poultry subsector. A number of pathogenic agents in food and agriculture have recently been shifting from an animal to a human host preference. An increase in demand for bush meat is believed to have contributed to the evolution of the HIV-AIDS virus (May *et al*., 2001). The recycling of ruminant carcasses brought the bovine spongiform encephalopathy (BSE) – new variant Creutzfeldt-Jakob disease (CJD) prion (Pattison, 1998). Pig production below trees with fruit bats introduced the Nipah virus (Field *et al*., 2001). Civet cats in wet markets brought out the severe acute respiratory syndrome (SARS) corona virus normally carried by horseshoe bats (Lau *et al*., 2005). Given the diversity of pathogens circulating in the natural ecologies, and food-animal chains, plus global factors such as human demography, urbanization, trade liberalization, and, last but not least, climate change, yet more problems will undoubtedly emerge (Slingenbergh *et al*., 2004). Hence, there is some urgency to identify and rectify the food and agricultural practices that amplify these risks.

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OIE standards and guidelines related to trade and poultry diseases

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SUMMARY

Recognizing the difficulty faced by some countries in fully eradicating animal diseases from their territories as a whole, or to maintain animal disease-free status in parts of their national territories, the World Organisation for Animal Health (OIE) has introduced the concepts of zoning and compartmentalization for purposes of disease control and international trade, in the Terrestrial Animal Health Code. Compartmentalization is based mainly on functional separation by biosecurity measures, whereas zoning is based mainly on geographical separation. Relevant animal subpopulations should be clearly defined, recognizable and traceable, and should be epidemiologically separated from other subpopulations. Veterinary authorities as well as the private sector have important responsibilities in the establishment and maintenance of compartments.

Key words: OIE, standards, guidelines, compartmentalization, zoning

1 INTRODUCTION

The World Organisation for Animal Health (OIE)[1] is an independent intergovernmental organization founded in 1924, and having 172 member countries in January 2008. OIE's mandate is to improve animal health worldwide. The organization achieves this mandate through its six primary objectives, which include ensuring transparency in the global animal disease situation, permanent update of disease prevention and control methods, provision of international solidarity in the control of animal diseases, publication of international animal health standards, and improvement of the legal framework and resources of veterinary services. For several years, the OIE has also had a strong focus on improving animal production food safety and animal welfare. OIE's headquarters are in Paris (France), and there are nine regional offices in the five regions. The OIE now has two regional animal health centres operating in collaboration with FAO, based in Bamako and Beirut, and is planning to establish other centres that will serve as regional centres of expertise.

In order to fulfil the mandate to ensure transparency in the global animal disease situation, the OIE manages the World Animal Health Information System (WAHIS)[2], based on

[1] The World Organisation for Animal Health: http://www.oie.int/eng/en_index.htm.

the commitment of member countries to notify the main animal diseases, including zoonoses, to the OIE. In 2004, OIE member countries approved the creation of a single list of diseases notifiable to the OIE to replace the former lists A and B. The content of the list is based on a decision tree which is part of the *Terrestrial Animal Health Code*. Currently, about one-hundred diseases are listed; thirteen of these are poultry diseases, among which are highly pathogenic avian influenza (HPAI), Newcastle disease, Marek's disease, infectious bursal disease and avian infectious laryngotracheitis.[3]

First outbreaks of all listed diseases should be officially notified to the OIE central bureau within 24 hours, and regular update reports should be provided on the outbreak situation. The information is immediately disseminated to the delegates of all member countries, who can use it to analyse the risk of introduction of diseases into their own countries. Member countries must also provide six-monthly reports on their animal disease situation. The World Animal Health Information Database (WAHID) interface provides access to all data held within WAHIS[4]. The OIE animal health information department actively approaches delegates to verify unofficial information on outbreaks of animal diseases in member countries. In the Global Early Warning and Response System (GLEWS), a cooperative mechanism between OIE, FAO and WHO, the official and unofficial outbreak information of the three organizations is shared to allow better intervention, better analysis of data and more targeted capacity-building in relevant member countries.

As the international standard-setting body for animal health, the OIE has defined standards on notification, trade aspects and surveillance of the listed diseases, including the poultry diseases. The aim of the *Terrestrial Animal Health Code*[5] is to ensure the sanitary safety of international trade in terrestrial animals and their products, by detailing the health measures to be used by the veterinary services of importing and exporting countries. The measures are also meant to avoid the transfer of pathogenic or zoonotic agents without imposing unjustified trade restrictions.

The OIE is in a continuous process of updating its disease standards, while taking into account the latest scientific information on the diseases. For example, the chapter on avian influenza in the *Terrestrial Animal Health Code* was updated in 2004. The new chapter has several significant changes compared to the previous one, such as differentiating between low and highly pathogenic avian influenza and defining HPAI as an infection of poultry. The chapter gives trade recommendations for poultry and poultry products like fresh meat, meat products, eggs, feathers and down. *The Terrestrial Animal Health Code* also provides general guidelines for surveillance and specific guidelines by disease.

The specific disease standards are further defined in related chapters, appendices and definitions, which include: standards for surveillance that have to be met if countries are to declare freedom from disease; standards for conducting risk assessments; humane methods for killing animals if stamping-out of infected populations is necessary; methods for disposal of dead animals; biosecurity standards for poultry establishments; standards for

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2 The World Animal Health Information System, WAHIS: http://www.oie.int/eng/info/en_info.htm?e1d5

3 http://www.oie.int/eng/maladies/en_classification2007.htm?e1d7

4 http://www.oie.int/wahid-prod/public.php?page=home

5 Sixteenth edition, 2007, available at http://www.oie.int/eng/normes/mcode/en_sommaire.htm

the inactivation of viruses; and definitions of "infected" and "uninfected" as applied to a country, zone or compartment. The OIE also publishes guidelines on the use of vaccination, when relevant (e.g. for avian influenza prevention and control).

The Code is accompanied by the *OIE Manual of Diagnostic Tests and Vaccines for Terrestrial Animals* (referred to hereafter as the Manual)[6], which outlines a harmonized approach to disease diagnosis by describing internationally agreed laboratory diagnostic techniques. The instructions in the Manual should be followed in order to allow comparison between results from different laboratories in different countries; for this purpose, quality systems should be implemented in laboratories. The Manual also gives general guidelines on principles for the quality of veterinary vaccine production and guidelines for the development, production and use of disease-specific vaccines.

2 AVIAN INFLUENZA AND NEWCASTLE DISEASE

The spread of the current HPAI strain H5N1 has given rise to an unprecedented situation over the past few years.[7] The disease has important economic and social consequences in affected countries, and humans may be infected due to its zoonotic nature. An important risk is the possible development of a human pandemic virus by mutation or recombination with a human influenza virus.

The OIE strategy focuses on eradication at the animal source through the following key actions: early detection; early warning; rapid confirmation of suspects; rapid response; and rapid and transparent notification. The main goal is to reduce the virus load and circulation in poultry and spread to unaffected areas or countries, and therewith also decrease the risk of human infections or the development of a human pandemic virus (FAO and OIE in collaboration with WHO, 2007). High-quality veterinary services complying with OIE standards, legislation and a clear national chain of command are the basis of animal disease control and eradication.[8,9] Important constraints to the effective control of animal diseases exist in developing and transition countries, as many of these countries have weak or non-existent veterinary services. Newcastle disease is a disease of poultry that is endemic in many parts of the world, and is an important differential diagnosis for HPAI, as the diseases can not be differentiated clinically. Most areas affected by HPAI are also affected by endemic Newcastle disease infections with high mortality in poultry. Many countries have expressed an interest in introducing the concepts of zoning and compartmentalization for these two diseases.

3 ZONING AND COMPARTMENTALIZATION

Recognizing the difficulty that some countries have in eradicating animal diseases from their territory as a whole and in maintaining an animal disease-free status, the OIE has introduced the concepts of zoning (Figure 1 below) and compartmentalization (Figure 2 below) for purposes of disease control and international trade, in the *Terrestrial Animal*

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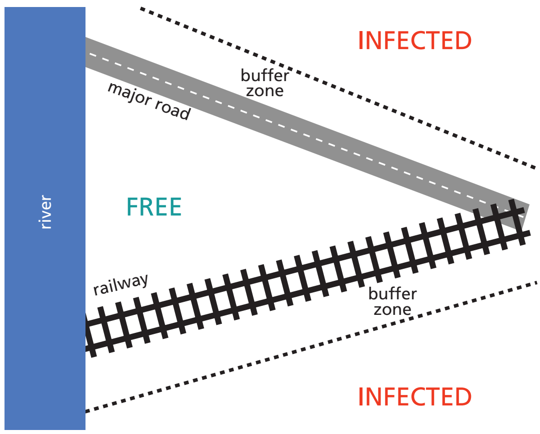
6 Fifth edition 2004: http://www.oie.int/eng/normes/mmanual/A_summry.htm

7 The OIE Avian Influenza Website: http://www.oie.int/eng/info_ev/en_AI_avianinfluenza.htm

8 Capacity-building of veterinary services: http://www.oie.int/eng/OIE/organisation/en_vet_serv.htm?e1d2

9 The new tool for evaluation of veterinary services (PVS Tool) using OIE international standards of quality and evaluation: http://www.oie.int/eng/oie/organisation/en_vet_eval_tool.htm?e1d2

FIGURE 1
The concept of zoning



Health Code. Utilizing these concepts, countries may eradicate a disease from only a part of their territory while the country as a whole is not yet free of the disease. Countries can do this by defining an animal subpopulation with a distinct health status ("free from a certain disease") within its boundaries. They may then resume trade from this part of the territory. Compartmentalization is defined as "one of more establishments under a common biosecurity management system containing animals with a distinct health status", and is therefore based on a functional separation. Zoning applies to animals with a distinct health status on the basis of geographical separation. Zoning has been used regularly by countries in their disease eradication programmes, whereas compartmentalization is a relatively new concept. Both concepts allow concentration of personnel and financial resources where there is greatest chance of success in controlling or eradicating the disease and in gaining or maintaining market access for certain commodities.

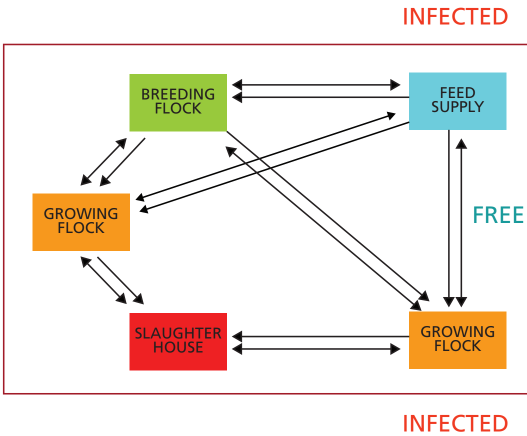
The international standards on zoning and compartmentalization can be found in *Terrestrial Animal Health Code* Chapter 1.3.5 on "Zoning and Compartmentalization". The "General Guidelines on the Application of Compartmentalization" are currently under development and should be added as an appendix to the *Terrestrial Animal Health Code* in 2008 after endorsement by the OIE international committee.[10]

For countries that wish to quickly implement compartmentalization for avian influenza and Newcastle disease as part of their disease control programmes, the OIE has developed a checklist on the practical application of the concept. This checklist is not yet part of the *Terrestrial Animal Health Code*, but can be found on the OIE website.[11] To implement zoning or compartmentalization, other factors like strong veterinary services, a good identification and traceability system, and good surveillance programmes are crucial. Relevant information on these issues can also be found in the *Terrestrial Animal Health Code*: Chapters

[10] See Footnote 5.

[11] http://www.oie.int/eng/info_ev/Other%20Files/En_final_Compartmentalisation_AI_ND_10_05_2007.pdf

FIGURE 2
The concept of compartmentalization



1.3.3 and 1.3.4: Evaluation of Veterinary Services; Appendix 3.5.1: General Principles for the Identification and Traceability of Live Animals; Appendix 3.8.1: General Guidelines on Animal Health Surveillance; and Appendices on disease specific surveillance.[12]

The OIE feels that the time is right to emphasize the possibility of introducing the concepts of zoning and compartmentalization in disease eradication programmes. However, it should also be recognized that the concepts are not automatically applicable to all situations. The basis for applying the concepts is the possibility of clear epidemiological differentiation between the animals that belong to the zone or compartment and those that do not. The effective implementation of the concepts will be influenced by several technical issues, such as the epidemiology of the disease(s) in question, the structure and distribution of the animal population, country and infrastructure factors, the biosecurity measures which may be applicable, the health status of animals in adjacent areas, and the necessary surveillance inside and outside the compartments or zones, which is linked to the efficiency of the veterinary services. For a disease that is transmitted only through direct contact between infected and non-infected animals, the biosecurity measures are different from those needed for diseases that can also be transmitted by air over long distances or that are transmitted only by feed. In the case of the poultry sector, it will in general be easier to implement biosecurity measures in areas where there is a high percentage of highly industrialized commercial poultry compared to areas with a high percentage of smallholders or backyard poultry.

4 PRINCIPLES IN DEFINING A ZONE OR COMPARTMENT

The first basic principle in defining a zone or compartment is clear definition of the animal subpopulation belonging to the zone or compartment. For a zone, this means that the extent of the zone, including its geographical limits including buffer zone, should be clear. For a compartment, it is necessary to define which establishments and related functional

[12] See Footnote 5

units (feed production units, slaughterhouses, etc.) are included. The functional relationships between the units belonging to the compartment, showing their contribution to the compartment, should be described. The animals belonging to the subpopulation in a zone or compartment should always be recognizable and traceable.

The second important principle is to ensure the epidemiological separation of the subpopulation in the zone or compartment from other populations and potential sources of infection. Physical and spatial factors, such as the location of the nearest flocks outside the zone or compartment, the structure of those populations and their health status, and the presence of wild-bird populations, may affect the status of the zone or compartment. Environmental factors, such as existence of nearby wetlands, or seasonal factors may also be important for epidemiological separation. A good biosecurity plan should always be provided for a zone or compartment.

In the case of zoning, the veterinary authority will be primarily responsible for providing the biosecurity plan, whereas in case of compartmentalization, the management of the compartment has the primary responsibility for providing such a plan. The biosecurity plan must describe all factors relevant to the integrity of the zone or compartment, and must show that the zone or compartment is epidemiologically closed. It must provide clear evidence that critical control points for introduction of the pathogen are well managed. Well-described standard operating procedures to implement, maintain and monitor the measures used to manage the critical points should be provided.

Important elements of a biosecurity plan include quality-assurance schemes, procedures for animal and human movement controls, poultry health measures including vaccinations, medications and other veterinary care, control over vehicles, security of feed and water sources, and control of pests and wild-bird populations.

To ensure that the subpopulation in the compartment complies with the defined health status, a surveillance programme should be implemented. Many different combinations of testing and surveillance may be applied to gain the necessary confidence with regard to freedom from the disease in question. However, they should be in compliance with the OIE general and disease-specific surveillance guidelines.[13] Information on the baseline health status of the subpopulation before the zone or compartment was established, and on the surveillance system implemented, should be available, as well as standard operating procedures to be followed in case of suspicion or confirmation of the presence of the disease. A prerequisite for a surveillance programme is the availability of high-quality diagnostic services.

5 RESPONSIBILITIES OF THE VETERINARY AUTHORITY AND THE SECTOR

Veterinary authorities as well as the sector/industry have responsibilities for the establishment of zones and compartments. The veterinary authority is responsible for the essential national infrastructure needed to maintain a zone or compartment (appropriate legislation, national reference laboratories, identification and registration systems, etc) and for the quality of the veterinary services.

Compartmentalization should ideally be the initiative of the private sector; it is par-

[13] See Footnote 5.

ticularly applicable in intensive industries that are vertically integrated. The compartments' responsibilities will lie primarily in the application and monitoring of biosecurity measures, including the use of corrective actions and the implementation of quality-assurance schemes. The management of the compartment should also provide information on the baseline health status of the subpopulation and the surveillance implemented to ensure early detection of disease introduction. The compartment should have standard operating procedures for all actions related to the maintenance of the compartment, and these actions should all be documented. The records should be readily accessible for supervision by the veterinary services. The management of the compartment also has the responsibility to clarify the relationships between the different units comprising the compartment.

The veterinary services are responsible for the supervision, auditing and certification of the compartments. Veterinary services should implement the surveillance programmes in cooperation with the private sector. The veterinary services may also provide model biosecurity plans and generic compartmentalization criteria to facilitate the establishment of the compartments. The costs of maintaining the integrity of compartments should be borne by the private sector.

The initiative for zoning will normally be taken by the government, and the veterinary services will be responsible for the implementation of the zone. Nevertheless, establishments in the zone will be responsible for the implementation of all measures required by the veterinary services, including the biosecurity measures.

Zones and compartments can be established for national disease-control purposes or for international trade purposes. The steps to be taken by veterinary services to resume or maintain trade between exporting and importing countries depend on the circumstances within the countries and on their previous trading history. The importing country must have confidence in the integrity of the zone or compartment as defined by the exporting country. The dossier provided to the importing country must, therefore, contain all information needed for the evaluation and for the country to determine whether it can accept imports from the designated zone or compartment. In the case of compartmentalization, a big part of the dossier will have to be provided by the management of the compartment itself. The importing country must be authorized to conduct an audit *in situ* at any moment.

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Animal welfare in poultry production systems: impact of European Union standards on world trade

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SUMMARY

Animal welfare receives more legislative attention in the European Union (EU) than in many other regions of the world. Animal welfare standards for poultry are generally taken to be higher in the EU than in producing countries exporting to the EU, particularly developing countries. The recent action plan for animal welfare introduced by the European Commission aims to further expand the body of regulatory standards.

In broiler production worldwide, birds are kept on deep litter. Recently, the EU agreed on a new directive to set maximum standards for bird density. However, this is not considered likely to have a great impact on global trade. At present, the difference between Brazil and Thailand and the EU in terms of animal conditions, including bird density, is limited.

In egg production, the majority of commercial layers are kept in battery cages. There is wide variation in space allowance per bird from 300 to 400 cm^2 in Brazil, Ukraine or India to the current 550 cm^2 per hen in the EU. After 2012, hens in the EU will be kept in enriched cages with a minimum space allowance of 750 cm^2 per hen. It can be expected that this will have an impact on world trade in egg products and especially egg powder. Trade in table eggs will continue to be limited to within regions.

The EU is considering the use of labelling to provide consumers with more information concerning the standard of production. Another option could be to use financial mechanisms such as taxes or tariffs. The likelihood that a measure is challenged depends on how difficult it is for exporters outside the EU to meet the requirements.

Keywords: poultry production, animal welfare, economics, international trade

1 INTRODUCTION

Animal welfare in commercial poultry production is an important topic in Europe. In other parts of the world too, there is an increasing focus on farm-animal welfare. In some countries this interest is only driven by export opportunities for poultry meat, especially to Europe. At the same time, increasing requirements pose a possible threat to the market position of meat not produced under upgraded animal-welfare standards or without the guarantee that it was produced under such standards. This could lead to protection by means of import tariffs to be payed at the EU border for products not produced according to the EU standards. In this article we discuss the worldwide status of poultry welfare at farm level and the impact of changes in welfare regulations and requirements in the EU on world trade. This is discussed for both broilers and layers.

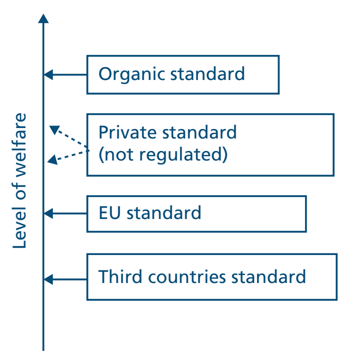
2 THE GLOBAL DIFFUSION OF ANIMAL WELFARE STANDARDS

Animal welfare in poultry production systems is given more legislative attention in the EU than in many other regions. The EU position is partly induced by specific features of the production environment. In addition, policy-makers claim that EU consumers have increasing preferences for the welfare of production animals (European Commission, 2006a). The current situation is presented in Figure 1, in which the vertical line represents a range of lower to higher standards of animal welfare. The legislated standards are placed along the line with no attention given to relative distance at this point. The organic standard for animal welfare is the highest level in the market, far above the regulatory minimum. Producer labels are distributed along the line. This means that some producers, in Europe and elsewhere, maintain animal-welfare standards above the regulatory minimum, usually under a premium-quality label.

Consumer researchers have revealed a wide divergence in the ambitions and motivations of private labels in the EU (Ingenbleek *et al*., 2007). Producers in developing countries also achieve levels of animal welfare that exceed regulatory minimum levels to a different degree. Selected production chains in developing countries already comply, or potentially will comply with EU standards for farm animal welfare and should be allowed to export their products to the EU.

The difference in standards concerning animal-welfare around the world is related to income, culture and religion. The extent of animal welfare-legislation generally reflects income levels, for a number of reasons. First, the consumption of livestock products grows

FIGURE 1
Current situation of regulatory and private standards for farm animal welfare in the EU and trading partners



Source: adapted from Eaton *et al.* (2005).

with rising income levels – this is initially manifested by increased demand for quantity, then by rising quality requirements and increased demand for superior types of meat and other animal products. Second, as incomes increase, demand for public goods rises as well as demand for private goods. Aspects of animal welfare can be considered public goods; welfare regulations typically serve to ensure that these are provided (McInerny, 2004). Countries in more advanced stages of development have governments that are more effective in supplying such advanced public goods.

Table 1 presents an overview of the relationship between welfare and income levels in a number of countries around the world. The level of legislation in place to regulate the welfare of poultry in these countries was investigated through a survey. For broilers, the level was determined by the maximum bird density per m^2 and for layers by the space allowance per hen and the situation with respect to mutilations (e.g. beak trimming). Each country was given a score on a scale of 1 to 5 for the level of legislation on poultry welfare. A country's income was scored on a similar scale. The following classes were used for gross national income (GNI) per person: 5 for GNI above US$30 000, 4 for GNI between US$20 000 and US$29 999, 3 for GNI between US$10 000 and US$19 999, 2 for GNI between US$5 000 and US$9 999, and 1 for GNI below US$4 999 (data from FAO, 2006).

Table 1 shows that Switzerland has an exceptional position, with a high standard for poultry welfare. Despite minor differences, all countries in northern and western Europe have higher standards for the welfare of both layers and broilers than the EU standard. In general, southern and eastern members of the EU have no poultry welfare legislation except for the EU Directives. The new EU member states, like Poland and Hungary, have a medium level of GNI, but are obliged to work with the EU standards. Outside Europe, only Australia, Canada, New Zealand and the United States of America show any interest in animal welfare.

TABLE 1
Welfare level and income level of selected countries

Welfare level	Income level	Main poultry-producing countries
5	5	Switzerland
4	5	Northern Europe: Denmark, Finland, Norway, Sweden
4	5	Western EU: Austria, Germany Netherlands, United Kingdom
3	4/5	Southern EU: France, Italy, Spain
3	3	Eastern EU: Hungary, Poland
2	5	Australia, Canada, United States of America
1	5	Japan
1	4/3	Near East: Saudi Arabia, United Arab Emirates
1	2/3	South America: Argentina, Brazil, Chile
1	2/3	Eastern Europe: Ukraine, Russian Federation
1	1/2	Asia: China, India, Thailand

3 BROILERS

3.1 Housing systems for broilers

Broilers are generally held in large groups either in environmentally controlled housing or in open, naturally ventilated poultry houses. Broilers are usually kept free on deep litter with automated provision of feed and water. In most countries, commercial breeds selected for rapid growth, are used. Farmers around the world understand that in order to raise the birds with maximum efficiency, many conditions must be fulfilled – stress prevention, supply of good feed and water, and good sanitation. In providing these conditions, farmers ensure a basic level of animal welfare. However, there is a growing consensus that good productivity and health are not necessarily indicators of good welfare (Jones, 1996).

3.2 Welfare regulations for broilers

Following a long period of discussion among the member states, in May 2007 the European Commission agreed on a new directive covering the welfare of broilers (European Commission, 2007). All European producers will have to meet minimum standards by June 2010. According to the EU Commissioner, the directive was needed because "EU consumers repeatedly expressed concern at the welfare problems arising in intensive chicken farming" (ibid.). The main provision of Directive EC/2007/43 is to reduce the stocking density by setting a maximum density of 33 kg per m^2. Under certain conditions, with good ventilation and temperature control systems, the maximum can be 39 kg. Under exceptionally high welfare conditions, the density can be increased by a further 3 kg. This can be achieved by low mortality rates. The directive also sets conditions covering lighting, litter, feeding and ventilation requirements.

Although scientists include more points when assessing the welfare of broilers, such as high growth rate, leg disorders, ascites and respiratory problems (SCAHAW, 2000), in this paper it is assumed that the welfare of broilers, according to the EU directive, can be measured by bird density and mortality. At EU level, there was previously no regulation on broiler welfare. However, Denmark and Sweden already had maximum densities of 40 kg and 36 kg per m^2 of poultry house, respectively (Berg *et al*., 2004). In Germany and the United Kingdom, the density was controlled by voluntary guidelines. Switzerland, not a member of the EU, maintains a stringent limit for broiler production of 30 kg per m^2 of poultry house. As far as the authors are aware, there is no country outside Europe with any regulation or legislation on maximum broiler density. In the United States of America, the National Chicken Council has developed animal welfare guidelines to ensure the proper care, management and handling of broilers; bird density (with a live weight between 2 and 2.5 kg) is restricted to 38 kg per m^2 (Hess *et al*., 2007). However, this is a voluntary guideline. In Brazil there are no regulations on the density of broilers; however, due to the climate, farmers keep broilers at a relatively low density of approximately 35 kg per m^2.

3.3 Trade in poultry meat

The international trade in broiler meat grew very rapidly in recent years. In many regions, poultry is increasingly preferred as an affordable source of animal protein, which unlike pork or beef is accepted for consumption by most of the major religions in the world. Figure 2 provides an overview of the global poultry-meat trade in 2004. In 2004, 12 percent of the

FIGURE 2
Main trade flows in poultry meat in 2004 (in 1000 tonnes)

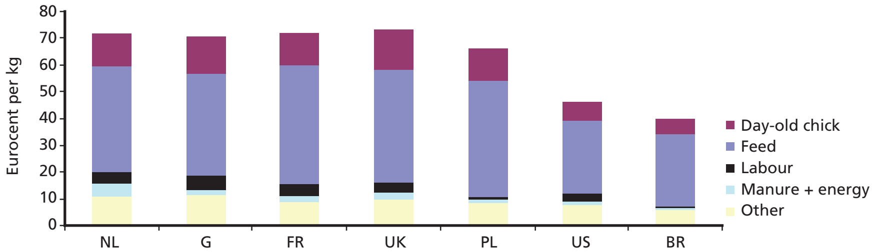
Source: PVE (2007).

poultry meat produced reached the world market (Windhorst, 2006). The main exporters of poultry meat are the United States of America, Brazil and the EU. The main importing regions are the Russian Federation, North Africa and the Near East, China and the EU.

Market developments and outbreaks of diseases (such as avian influenza) affect the make-up and flows of trade in poultry products. While the effects of most outbreak-related disruptions fade after one to two years, endemic diseases may have a lasting impact on trade. Other factors that exert a longer influence are related to the cost of production and consumer preferences (Dyck and Nelson, 2003). In addition, trade policies are particularly determinant for the poultry trade. Each element is discussed separately below.

Production costs. Natural resources and the costs of feed and labour are the main determinants of the competitiveness of livestock and meat-processing sectors. Van Horne and Bondt (2006) analysed the differences in production costs for broiler production across countries. Based on the findings of that study, Figure 3 compares production costs in several EU countries with those in the United States of America and Brazil. In 2004, the production costs of broiler meat in the United States of America were 36 percent lower than in the Netherlands; in Brazil, the production costs were more than 40 percent lower. The lower production costs in the United States of America and Brazil compared to the EU countries were largely due to the lower price of feed (local supplies of feed raw materials) and other favourable conditions. Production is carried out by means of efficiently organized integration. The broilers are kept in relatively simple and cheap poultry houses. In addition, production costs are lower in both countries because of lower levels of legislation and

FIGURE 3
Production costs for broiler meat (eurocent per kg live weight) at farm level in the Netherlands (NL), Germany (G), France (F), United Kingdom (UK), Poland (PL), United States of America (US) and Brazil (BR) in 2004



Source: data from van Horne and Bondt (2006).

regulation. One example is the use of meat-and-bone meal, which is permitted in both countries.

Consumer preferences. Much of the global trade in poultry meat is explained by variations in consumer preferences across the globe. While consumers in the United States of America and the EU largely favour breast cuts, consumers in Asia prefer the meat on legs and wings. Producers export the cuts to the markets where they get the best price (Dyck and Nelson, 2003). The EU provides an example of the way this trade works. All breast cuts from EU slaughters are sold in EU markets, while the meat of legs and wings is exported to the Russian Federation. Imports from Brazil and Thailand satisfy the excess demand for breast cuts in the EU. Similarly, the United States of America's poultry industry supplies boneless chicken breasts to the home market, where consumers pay a relatively high price. The other parts of the carcass are exported to foreign markets where a higher price can be fetched. This explains why meat-producing countries both import and export, and why most of the trade in poultry products takes place in cuts and not whole carcasses.

Trade policy. Trade policy on broiler meat has a large impact on trade flows, in particular the policies of the EU. In order to accommodate a higher domestic price level for poultry by limiting imports, the EU allocates quota for imports from a selected number of exporters, most importantly Brazil and Thailand. Poultry meat from the United States of America is banned from EU markets for sanitary and phytosanitary (SPS) reasons. Following the avian influenza outbreak of 2003/2004, the EU accepts only cooked poultry meat from Thailand (Eaton *et al.*, 2005).

3.4 Relation between broiler welfare and world trade

It is considered unlikely that the upgrade of legal EU animal welfare standards will have a large impact on the composition of global trade in poultry meat. The EU has reached agreement with Brazil and Thailand on maximum quota to be imported. Breast meat from Brazil can compete in the European market due to very low production costs. Breast meat from Thailand can compete in the European market as a result of a preference for dark leg meat in the regional market. Production costs in the EU are expected to increase following the implementation of the EU directive on broiler welfare. The implementation of the broiler directive may, therefore, lead to stronger calls from EU producers for continued border protection to check the competitive pressure from foreign producers. This raises the question of whether EU demand for animal welfare provides a justifiable basis for continued protection.

There are at least two economic arguments as to why it should be considered inappropriate to allow border protection for broiler meat on the grounds of animal-welfare requirements. First, differences in animal-welfare conditions between the EU and exporting countries are currently limited, although there are limitations to a reliance on bird density as a measure of welfare. The density at which broilers are kept in the exporting countries is already at the EU target level. Second, the incremental costs of a further reduction in Brazil and Thailand are lower than in the EU, due to lower costs for housing and labour. Producers in exporting countries would be likely to adapt in response to regulatory demands in the EU for increased animal welfare if they were to be implemented. Meat exporting firms have demonstrated a willingness and capacity to adapt. Bowles *et al*. (2005) provide preliminary evidence of restructuring and certification within Argentinean and Thai broiler meat supply chains in response to changing buyer demands in the EU. Both observations raise questions as to whether continued border protection for EU poultry producers serves as an economically rational instrument to achieve higher levels of animal welfare in the production of the broiler meat consumed in the EU. Furthermore, these points demonstrate that, in principle, an upgrade of EU regulation requirements for animal welfare in imported broiler meat would not operate as a non-tariff barrier to exporters, but rather as an opportunity to create additional added value.

4 LAYERS

4.1 Housing systems for layers

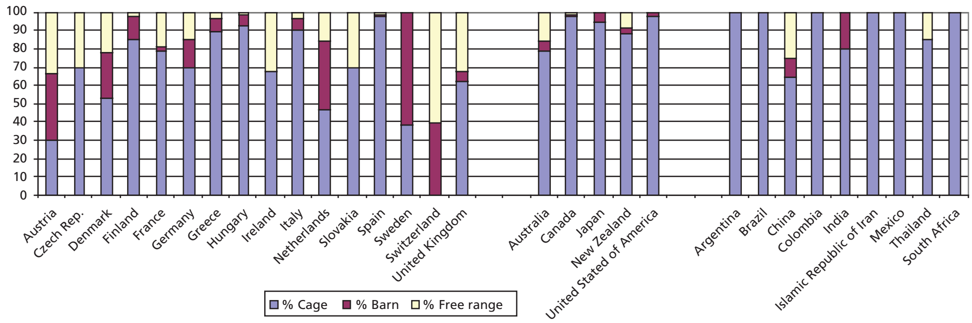
The majority of commercial layers in the world are kept in confined housing systems with light control, power ventilation and mechanical feeding. The space per hen in cages is very limited, with no space to express natural behaviours like sand bathing and wing flapping. In Europe, to accommodate social concerns about animal welfare, alternative housing systems have been developed to improve the welfare of layers. In general, today's egg producer has the choice of three main housing systems:

- battery cages – small enclosures with welded wire mesh sloping floors;
- barn systems – in which the layers are kept on litter and the birds have freedom to move around within the poultry house; and
- free range systems – in which the layers also have access to an outdoor run.

The battery cage is still the most economic way to produce eggs (van Horne, 2006). Such housing has also proved to be the best option for disease prevention (Hulzebosch, 2006). Figure 4 gives an overview of the share of hens kept in cage, barn or free range systems in 30 countries around the world. The data are provided by the IEC (International Egg Commission) reporters in the member countries (IEC, 2007).

Figure 4 shows a wide variation in housing systems. Outside the EU, only Australia and New Zealand have some commercial non-cage systems. In all other countries, farmers

FIGURE 4
Share of hens kept in cages, barn or free range systems in 30 countries around the world



Source: IEC (2007).

mainly work with cage systems. In China, India and South Africa, the numbers with non-cage housing probably refer to non-commercial backyard farming (IEC, 2007). Also within the EU there is a wide variation in the percentage of hens in non-cage systems. Due to growing concern about animal welfare in cages, especially in northwest Europe, farmers are investing in alternative housing systems. The countries with less than half the hens in cage systems are Austria (30 percent), Sweden (39 percent) and the Netherlands (47 percent). Hens are mainly kept in cages in Spain, Hungary, Italy and Greece. Switzerland, not a member of the EU, already has a ban on traditional cages, and as a result all hens are kept in alternative systems.

4.2 Welfare regulations for layers

In the EU, a directive (1999/74/EC) established European standards for improving the welfare of commercial hens. By 2012, all traditional cages in the EU should be replaced by enriched cages or alternative housing systems. In an enriched cage, a hen has 750 cm^2 of cage area, a perch, a nest and a litter box. In the current situation, layers kept in cages within the EU have access to 550 cm^2 per hen. Although there is an EU regulation, individual countries are allowed to have stricter laws. This is the situation in Austria, Germany and Sweden (Berg, 2006). In the Netherlands, a possible ban on all cage systems is being discussed (summer 2007). In this article we take the EU directive as a guideline for defining the main components of welfare. The space allowance per hen, enrichment of the cage and proper beak trimming are the main components regulated by the EU. However, scientists also include expression of natural behaviour, induced moulting, cannibalism, injuries, osteoporosis and depopulation processes in their discussions of poultry welfare (da Cunha, 2007).

In the United States of America, some fast-food chains are demanding minimum standards for housing densities from their suppliers. In 2008, United Egg Producers (UEP) will start a voluntary certification programme to implement a housing density of 430 cm^2 per hen. In Canada, a code of practice recommends a similar density. In Brazil, there is no nationwide legislation governing the welfare of poultry (ibid.).

In general, it can be stated that in countries in Asia and South America, there is no legislation at all to regulate the welfare of layers. An inventory (van Horne, 2006) showed that hens in India, Ukraine and Brazil are kept in cages with a space allowance of 300 to 400 cm^2 per hen. Farmers choose this density as the economic optimum giving the highest income per cage. American calculations (Bell, 2000) show that in purely economic terms, 350 to 400 cm^2 per hen gives the highest income for a farmer in the United States of America.

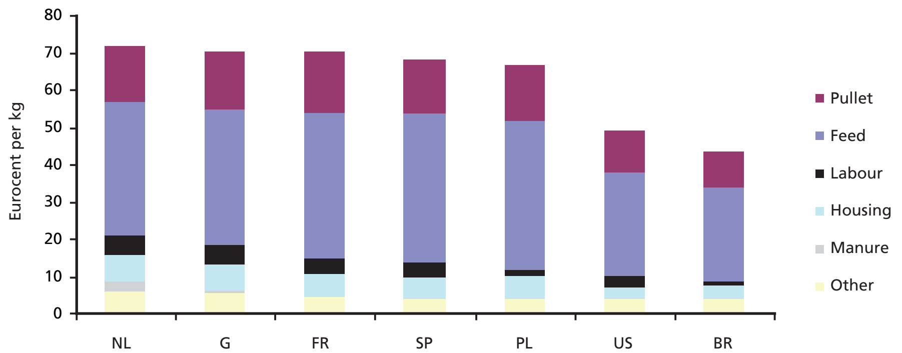
Mutilations, like beak trimming, have also been subject of discussion for many years. Beak treatment of laying hens is regulated at EU level. In order to prevent feather pecking and cannibalism, member states may authorize beak trimming, provided it is carried out by qualified staff on chickens that are less than ten days old. However, within Europe there is great variation between countries with regard to legislation and practice in the field (Fiks-van Niekerk and de Jong, 2007). Beak trimming is not allowed at all in Sweden, Norway and Finland. Beak trimming is strictly regulated in Austria, Belgium, Denmark, Germany, the Netherlands, Switzerland and the United Kingdom. Most southern and eastern European countries (e.g. France, Hungary, Italy, Poland and Spain) have no legislation other than the EU Council Directive 1999/74.

4.3 Trade in eggs and egg products

Worldwide, trade in eggs is very limited. In 2004, only 2 percent of the eggs produced reached the world market (Windhorst, 2006). The main exporters of eggs are the Netherlands (26 percent of total world trade), Spain (10 percent), China (8 percent), Belgium (8 percent) and the United States of America (7 percent). Eggs are mainly traded regionally within Europe as well as among Asian countries. Besides trade in shell eggs, there is some trade in egg products. Trade in egg powder is particularly increasing. Egg powder can be stored for a long period and involves low transportation costs. It is expected that in the near future egg powder will be produced in low-cost countries and exported to the food industry (bakeries, pasta and sauce factories) in developed countries (Tacken *et al*., 2003).

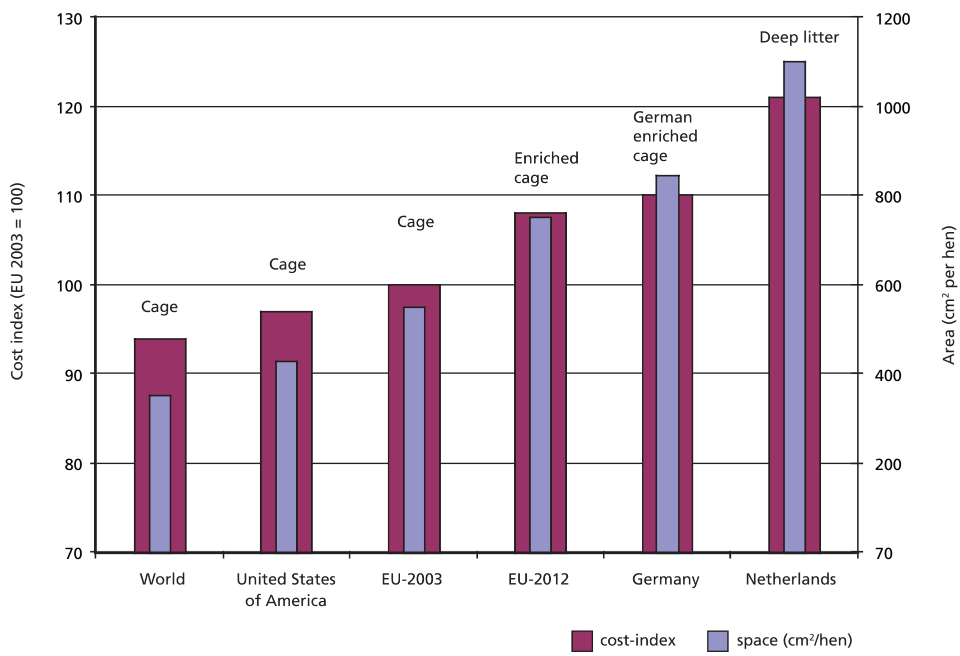
Cost of production. Trade in eggs and egg products is mainly influenced by differences in production costs. Van Horne and Bondt (2006) analysed the differences in production costs for egg production across countries. In this study, the United States of America and Brazil were selected as examples of the situation outside the EU. In 2004, the production costs of eggs in the United States of America were 30 percent lower than in the Netherlands, while in Brazil the production costs were more than 40 percent lower. Figure 5 gives a breakdown of the cost components. The lower production costs in the United States of America and Brazil were largely due to the lower feed price (local supplies of feed raw materials) and the favourable climatic conditions. In addition, production costs in both countries are lower due to lower levels of legislation and regulation, more specifically relating to: a) the absence of legislation on housing requirements (the floor area per hen is between 350 and 400 cm^2); b) the absence of a ban on the use of meat-and-bone meal; and c) the absence of legislation on beak trimming.

FIGURE 5
Production costs for eggs (eurocent per kg) at farm level in the Netherlands (NL), Germany (G), France (F), Spain (SP), Poland (PL), the United States of America (US) and Brazil (B) in 2004



Source: data from Van Horne and Bondt (2006).

FIGURE 6
Relationship between costs for animal welfare and the area per laying hen



4.4 Comparing production cost in housing systems for layers

In general, there is a relationship between production costs and the space standard for laying hens. Figure 6 gives an overview of this relationship in different parts of the world. The calculations were made as part of a study in which a possible ban on enriched cages in the Netherlands was discussed (van Horne *et al*., 2007). If the enriched cage is prohibited unilaterally in the Netherlands in 2012, laying hens will have to be kept in barn housing systems with a minimum area of 1 100 cm^2 per bird. Since 2003, layers in the EU get 550 cm^2, and after 2012 layers will be kept in enriched cages with 750 cm^2 per hen. In the United States of America, voluntary rules apply, which are based on 430 cm^2 per hen with effect from 2008. In the other countries of the world, hens are kept in cages with 300 to 400 cm^2 per hen. Figure 6 shows that the production costs of eggs increase when the area per bird in cage housing is increased from the world level (350 cm^2) to the standard in the United States of America (430) and to the current EU level (550 cm^2). The production costs further increase when there is a switch to enriched cages (750 cm^2), German enriched cages (800 cm^2) and barn systems (1 100 cm^2).

4.5 World trade in relation to welfare of layers

The international trade in table eggs continues to be limited primarily to within regions. This also applies to liquid egg products. Some of the eggs are processed into egg powder. Because of its long-keeping qualities and the relatively low transport costs, there is an international trade in this product. In some countries, such as Brazil and India, the production cost of eggs is much lower than in the EU. This is due to cheaper feed (supply of feed ingredients) and the absence of animal-welfare legislation. The European market is currently protected by import duties which, together with the transport costs, compensate for the difference in production costs. The European purchase price of eggs is increased by animal-welfare measures, while at the same time, the EU intends to reduce the import duties in the context of the World Trade Organization (WTO) negotiations. In this situation, it is economically more attractive for the food industry to replace European liquid-egg products with powdered egg from countries outside the EU. Consequently, egg products will be purchased from third countries where animal welfare standards are significantly lower than in the EU.

5 GENERAL DISCUSSION

Animal welfare is given more legislative attention in the EU than in many other regions. This is especially the case for layers. Some producer labels operate animal welfare standards above the regulatory minimum. Also, producers in developing countries achieve levels of animal welfare that exceed EU regulatory minimum levels to a different degree. Animal welfare concerns should not motivate categorical trade restrictions on imports of poultry products from developing countries into the EU. The European Commission, backed by a group of core member states in northwestern Europe, has indicated strong ambitions to improve animal welfare in the EU and its trading partners (European Commission, 2006b).

The EU focuses on animal welfare via various paths. EU countries are among the driving partners in discussions on animal protection within the World Organisation for Animal

Health (OIE) which has a working group on animal welfare. The OIE is accepted under the WTO agreement as the body that sets the standards on veterinary issues in global trade. Currently, the WTO has not explicitly recognized animal welfare as a legitimate concern, i.e. a cause for impeding trade. The EU has placed the issue of animal welfare on the agenda for negotiations under the Doha Round, but there has been very little discussion recently. Since the 2005 Annual Meeting, the member countries of OIE agree on general guidelines for animal welfare in relation to slaughter, protection for animals during transport and the killing of animals for disease-control purposes (OIE, 2004). In the short term it cannot be expected that the OIE will provide comprehensive global standards on animal welfare at farm level.

Meanwhile, one option is to promote either voluntary or mandatory use of labelling to provide consumers with more information concerning the standard of production. Consumers could then make better-informed choices with respect to their concerns over animal welfare. The aim of such labelling is also to provide an incentive for domestic and foreign producers to increase animal-welfare standards above the EU's minimum requirement. In addition to providing more information to consumers by means of labelling, there is also the possibility of using financial mechanisms such as taxes or tariffs to reduce the price difference for consumers. This could be a European label, tax or tariff based on animal welfare performance. Such a scheme is open to challenge under WTO rules if considered discriminatory against producers of livestock products that want to export to the EU. The likelihood that a measure is challenged depends on how difficult it is for exporters to meet the requirements and the expected effectiveness of the label or (border) tax in segmenting the meat market.

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Zoonotic disease risks and socio-economic impacts of industrial poultry production: review of the experience with contract growing in the United States of America

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SUMMARY

The model of food animal production in the United States of America, which is characterized by an industrial scale and organization, is currently expanding globally, particularly in Asia. The practice of contract poultry growing, in which firms contract out the raising of live chickens to independent farmers, is often a key component of this system. The poultry industry in the United States of America is highly vertically coordinated, and contract growing within this coordinated system reduces economic risk and costs to the firm (known as the integrator), and to some extent to the growers as well by providing the growers with market access for their products. However, contract growers assume the burdens of many of the costs as well as the negative health and social externalities of poultry production, including waste management, occupational and community health risks, implementation of farm-level biosecurity and socio-economic decline. The disparity in economic power between integrator and grower allows the integrator to outsource these externalities onto the grower, and exclude these negative by-products from their costs of production. In light of concerns regarding emerging zoonoses, particularly pandemic influenza, the potential consequences of this system for global public health are significant. A full understanding of experience in the United States of America with respect to the implications of the zoonotic disease risks and economic impacts associated with contract growing can inform policies aimed at reducing these risk factors in nations where the private sector is increasingly adopting a contracting model.

Key words: poultry, United States of America, model, contract

1 INTRODUCTION

Methods of food animal production affect consumer food safety, agricultural and national economies, and the environment. Despite growing awareness of the global implications of food animal production in terms of food safety, its effect on the health, economic and social wellbeing of rural communities is less frequently studied. Over the past 70 years, the production of animals for human consumption has undergone dramatic transformations in intensity, scale and geographic concentration. The poultry industry in the United States of America was the first sector in which rapid consolidation and vertical coordination occurred, starting in the 1930s, and this process has altered broiler poultry production from household-level enterprises to a high-throughput agribusiness on an industrial model. Today, this highly integrated and intensive nature characterizes the poultry industry in developed countries. Middle-income countries, particularly Thailand, Brazil and China, have witnessed a rapid industrialization of the production of food animals for domestic consumption and export in recent years, and these trends are expected to continue as demand for poultry increases around the world (OECD-FAO, 2006). These changes have clear public benefits, in that they facilitate the reliable production and delivery of low-cost animal protein to both domestic and global markets, providing improved quality control and the structure for rapid uptake of new technology. Along with these benefits, however, high-throughput animal husbandry has led to increased concerns about food quality, animal welfare, environmental contamination, cohesion of farming communities and the development of antibiotic resistance (Cole *et al*., 2000; Silbergeld *et al*., 2008).

Human contact with poultry, both at the household and the industrial level, is a clear risk factor for exposure to avian commensals that can infect humans, including bacteria such as *Campylobacter* spp., *Salmonella* spp. and *Listeria monocytogenes*, as well as viruses such as those causing avian influenza. Epidemiological analyses of human infections with the H5N1 strain demonstrate that close interaction with domesticated live poultry is a risk factor for human infection with the virus (van Boven *et al*., 2007; Babakir-Mina *et al*., 2007). Given challenges in animal-disease monitoring in areas with widespread household-level poultry production, coupled with difficulties in active human-health surveillance in most regions of the world, the industrialization of poultry production is viewed by some policy-makers as a way to reduce risk at this critical human–animal interface. Yet, recent H5N1 outbreaks in poultry in the United Kingdom and China, as well as a little-publicized outbreak of low pathogenic avian influenza in the United States of America in 2007, demonstrate how industrialized production poses distinct risks for cross-infectivity between wild birds and poultry, and reinforce how these risks are not prevented by standard biosecurity practices. This is because these large operations, while confined, are not inherently biosecure or biocontained; the lack of adequate management of animal wastes and the transport of these and other by-product materials over long distances may, in particular, provide a major route of pathogen release and transfer.

The industrial poultry model often includes the practice of contract growing, in which firms contract the raising of chickens to independent farmers, who are responsible for the delivery of chickens of market weight back to the firm. The farmer is paid according to the acceptability and total weight of the finished product; he or she bears the costs of feed, energy, labour, and any loss of chickens over the growing period. Contract growing is a central component of the industrial poultry model in the United States of America. The practice is being expanded by firms from the United States of America in other countries (e.g. Tyson in Mexico) as well as being adopted by local businesses in middle-income countries (e.g. Sadia in Brazil). Vertical coordination and contract growing in this industry are not driven by evidence that these methods decrease zoonotic disease risk, but by the economics of poultry production on a commercial scale.

The implications of contract growing for zoonotic disease emergence and the socio-economic sustainability of rural communities are not well understood. As industrial-scale contract growing is exported to the middle- and low-income nations, it is critically important to examine the consequences of this model for factors relevant to health, including the autonomy and economic solvency of contract growers, poultry workers and their communities. In this paper, we examine the potential consequences of the transition for zoonotic disease exposure and social decline, focusing on experience in the United States of America in order to highlight potential risks facing the developing world.

2 STRUCTURE OF THE POULTRY INDUSTRY IN THE UNITED STATES OF AMERICA

Industrial food animal production is defined by its high-throughput production methods, in which thousands of animals of a single breed are grown at one site under highly controlled conditions. The animals are typically raised in confined housing, provided with defined feeds rather than access to forage, and managed in order to facilitate the uniform and reliable production of meat, milk or eggs.

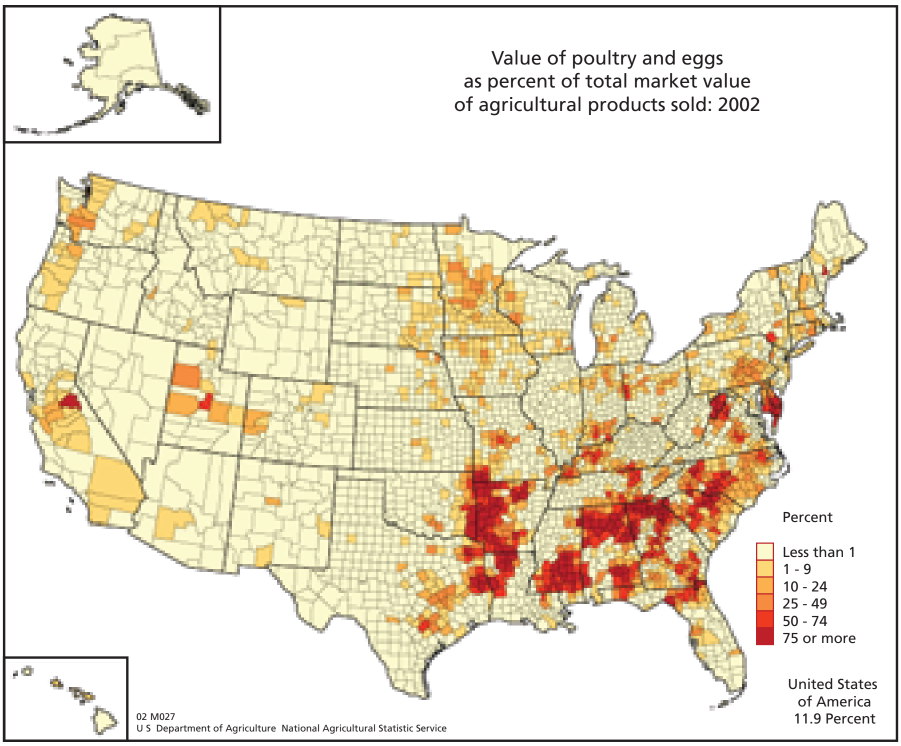
The transformation of poultry production in the United States of America over the past half century is characterized by vertical integration, vertical coordination and specialization. Vertical integration occurs when a single firm, known as an integrator, controls all or most aspects of production from "farm to fork". Vertical coordination is an organizational structure in which the firm ensures that each production process is managed and coordinated, without the firm necessarily controlling all aspects of production. From a precise definitional perspective, the poultry industry in the United States of America is vertically coordinated, rather than integrated, as key functions (notably raising the animals) are contracted out; however, the firm in this structure is commonly referred to as an integrator, and we will use this term in this paper.

In the United States of America, a relatively small number of corporations function as integrators. Tyson Foods, Pilgrim's Pride, Gold Kist and Perdue, together, produce 75 percent of the broilers sold annually by weight (USPEA, 2005). The poultry industry is highly specialized, with different firms dominating egg, broiler and turkey production. Specialization allows firms to enhance economies of scale by narrowing the range of products produced and streamlining operations. Moreover, a key characteristic in the organization of the integrated industry is that the integrator controls the slaughter and processing of animals into consumer products, thus maintaining economic control at the switch point from agriculture to the food industry. Because of this control, it is difficult for other entities, such as independent farmers, to enter the market.

The poultry industry in the United States of America currently produces nearly 9 billion broiler chickens per year (USDA, 2005). The industry observed staggering increases in production and density over the last half century. In 1954, there were no broiler poultry farms in the United States of America with more than 100 000 birds. By 1974, 30 percent of farms had 100 000 birds or more, and by the middle of the 1990s, nearly 100 percent of broiler facilities housed more than 100 000 live birds at a time (Hinrichs and Welsh, 2002). Broilers are the single largest commodity among poultry products, accounting for US$20.9 billion of the US$28.8 billion revenue from poultry in 2005 (USDA, 2005). Poultry production in the United States of America is highly concentrated along the eastern seaboard and in the southeastern states, with nearly 70 percent of total value from poultry generated in the Northeast, Appalachia, Mississippi Delta and the Southeast. Figure 1 depicts dominant regions for poultry and egg production in the United States of America.

The localization of poultry production in the United States of America is independent of major markets or population centres. The ability to absorb costs, including energy, associated with transporting poultry products from these concentrated areas to major market centres speaks to the vast economies of scale derived from consolidation. Consumption of broilers has increased dramatically in the United States of America, coinciding with the coordination of the industry, even as demand for other meat products has remained stable (Figure 2).

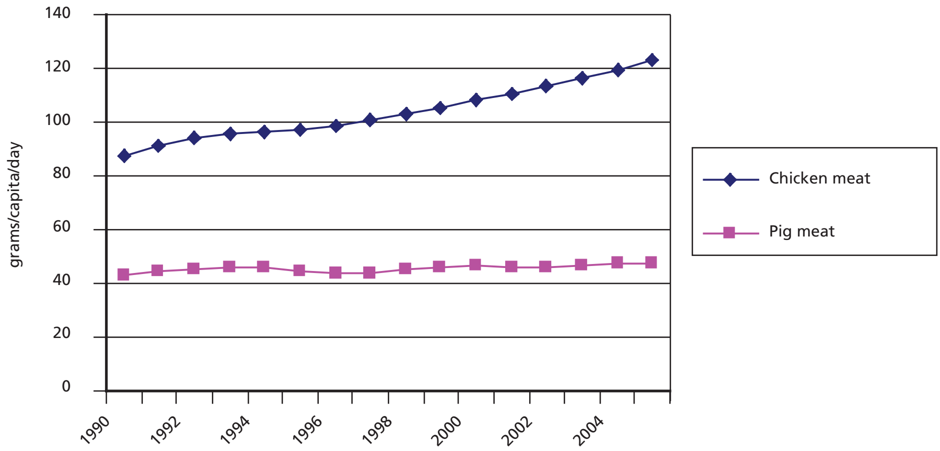
FIGURE 1
Value of poultry and eggs as a percentage of total market value of agricultural products sold in the United States of America in 2002



Source: United States Department of Agriculture. (http://www.nass.usda.gov/research/atlas02/).

FIGURE 2

Per capita consumption of chicken and pig meat in the United States of America, 1990–2005



Source: FAOSTAT (2005).

This transformation in organization and density of production affected the workforce involved in food-animal production and the nature of this work in the United States of America. Grey *et al*. (2007) estimate that at present there are 54 000 poultry and pig workers in the United States of America, of which 10 500 work in broiler confinement facilities (Gray *et al*., 2007). This represents a substantial decrease in the numbers of farmers and farm workers, while the numbers of processing plant workers has increased. On the farm, the growers manage and tend to flocks, usually with the help of hired labour and family members. Chicken catchers, who are contracted or employed by the integrator, harvest live chickens from the growers' facilities at the end of the six-week growing cycle. The remaining workers in the industry work in processing facilities.

3 CONTRACT GROWING: A MODERN "SHARECROPPING" MODEL

Growers play a unique role in the system in that they are responsible for mitigating important health and environmental risks, but are outside the direct employ of the integrator. Contract growing became commonplace in the United States of America soon after mid-century. By 1960, 90 percent of broiler production occurred through contract growing (Welsh, 1997). Integrators breed the parent stock, produce and hatch eggs, provide chicks, feed and veterinary care (including antibiotics and other additives). Growers provide chicken houses, labour, utilities and operating and maintenance costs. Growers are responsible for the disposal of animal wastes and dead birds, as well as cleaning and sanitizing their facilities. Notably, growers are also responsible for many of the costs associated with the implementation of biosecurity measures at the farm level. Growers often, but not always, own the land on which animals are raised, but they do not own the animals. Integrators retain ownership of the animals throughout the growing process and have full access to the contract growers' facilities. In essence, the grower's product is his or her labour and capital investment, not the animals he or she raises. The system is reminiscent of sharecropping, an agricultural system common in the southern United States of America in the second half of the nineteenth century, in which the farmer sells his or her labour, and works land owned by others, in exchange for a share in the profits determined by the firm to which he or she is contracted. Sharecroppers of this period, like poultry growers, did not sell directly to the consumer market and, therefore, could not adjust directly to market demands.

Integrators set the criteria for raising chickens in the contract, which requires chicken houses to be built to precise specifications, including stipulations for design, construction, ventilation, heating, cooling and lighting systems. Broiler growers typically build at least four houses on their property, each holding between 25 000 and 70 000 birds, and some build as many as 16 (Stull and Broadway, 2003). In fact, one of the incentives to grow poultry rather than other animals or crops is that return per acre of land is relatively high and labour inputs are relatively low for an agricultural investment. However, the costs are considerable, and growers may borrow as much as 110 percent of the cost of construction over 10–15 year loans. A contract with an integrator makes it easier for growers to secure loans (Stull and Broadway, 2003). Start-up costs per growing house average US$170 000, and new growers entering the industry often face costs up to US$600 000 for multiple houses (Cunningham, 2005).

The production contracts also specify payment in terms of weight of acceptable live broiler produced at the end of the growing period. However, this payment is reduced by the cost of feeds required to bring the flock to market weight, and the grower bears the costs of the time taken to reach market weight in terms of energy and labour costs (hiring workers). Specifics of grower contracts differ by integrator, but most are structured using a "tournament scheme" in which a component of payment is based on the relative performance of a given grower. For the tournament component of payment, growers are rewarded or penalized based on their feed conversion rate (the amount of feed required to produce the weight of acceptable broiler at the end of the growing period) in comparison to that of a comparable group of growers contracted with the same integrator during that same harvest period. Contracts also generally include a minimum guaranteed payment per pound[1] of saleable meat (currently about 5 cents/pound). Contract duration varies in length, but most are very short term and only cover a single flock at a time (about six weeks) (Vukina and Leegomonchai, 2006). Contracts generally do not guarantee the number of flocks the grower will receive per year (Vukina and Leegomonchai, 2006). These conditions give considerable power to the integrator.

Growing contracts provide clear benefits to integrators. They allow integrators to maintain control of the stages of production most critical in maintaining the link between demand and supply and safeguard them from a central form of uncertainty in the poultry production process: the actual rearing and survival of marketable chickens. Tournament payments reduce the cost of contracting to the integrator and allow the integrator to pass on some of the market-based uncertainty to the grower. This structure also rewards technical efficiency among growers, to the extent possible given integrator specifications, promoting

[1] 1 pound = approximately 0.45 kg.

efficient use of feed, antibiotics, energy and labour inputs (Knoeber, 1989). Contracting also allows integrators to accommodate new technology into production practices without incurring significant costs (Vukina, 2001). Costs associated with waste management are also shifted to the grower, allowing the integrator freedom to increase production density with reduced concern for constraints posed by disposal of animal wastes.

Importantly, contracting allows integrators to avoid the costly capital investment of building and maintaining chicken houses. Modern high-density poultry houses are highly specific assets, meaning that the design and financial investment associated with facilities renders use for a different purpose difficult, if not impossible. Growers absorb the risk associated with this specific asset, effectively binding them to poultry production under contract to the integrator that stipulated the specifics of house design and management. The location of the growing facilities in close proximity to a particular processing plant and feed mill may also bind a grower to a specific integrator, as can construction and maintenance specifications that vary among firms, making it difficult for a grower to switch integrators (Vukina and Leegomonchai, 2006). Additionally, the integrator may request frequent upgrades and technological improvements to poultry houses as a condition for contract renewal (Vukina and Leegomonchai, 2006). Due to their substantial personal investment in highly specialized chicken houses and a scarcity of other economic opportunities in the region, contract growing creates an uneven economic dynamic that disadvantages growers (Knoeber, 1989; Vukina and Leegomonchai, 2006).

Contracting also has benefits for growers, and these relationships are entered into voluntarily. Contracting has the central benefit of ensuring the growers a market for their products during contracted periods and alleviating cash-flow problems (Vukina, 2001). As noted above, the intensive methods of broiler production reduce the labour costs for farmers. Additionally, contract growing provides an opportunity for farmers to maintain a rural, agricultural lifestyle despite national declines in the numbers of small farms, especially in the traditionally agricultural regions of the southern United States of America. Despite these benefits, however, many contract growers express significant discontent about relationships with integrators. A 1999 survey of 1 424 contract growers in ten states found the tournament scheme, in particular, to be a source of considerable grievances (Farmers' Legal Action Group, 2001). Nearly half the growers believed that the tournament scheme provided poor incentives for hard work. Seventy-eight percent of growers responded that their pay depended more on the quality of the inputs provided by the integrator (chicks, feed) than on the quality of their own work. Grower distrust of the integrator's measurements was also a significant issue in the survey. One-third of respondents expressed confusion regarding their post-harvest settlement sheets, and growers also expressed mistrust about the accuracy of feed weighing, the prompt weighing of birds at the processing facility, and higher than expected condemnation rates at processing. One-third of respondents reported that they are sometimes or often left without birds long enough to cause financial hardship. While 75 percent of growers in the survey believed that broiler growing had been a good decision for them, only 35 percent would encourage others to enter the business.

4 CONTRACTING: SHIFTING THE BURDENS OF POULTRY PRODUCTION

From a financial perspective, as discussed above, contracting allows integrators to maintain equity in the product and control over its production and quantity, while shifting some of the risk involved in the variability of producing live animals to the contractor. From a public-health vantage point, contracting results in a transfer of the health risk associated with intense exposure to live animals and their wastes from integrator to grower, and, in the absence of regulatory controls, ultimately to the public. This phenomenon is the central focus of this paper.

We highlight five negative externalities of contract growing that are relevant to public health: 1) waste management; 2) occupational exposures to, and human infections with, zoonotic pathogens; 3) peri-occupational and community exposures to these pathogens; 4) decline of rural communities; and 5) farm-level biosecurity. High-density animal production is associated with a host of other risks to occupational health (Gray *et al*., 2007; Donham *et al*., 2007) and community well-being – from respiratory disease to odour pollution (Cole *et al*., 2000; Warner *et al*., 1990; Wing and Wolf, 2000). In this paper, we focus on specific risks for zoonotic disease emergence that arise from the outsourcing of negative by-products of production from integrator to grower.

4.1 Waste management

The United States Department of Agriculture (USDA) estimates that confined food animals produce approximately 303 million tonnes of waste per year, which is more than 40 times the mass of human biosolids generated annually (Agricultural Research Service, 2007). It is estimated that the 9 billion broiler chickens grown annually in the United States of America produce between 12 and 23 billion kg of waste annually (Nachman *et al*., 2005). The management of animal wastes and the disposal of dead birds is the sole responsibility of the grower.

Unlike human wastes, animal manure is subjected to few regulations regarding treatment and none for disposal. Ninety percent of poultry litter (which includes excreta, spilled food, dead animals, and the layer of sawdust or other material spread on the floor of the poultry house) is applied to land, or stored in heaps until it is applied to land or transported off the farm (Graham, 2007). The lack of regulation regarding the treatment of animal biosolids is surprising, given that animal waste often contains levels of pathogens higher than those found in human faeces. Many enteric organisms can survive for long periods of time, from days to months, in manure and wastewater (Nicholson *et al*., 2005; Guan and Holley, 2003). Bacterial pathogens such as *Campylobacter* spp, *Salmonella* spp, *Brucella* spp, *Clostridium perfringens* and *Listeria monocytogenes* can be present in fresh poultry manure at high levels, and infectious doses are observed even following holding on site (Cole *et al*., 2000). Additionally, viral persistence in poultry manure poses risks of exposure to zoonotic viruses. Infectious titres of avian influenza virus have been recovered from the manure of infected chickens for up to three weeks (Lu *et al*., 2003), and methods of storage and transport of manure are hypothesized to be potential sources of spread of zoonotic agents (Gilchrist *et al*., 2006).

4.2 Consequences for occupational health and illness

Growers, catchers and their families experience exposure to zoonotic pathogens from direct and indirect occupational contact with live birds and poultry manure. Among these populations, exposure to viral and bacterial pathogens may result from working in the confinement house itself, handling live chickens, cleaning the confinement house or transporting animal waste. Potential exposure pathways include inhalation and ingestion of dusts (inside and near to the poultry house), exposure from lacerations, eye exposure and cross-contamination of drinking water on the farm. In the United States of America, the agricultural workforce in food animal production is not unionized (except for processing-plant workers in some cases) and is not provided with clothing or other personal protective equipment when entering the poultry house. There are typically no cleaning and hygiene facilities provided to these workers.

Occupational exposure to broilers has been shown to increase risk of infection with enteric bacteria, including enterococci (van den Bogaard *et al*., 2002) and *E. coli* (Price *et al*., 2007) and *Campylobacter jejuni* (Wilson, 2007). Poultry workers on the Delmarva Peninsula were shown to have 32 times the odds of carrying gentamicin-resistant E. coli and five times the odds of being infected with a multidrug resistant strain of *E. coli* compared to community referents (Price *et al*., 2007). In an experimental study, Ojeniyi (1989) inoculated chickens with an introduced strain of *E. coli*; poultry workers in contact with these birds were quickly infected by this strain. The implications of zoonotic bacterial infection are clearly intensified by the presence of antibiotic-resistant strains, which complicate treatment and may prolong illness.

Confinement workers and growers also have elevated exposure to zoonotic viruses, and this is of clear concern in relation to viral re-assortment and the development of human–human transmissible strains of influenza viruses. An analysis of human infection with H5N1 in Hong Kong SAR during the 1997/1998 outbreak found that occupational tasks involving direct contact with live poultry were a statistically significant risk factor for seropositivity (Bridges *et al*., 2002); in fact, only those occupational tasks which involved handling live poultry were associated with increased risk of infection. A study of the H7N1 outbreak in the Netherlands in 2003 indicated that the highest rates of human seroprevalence were among individuals with occupational contact with poultry, including cullers, veterinarians and farmers (Koopmans *et al*., 2004). Puzelli *et al*. (2005) reported serological evidence of avian-to-human transmission of both high- and low-pathogenic strains of H7 in Italy. Together, these observations indicate that occupational exposure to industrial poultry production, through growing and working with live poultry, poses a distinct and significant risk of infection with avian influenza viruses.

4.3 Peri-occupational and community exposure

While growers and poultry workers themselves experience the most direct contact with live poultry and are at highest risk of exposure to zoonotic disease, their families and communities are also at elevated risk of exposure and subsequent infection. More research is needed to fully depict the peri-occupational and community infectious-disease risks from confinement facilities, but recent analyses indicate ample reason for concern, particularly for influenza transmission (Graham *et al*., 2007; Gray *et al*., 2007). In an analysis of the H7N1 outbreak in the Netherlands, Fouchier *et al*. (2004) identified H7 seroprevalence in members of farm workers' families, indicating that peri-occupational pathways of exposure are viable for influenza viruses (Fouchier *et al*., 2004). Fey *et al*. (2002) documented the case of a farm child infected by ceftriaxone-resistant salmonella and Gupta *et al*. (2003) identified indistinguishable isolates of ceftriaxone-resistant salmonella in cattle and farm communities. Transmission of methicillin-resistant *Staphylococcus aureus* to families of pig farmers has been reported in the Netherlands, with molecular methods confirming the clonality of human and pig isolates (Huijsdens *et al*., 2003). These studies imply that farm families and communities are a population at elevated risk of infection with farm-based zoonotic pathogens.

Furthermore, exposure among farm communities to drug-resistant bacteria from confinement houses is of significant concern for public health. The presence of pathogens and drug-resistant pathogens has been documented in air and water near to these facilities. Poor waste-management practices contribute to the spread of antibiotic-resistant bacteria in the environment near food animal production facilities (Chapin *et al*., 2005; Sapkota *et al*., 2007; Anderson and Sobsey, 2006), putting community members at increased risk of exposure to drug-resistant strains through air and water pollution. The geographic concentration of industrial food animal production intensifies the impacts of these exposures for farm communities (Silbergeld *et al*., 2008).

The economic burdens associated with treating zoonotic illnesses, particularly drug-resistant infections, among farmers and their families are also significant. In the absence of national health-care resources in the United States of America, the costs associated with these illnesses (including lost work time and any treatment) are largely borne by the grower or the workers. As contract employees, growers generally receive few, if any, health benefits from integrators, which may result in reduced access to primary care and delayed identification and treatment of disease. Farm-based practices to reduce grower exposure to zoonotic agents, such as the purchase and use of personal protective equipment, are also the sole financial responsibility of the grower. In these ways, the health conditions and health-care costs that result from continuous exposure to a high density of live chickens in a confined environment – an exposure required by the very nature of contract growing for a broiler integrator in the United States of America – remain an externality of production, borne not by the integrator but by the grower and the community.

4.4 Investments for biosecurity

Farm-level biosecurity is critical in reducing opportunities for the transfer of pathogens among birds and between poultry and humans. In a vertically coordinated system, integrators can set company-wide biosecurity standards and guidelines for growers to follow. However, these standards often entail additional costs for the grower – including the purchase of new equipment, disinfectant, or structural adjustments – for which the integrator does not provide financial compensation; this reduces incentives for compliance or maintenance of equipment. In the event of an outbreak, growers may experience significant financial losses from culling or flock loss. Compensation schemes typically exclude direct payment to contract growers (World Bank, 2006), despite the fact that both integrators and growers have invested resources into the flock. In the United States of America, the United States Department of Agriculture (USDA) and states pay integrators up to 75 percent of the appraised value of the flock lost to HPAI. Integrators are encouraged, but not required, to compensate the growers for their losses on the basis of what they would have earned had the flock not been culled (Ott and Bergmeier, 2005). Yet, given the low profit margins in the industry, the established level of compensation is generally not high enough for integrators to cover their own losses as well as those of growers. Costs associated with depopulating and disinfecting growing houses, as well as with waste management, in an outbreak are not included in the compensation scheme, and are borne entirely by the grower. Compensation schemes are intended to provide incentives for the early reporting and culling of infected animals to prevent disease spread. Strategies that fail to acknowledge the full financial investment of growers may have the effect of discouraging the early and complete reporting they were designed to facilitate.

4.5 Economic impacts of contracting: social justice concerns

There are also significant economic impacts of industrial poultry production at the community, and even regional, level. These operations often bring increased investment in the local communities in which the industry is based, including jobs, tax revenue, and road and utility infrastructure. These local benefits can be significant, especially in low-income rural areas, and for this reason are often welcomed by some individuals in local communities. Across the agricultural sector, however, concentration and industrialization is associated with economic and community decline (MacCannell, 1988) as well as decreased tax receipts and local purchases (Foltz *et al.*, 2002; Durrenberger and Thu, 1996). Property values have also been observed to drop after a confinement house locates in a community (Abeles-Allison and Conner, 1990).

Most importantly, individual benefits in terms of profits are relatively low. Poultry growers do not earn significant profits through contract relationships. Growers invest approximately 50 percent of the capital necessary to produce broiler chickens, but earn less than 3 percent of returns on the investment (Morison, 2007). In the 1999 grower survey, 75 percent of growers in the study made less than US$30 000/year from broiler production, and 45 percent made less than US$15 000/year (the federal poverty standard for a two-person household in 1999 was US$17 029/year) (Saenz *et al.*, 2006). According to the survey, the majority of growers earn 50 percent or more of their income from broiler production. Additionally, more than half of survey respondents took on US$100 000 or more to finance the operation, and 52 percent still owed 75 percent or more of the total farm debt (Farmers' Legal Action Group, 2001).

Growers blame lower than expected income on poor chick quality and higher than expected operating costs. From 1980 to 2002, poultry growers experienced an increase in building and equipment costs of more than 200 percent (Cunningham, 2005). Variable costs associated with fuel, electricity and labour – all the sole responsibility of the grower – have also increased in recent years. Yet, integrator payments to growers have not kept pace with these increasing fixed and operating costs; over a 22 year period, base payments per pound increased by only 54 percent, from 3.3 cents in 1980 to 5.0 cents in 2002 (ibid.). Simply adjusting for inflation, 3.3 cents in 1980 would be worth 7.0 cents in 2002; this calculation highlights that grower payments have actually decreased in value as they have not kept pace with baseline inflation (US Department of Labor, 2007).

Financial challenges are only one of the issues facing poultry-growing communities. In the United States of America, one reason for the geographic location of poultry production is related to community empowerment: the siting of confined animal facilities is disproportionately in non-white, low-income communities, who may not have the political or economic resources to resist the industry or mitigate its health and environmental consequences (Wing *et al*., 2000). Confinement houses are more likely to be located in communities with high percentiles of African Americans or persons living in poverty (Wilson *et al*., 2002; Ladd and Edward, 2002), and near low-income and non-white schools (Mirabelli *et al*., 2006). As a consequence, the presence of confinement houses negatively impacts already tenuous social capital, causing rifts and social gaps between independent and contract farmers, and antagonism and hostility directed towards supporters and opponents of industrial food animal production (Wright *et al*., 2001). These studies strongly suggest that the practice of contract growing has important negative implications for both equity and community cohesion, which are independent factors in community health.

5 POLICY IMPLICATIONS

Industrial poultry production brings clear benefits to consumers through reduced prices, and greater security and availability of food products. Yet, the negative public-health implications of poultry production are largely externalized from the production costs faced by integrators. The practice of contract growing facilitates the outsourcing of negative externalities onto growers, poultry workers, local communities and the general public. As contract growing becomes more commonplace in the middle- and low-income nations, attention must be paid to these negative externalities. These practices have local impacts on the health and economic survival of farm communities as well as critical implications for global disease emergence. Contract systems require specific policies in order to mitigate these local, national and global risks.

Policies regarding the treatment and use of animal waste, based not just on nutrient balance, but also on pathogen levels, are imperative in reducing the environmental and health risk caused by exposure to animal waste. The geographic concentration of industrial animal production in rural and peri-urban areas in the developing world, which have high population density and limited public-health surveillance and environmental monitoring, intensifies the need for regulations for the treatment of animal waste in these areas. Waste-management strategies must also consider the liability of the integrator for the by-products of production. Liability strategies that fall solely on the resource-constrained grower may contribute to mismanagement of animal waste and limit incentives for innovations in waste-treatment technologies. Strategies that provide financial incentives for the development of inexpensive, on-farm waste-treatment technologies that reduce pathogens below infectious levels should be a central priority of municipal and federal governments.

Improving occupational health among growers and their communities is another area in which policy action is required. At the farm level, growers, farm workers and their families internalize risks to personal health from exposure to zoonotic pathogens, which may be amplified due to the density of animals within a confined facility. In the absence of employer- or state-sponsored health care, this is both a health and a financial risk. Regulatory standards should mandate the use of personal protective equipment (including goggles, gloves, aprons and boots) to shield growers and poultry workers from zoonotic-disease exposure. Policies that include growers in health-care programmes, through employer- or state-sponsored systems, can mitigate the financial burden on growers and local communities and reduce disease transmission within farm communities.

Health-care services for contract growers and farm communities are also necessary to provide front-line surveillance for emerging zoonotic diseases. However, in the United States of America, these communities are among the least likely to be served by accessible health-care resources. Active surveillance of poultry-worker and community health is a vital component of public-health policy in nations with industrial animal production; the lack of health surveillance among growers, poultry workers and their families represents a critical missing link in plans for preventing pandemic influenza (Gray *et al*., 2007). Public-health resources should also be devoted to monitoring the health of these workers, even those who are undocumented, so that emerging diseases are identified quickly. Given that both integrators and the public benefit from intensive animal production, community health monitoring provides a potential opportunity for public/private partnerships that can involve private corporations, governments, universities and non-governmental organizations.

Farm-based biosecurity standards, as well as compensation schemes, must be designed to include consideration of the burden on contract growers, to ensure both fairness and effectiveness. One of the most obvious gaps in this respect is the current practice of compensation for flock-loss associated with outbreaks, which does not include direct payment to growers, but, like a bankruptcy claim, considers the grower as a party of last resort. Since growers are the most closely involved with chickens on a daily basis, fair compensation schemes reimbursing growers are vital in setting incentives to report infected birds quickly. When compensation schemes exclude direct payment to contract growers, this provides perverse incentives with respect to halting emerging diseases. Similarly, costs associated with implementing biosecurity plans should be shared between integrators and growers – acknowledging the shared investment in the flock.

Addressing the socioeconomic impacts of contract growing is a challenging issue that requires regulatory, legal and non-governmental approaches. Zoning that limits geographic concentration of industrial food animal facilities, based on human population density, regional infrastructure or environmental carrying capacity could reduce community decline and also impart environmental benefits. Such measures could also reduce the ready movement of pathogens, including viruses, among animal houses. This movement can occur by airborne movement of dusts and aerosols, as well as by vector-transport via insects, small rodents, and wild birds that enter and leave poultry houses that are not completely biosecure. There are also specific suggestions regarding limiting the proximity of poultry and pig houses in order to reduce the possibility of viral mixing of influenza strains (Saenz *et al*., 2006). Laws to strengthen contractor rights within negotiations and ensure fair payment schemes can protect workers, and non-governmental organizations play an important role in improving contract conditions for growers.

The experience with contract growing in the United States of America provides important insights to developing nations who adopt this practice as a component of industrialized poultry production. Contract growing imposes significant health and economic risks on growers and farm communities, as well as the general public. Public health and agricultural policies must consider factors specific to the contracting relationship and the externalities of industrial poultry production in order to successfully mitigate these risks.

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Response of the Thai poultry industry to highly pathogenic avian influenza

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SUMMARY

Significant markets remain much the same as they were before highly pathogenic avian influenza (HPAI). Thai producers are continually adjusting their marketing strategies. Following the severe HPAI outbreaks of 2003, government stepped in to regulate processing plants through certification programmes. Despite these measures, only half of the existing plants managed to meet the required standards and producers had to adjust their strategies. Adjustment in the private sector is far from easy and requires significant investment in equipment. Skilled labour, however, is one of Thailand's strong points. A cooked-meat customer base is essential for industry survival, and the Thai industry has been successful in meeting customer needs. Thailand will continue to increase exports of cooked chicken meat.

Key words: Thailand, poultry, export, HPAI

1 INTRODUCTION: LOCATION OF BROILER PRODUCTION

Before the outbreak of highly pathogenic avian influenza (HPAI) in 2003, the United States of America, China, Brazil and the countries of the European Union (EU) were the world's four dominant locations of broiler production, followed by Mexico and India. Thailand was placed seventh. Japan, Canada and Argentina, in that order, filled the remaining three places in the top ten broiler-producing countries. In 2007, after the HPAI outbreaks, there were no changes among the top six in the table, but Thailand dropped from position seven to position ten, surpassed by the Russian Federation, Argentina and Japan.

2 BROILER EXPORT

The outbreak of HPAI caused a significant drop in the export of broiler meat from Thailand. HPAI broke out in 2003 when Thailand was the world's fourth largest exporter of broiler meat, behind the United States of America, Brazil and the countries of the EU. While the HPAI crisis led to a virtual cessation of exports from Thailand, by 2007, the country was back to number five among exporting countries, with the same countries as in 2003, plus China, exporting more than Thailand. Before the 2003 HPAI outbreak, broiler exports from Thailand constituted 40 percent of the total broiler production in the country, in comparison to 14 percent in the United States of America and 25 percent in Brazil, while exports constituted only 4 percent of total production in China. In 2007, this proportion had hardly changed for these three countries, but in the case of Thailand, it had fallen to 29 percent.

Among countries that introduced a total ban on imports of all poultry products were Malaysia and Turkey, while the countries or regions that banned only the import of fresh meat included : Japan, the EU, the Republic of Korea, Singapore, Hong Kong SAR, Canada, South Africa, Switzerland and the Middle East.

3 EXPORT OF COOKED PRODUCTS AND MAJOR MARKETS

Thailand began working with cooked broiler products for export in the early 1970s, and after the HPAI shock all exports consist of cooked products.

The heating temperature required varies from one importing countries to another. In all cases, it is above the requirements set by the World Organisation for Animal Health (OIE), as shown in Table 1.

In 2003, the year that HPAI broke out, the total export of broiler meat from Thailand was 546 000 tonnes, of which approximately 35 percent, or about 190 000 tonnes, were cooked meat. In 2007 it is estimated that the export will be 320 000 tonnes, all of which is cooked meat.

Thailand's major export markets in 2003 were Japan and the EU, which accounted for 50 percent and 38 percent, respectively, of the export, while minor shares went to the Repubic of Korea, China, the Middle East and some other countries. In 2006 after the HPAI outbreak, the share going to Japan and the EU went up to 51 percent and 43 percent, respectively. Nothing was reported to be going to the Repubic of Korea, China or the Middle East, while 6 percent went to other countries.

4 CONCLUSION

Broiler export from Thailand is now based on cooked meat, and this is expected to be the basis for future exports.

TABLE 1
Core temperature and time required for cooked products by different countries

Core temp.	OIE	EU	Japan	Singapore	Hong Kong SAR	New Zealand	Canada	Australia
70°C	3.5 seconds		1 or 30 minutes	3.5 seconds	2 minutes	30 minutes		
74°C					75°C 15 seconds			165 minutes
80°C						5 minutes	15 minutes	125 minutes
100°C						1 minute		
100°C						1 minute		

Food-safety concerns in the poultry sector of developing countries

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SUMMARY

Poultry production is one of the fastest growing livestock industries as a result of its advantages in terms of land use and improvements in the food conversion rate of genetically superior poultry breeds. Among the major concerns related to this development are health issues threatening not only animal production, but also the people using the products derived from these animals. Microbiological risks, such as salmonella-related food poisoning, pesticide residues from feed production, and resistance problems following the use of antibiotics in animal production have become the focus of attention.

In the industrial world, legislation and regulations have been implemented, involving both the public and the private sectors. However, in many developing countries such measures do not exist. Food-borne illnesses are, therefore, still major problems in developing countries. This paper discusses the measures that can and should be taken by developing countries to ensure safe products from the poultry sector. Examples are given from Bangladesh. As production conditions vary greatly as a result of socio-economic, political and environmental factors, regulations applied in one part of the world may not be suitable elsewhere. It is also questionable whether a developing country that does not aim to enter the export market for poultry, or livestock products in general, should apply the same standards as an exporting country. Many countries only produce for their national markets and therefore lack the incentive to follow international regulations; approximately 90 percent of global livestock products are sold in domestic markets. Nevertheless, the prevalence of food-borne diseases in developing countries is alarmingly high, and action is needed especially with regard to consumer awareness. To achieve this, there is a need for more information to be gathered about the conditions in individual countries, and for country-specific political action.

1 INTRODUCTION

The world is experiencing a growing population and rising incomes. This has led to increasing demand for food products, especially meat, milk and eggs. Together with innovations on the supply side, this has caused rapid growth of the livestock sector as a whole. The process has been referred to as a "livestock revolution" comparable to the "green revolution" of the 1960s.

The search for the most viable protein sources has resulted in particularly rapid growth of industrial poultry production. Poultry does not need pastureland, and the food conversion rate of genetically superior poultry breeds is very good compared to other livestock such as cattle. Technical advances in the feed industry have added to the progress. Pork production has followed a similar pattern to poultry. Intensification has brought food-safety concerns into sharper focus (Blancou *et al*., 2005), and these concerns have been increasingly acknowledged, at least in developed countries, as information technology and medical science have advanced (Nelson, in FAO, 2005).

Per capita demand for meat and fish products in developing countries has grown a rate of 3.7 percent over the last 20 years (FAO, 2003). At the same time, the new intensive production systems of the developing world are facing more and more pressure to comply with the regulations that prevail in the global market.

The various factors that influence production conditions (e.g. environment, infrastructure and culture) give rise to differing demands for food-safety standards in different parts of the world. Food-borne diseases can also be related to demographic movements from rural areas to the cities, which cause overcrowding and, therefore, problems with hygiene, sanitation, housing conditions, etc., particularly in developing countries (Heath, 2006). Public health service systems are often unable to adapt to the rapid pace of urbanization. The urban lifestyle has also led to changes in consumption patterns, with more food products consumed outside the home, and to growing consumption of prepared foods (Stamoulis *et al*., 2004). Increased trade in food and feed across country borders, together with increased

TABLE 1
Some factors influencing the incidence of food-borne disease

Food supply system	Health and demographics	Social situation/ lifestyle	Health system and infrastructure	Environmental conditions
Mass production and distribution – larger outbreaks, etc.	Population growth	Increased consumption outside	Decrease of resources and increase of food businesses	Pollution
Intensive agriculture – increased use of drugs and pesticides, etc.	Increase in vulnerable groups, e.g. the elderly, immunosuppression, malnourishment	Increased travel	Lack of water supply, sanitation and fuel for cooking	Changes in ecosystems – lack of water and resources
International trade	Increase in the number of displaced people	Changes in food preparation habits	Inadequate training of health workers	Climate change
More food service establishments – lack of training	Rapid urbanisation – lack of sanitation and water	Poverty and lack of education	Weak surveillance and monitoring systems	
Longer food chain		Lack of time	Lack of access to technologies	
		Changed social and cultural behaviour	Lack of consumer awareness	

Source: adapted from Motarjemi and Käferstein (1999).

leisure and business travel, is contributing to the global character of the food-safety problematic (see Table 1).

Food safety can be defined as the system that keeps food and food products free from substances hazardous to human health. Food safety should be a part of governments' strategies to ensure secure food for the consumers. In this context, a "hazard" refers to any biological, chemical or physical property that may cause unacceptable risk (FAO, 1998). The emergence and discovery of new food-borne pathogens and other food-related hazards has increased the need for food-safety measures. The intensification of food production has also changed food processing and handling systems and raised new challenges for food-safety institutions. Intensification has led to large amounts of potentially infectious material being concentrated at single sites, such as large industrial production establishments or processing plants, and has therefore contributed to the potential for large-scale outbreaks of infection. Changing consumption patterns – street vendors and home cooking of primary products are giving way to the purchase of processed food from supermarkets – make food-safety an issue of public concern rather that just a matter for individual consumers.

Developing countries face difficulties in achieving food-safety goals in animal production systems. These difficulties result from *inter alia* unstable administrative and political structures, lack of infrastructure, and lack of investment in food-safety measures and research, as well as from inadequate consumer information.

Responsibility for ensuring safe food for the consumer has traditionally been seen as the responsibility of public institutions. However, with the intensification and industrialization, responsibility has been shifted to a wider set of stakeholders including the private producer and the consumer.

2 BACKGROUND

2.1 Objectives

The objective of this paper is to describe the food-safety problems facing industrial poultry production systems in general, and then to examine the situation in developing countries – illustrated by a country example. The main risk factors affecting the whole vertical chain of industrial poultry production are described. The control measures, regulations and tools that are commonly applied in developed countries are also briefly described. Some common food-safety issues affecting developing countries are discussed. Utilizing the country example, the question of whether it is appropriate in developing countries to enforce control and regulation systems of the type commonly applied in the developed countries is addressed. Some of the constraints faced by developing countries, such as difficulties in risk management, and lack of administrative capacity, technical qualifications, information technology and so forth, are examined. The importance of cultural, environmental and political factors is highlighted.

The above-mentioned factors certainly differ across the developing world. Nonetheless, the objective is to use the country example to shed some light on the general situation in the developing world. Bangladesh, one of the poorest countries in the world but which has a relatively rapidly growing poultry sector, is used as the example.

The information presented here is drawn from the literature and from personal communication with experts working in the field or in research.

2.2 Defining the production systems

Seré and Steinfeld developed a framework for classifying livestock production systems (FAO, 1996). This classification first distinguishes "solely livestock" from "mixed farming" systems. The first category is then divided into "landless" and "grassland-based" systems. The landless system can also be referred as "industrial". This group has two subgroups: monogastric and ruminant production. Finally, the monogastric system is divided into pork and poultry (meat and eggs) production. This paper will first focus on the "industrial" poultry production system, and will then consider whether the other production systems could be included under food-safety regulations of the type implemented in the industrial system.

FAO has formulated an additional classification of poultry production – Sectors 1 to 4 – based on the level of biosecurity. Sector 1 is defined as "an industrial integrated system with high level biosecurity and bird/products marketed commercially". Sector 2 is described as a commercial system with moderate or high biosecurity and birds/products usually marketed commercially. Sector 3 is also described as a commercial system, but with low or minimal biosecurity and birds/products entering live-bird markets. Sector 4 produces chickens for local consumption only, and is described as having minimal levels of biosecurity. This sector is sometimes called the village or backyard sector. The definitions are constantly under discussion, and some doubts are expressed about categorizing sectors on the basis of biosecurity levels, due, for instance, to disputes about the definition of the term "biosecurity" itself. This paper focuses on the differences that these sectors face with regard to the global regulatory food-safety environment.

Parallel markets for poultry products can be identified in developing countries. On the one hand is industrial production or the formal sector, and on the other the informal market where official hygiene regulations and control measures are not followed (Enste and Schneider, 2000). It is also possible to categorize the poultry market into the export and domestic production sectors. Some vertical integration exists in developing countries – mostly involving Sector 1 and 2 farms. Such farms follow the regulations set by the industry. These are often private rules that have been set according to the needs of the target market and the local circumstances. There is quite an important difference between the two markets. However, there are many examples of interaction between the two, so the division is far from clear cut.

This paper concentrates mostly on broiler meat production, but some parallels to the production of chicken eggs are drawn.

3 THE POTENTIAL RISK FACTORS

Three types of food-borne risk factors for human health can be recognized (FAO, 1998). The first group of risk factors comprises microbiological factors such as *Campylobacter* spp. and *Salmonella* spp. The second group of risk factors comprises chemical factors such as residues from veterinary medications, pesticides, natural toxins or environmental pollution. Excessive use of medication during poultry production, or disinfectants used in the food-processing industry, can give rise to the problem of resistance. This adds to the problem of food hygiene. The third group of risk factors comprises physical hazards such as bone-pieces in meat; this group is not further considered here.

3.1 Microbiological risk factors

Microbiological risk factors include bacteria, viruses, protozoa, helminths, prions and mycotoxins. The most important group with respect to poultry are bacteria such as *Salmonella* spp., *Campylobacter* spp., *Listeria*, clostridia, enterococci and *E. coli.* As far as viruses are concerned, the significance of avian influenza should not be overlooked. Helminths, prions and protozoa are not considered to be major threats to food hygiene in industrial poultry production. Microbiological risk factors can be found in all poultry production systems. The most common microbiological pathogens connected with shell eggs are *Salmonella, Campylobacter, Listeria* and other enterobacteriaceae (Jones *et al*., 2006). The eggs can be infected vertically before laying or as a result of contamination from the environment. Cracks and other damage to the egg shell are obvious locations for pathogen multiplication.

Bacteria

One of the most studied food-borne pathogens is *Salmonella* spp. It is easily spread during the trade and processing of poultry products, specifically non-processed and non-heat handled products. This spread has been facilitated by industrialization and the growing international trade in animal feed, live animals and food. Food-borne *Salmonella* infection in humans is a very widespread problem in the industrialized world. In the European Union (EU), almost 200 000 people were infected during 2004 (EFSA, 2006); Mead *et al*. (1999) report an estimated annual figure of 1.4 million infections in the United States of America. The risk of infection with *Salmonella* has been worsened by the spread of pathogen strains with resistance to antimicrobials, a possible consequence of excessive use of antimicrobials in animal feed and as veterinary treatments (Antunes *et al*., 2006). The virulence of *Salmonella* is related to its ability to avoid host defence mechanisms and to invade non-phagocytic cells, its resistance to environmental factors and its production of enterotoxins (Plym Forshell and Wierup, 2006).

The increasing problem of *Salmonella* infection is not necessarily attributable entirely to the growth and intensification of poultry production; changing consumption patterns may also be a factor. Forsythe and Waldroup (1992) suggest that changes to consumer behaviour, such as eating out more, increased use of microwaves for heating and re-heating food, and increased use of salad bars outside the home, have contributed to the increase in human *Salmonella* infections in the United States of America. More or less similar patterns of consumer behaviour can be found in the other parts of the industrialized world. The above-mentioned study showed, however, that the incidence of human infections increased during the summer months, which implies that processing procedures may not be adequately adjusted to account for high temperatures.

Salmonella is also vertically transmittable, and some human infections can be traced to eggs. Infection with *Salmonella* can occur before laying (Humphrey, 1994), but the surface of the eggs gets contaminated quickly if there is infection in the environment. Chicks hatched uninfected can also be colonized very quickly. In the latter case, the infection can be detected two weeks after hatching, i.e. after the so-called lag phase.

Animal feed is a potential source of *Salmonella* infection. Crump *et al*. (2002) report several cases in which the *Salmonella* strains found in human food have been traced back to animal feed. In countries in the EU, there are specific requirements for the application of feed-processing techniques to control the most common pathogens, including *Salmonella*. For example, in Denmark there are requirements for heat treatment of feed, and for feed producers to follow HACCP (hazard analysis and critical control points) regulations (Danish Veterinary and Food Administration, 2006).

Sander *et al*. (2002) investigated the additional problem of resistance arising as result of the use of disinfectants in the hatcheries; they identified the same strains of resistant *Salmonella* in the processing plants as in the related hatcheries.

Campylobacter is one of the pathogens most commonly causing food-related illnesses in humans. The bacteria can cause diarrhoea, gastro-intestinal pain and nausea in infected people. In rare cases it also causes Guillain-Barré syndrome, an immunological failure that causes damage to parts of the peripheral nervous system.[1] The most common species of *Campylobacter* diagnosed in humans are *C. jejuni* and more rarely *C. coli* (Jacobs-Reitsma *et al*., 1995); however, there are some small differences between geographical areas. Infections with multiple strains have been identified in most of the flocks of broiler chickens (Jacobs-Reitsma *et al*., 1995). *Campylobacter* does not cause clinical signs in poultry (Wagenaar *et al*., 2006). It remains unclear how flocks get infected with *Campylobacter* before harvesting, but there are several theories. Feed and water, vectors such as rodents and flies, horizontal transmission between birds, and contamination in the hatcheries are possible routes of entry (Hald *et al*., 2004). The view has been that *Campylobacter* is not transmitted vertically, and that chicks are born infection free. The young birds are rapidly colonized only after hatching – infection can be detected after the so-called lag phase of one or two weeks. Vertical transmission has, however, been provoked in experimental conditions, and *Campylobacter* has been found in the oviduct of the chicken and in the semen of the rooster (Byrd *et al*., 2007). This could imply that the bacterial contamination is traceable to the hatcheries and that layers might be infecting the eggs.

Campylobacter is particularly found on raw poultry meat. It is very vulnerable to drying out, but can survive for months in small pools of dirty water. Warm-blooded animals serve as reservoirs (Adams and Moss, 2004). Because of the vulnerability of the bacteria there have been many successful programmes of eradication in primary production. However, the end-result of these measures is questionable; the most probable site for recontamination is the carcass processing plant. Shell eggs are not a major source of *Campylobacter* infection in humans.

Other bacteria, such as *Clostridium perfringes*, *C. botulinum, Listeria monocytogenes* (Rørvik *et al*., 2006) and *E. coli* O157:H7 can also be found in poultry products (WHO, 2007), but these organisms cause food-borne illnesses less frequently than do the two pathogens described above. Besides pathogens associated with the animals themselves, organisms associated with humans, such as members of the enterobacteriaceae and Staphylococcus, are major hygiene concerns in the handling of food products.

Mycotoxins

Mycotoxins secreted from certain strains of fungus can be found in various feed ingredients, including those used in poultry feed. Mycotoxins can infect the plants during their

[1] National Institute of Neural Disorders and Stroke: http://www.ninds.nih.gov/disorders/gbs/gbs.htm

growth or during processing and storage; they can be distinguished into plant pathogens and storage mycotoxins (D'Mello, in FAO, 2004a). Types of feed differ from region to region, and therefore the range of mycotoxins also varies. In tropical areas, *Aspergillus* spp. are the most common organisms involved, while in more temperate areas, *Penicillium* spp. are more common. The third group of toxin-producing fungi is *Fusarium*, which produces fumosin toxin (ibid.). The main toxins of food-safety concern are the carcinogenic mycotoxins aflatoxin B1, aflatoxin M1 and ochratoxin A (FAO, 2000). Oyaejide *et al*. (1987) report that over half the poultry feedstuff examined in Nigeria was contaminated with aflatoxin B1. The Nigerian findings also indicated a higher prevalence of mycotoxins in feeds stored on the farm than in those stored by the feed producer (ibid.). This implies a lack of good management practices on the part of the poultry producer. These substances should be carefully monitored in poultry meat and eggs because of their carcinogenicity to humans. Industrial feed processing mills use various methods to control the risks associated with mycotoxin, including pelleting, heat treatment and irradiation.

Other microbiological risk factors

Parasites of poultry that can cause human infection are very rare. Moreover, virus infections caused by orthomyxoviridae (avian influenza viruses) can be described as a risk factor for the actors involved in food production, but not directly as a hazard for the consumer of the processed poultry product. Prions are mostly considered to be a hazard associated with cattle and sheep meat products rather than poultry products (van de Venter, 2000).

Another important issue, related to both microbiological and chemical risk factors, is the problem of resistant strains of pathogenic bacteria that can affect humans. The spread of resistant strains may be related to the widespread use of antibiotics to treat animals and as growth promoters especially in broiler feed.

3.2 Chemical risk factors

Some chemical substances can be traced all the way into poultry end-products. There are, nowadays, strict restrictions in many countries, but elsewhere residues of antimicrobial medicines can still be found in the end-products.

During the production of feed, there is a need to control the residues of organic and inorganic environmental pollutants such as dioxins, chlorinated biphenyls, furans and heavy metals (Saegerman *et al*., 2006). The control of feed quality and safety is increasing in importance as a result of the expanding international trade in animal feed products. Other risk factors that should be considered are pesticide residues from feed production, and genetically modified organisms (GMOs). A discussion of the latter issue is, however, beyond the scope of this paper.

Antibiotic residues

Antibiotic residues in food products can be the result of excessive use of antimicrobials in veterinary practice or as a supplement in ready-produced animal feed. Policies regulating the use of antibiotics vary greatly between countries; in the developing world, the control is probably generally insufficient.

There are two ways in which the antibiotics in feed can affect human health: the direct effect of the residues in poultry meat and eggs, and the indirect effect resulting from the selection of antibiotic resistant strains of pathogenic bacteria. The issue of the use of antibiotics as feed additives and the restriction of this use is somewhat controversial. Some suggestive studies imply that the benefits of reducing the amount of resistant bacteria by controlling the use of antibiotics as feed additives might be overshadowed by an increase in the number of cases of human food-borne illnesses (Singer *et al*., 2007) The latter authors describe a model that illustrates the relationship between food-borne illness and the health status of the flocks that supply the food products. The model, which used *Campylobacter* infection as an example, suggests that a small decrease in the levels of illness in the animal flocks will significantly decrease the rate of human infections (ibid.). Moreover, the correlation between the use of antibiotics as growth promoters and the prevalence of pathogen strains has not been definitely proven. The ban in the EU (European Council Directive (EC) 2821/98) was partly a result of pressure from certain member countries; it was accepted as a preventive action in accordance with the precautionary principle (Williams, 2001). Developing countries might not have the motivation or the capacity to enforce such regulations. However, the desire to continue or commence exports to European markets might be a driving force favouring a ban.

The continuous development of techniques for detection also contributes to the problems that developing countries face in terms of conforming to international standards. Technological differences can lead to confusion and unpredicted economic losses associated with the disqualification of export products (Phongvivat, in FAO/WHO, 2004). The acceptable levels for most antibiotics are described under the minimum residue level system (MRL) (ibid.).

Antibiotics are still used as growth promoters in many developed countries, including the United States of America. However, the four main additives, virginiamycin, bacitracin, spiramycin and tylosin, were banned in the EU in 1998 (European Council Directive (EC) 2821/98). Four others, bambermycin, avilamycin, salinomycin and monensin, were banned in 2006 (Hong *et al*., 2005). The antibiotics are used in order to enhance the production qualities of poultry and other livestock. Some studies have shown that production systems using antibiotics as feed additives achieve growth rates up to 10 percent higher than those not doing so (Hughes and Heritage, in FAO, 2004b). There have been other beneficial effects on the product quality, such as decreased fat and increased protein in the meat, as well as indirect benefits such as a reduction in the amount of feed needed, and therefore a reduction in the amount of waste. The practice evidently also decreases the occurrence of gastro-intestinal infections – adding an animal-welfare component to the considerations.

Pesticides

Intensive use of pesticides in many developing countries also affects the safety of food via animal feed with a high level of residues. In order to control plant pests and vectors of disease, the use of versatile pesticides has been widespread in many parts of the developing world. This practice has not been without consequences for the environment, production animals, feed, food crops and public health. There have been studies of immune system-related illnesses, such as immunosuppression and hypersensitivity (Street, 1981), as well as many other illnesses that could be related to the excessive use of pesticides and the resulting residues in food products. These illnesses, but also both acute and chronic toxicities, have been reported both in human and animals (Lu and Kacew, 2002).

Pesticide use is highly regulated in the EU and in the United States of America; residue levels are therefore under strict control. However, in a developing country the situation may be quite different. This is illustrated by a study from India (Singh, 2001), which examined various food products for pesticide residues. All the Indian states were included in the study and several pesticides were examined – HCH (hexochlorocyclohexan, also called hexachlorebenzen HCB), DDT, monocrotophos, cypermephrin, quinolphos, aldrin and endosulfan. Of the 12 eggs examined, 83 percent were found to contain residues. Ninety-two percent of the livestock tissues examined were found to contain traces of pesticides. HCH, DDT and aldrin were found at toxic levels in poultry products. In addition, HCH residues were found at toxic levels in livestock feed. HCH, DDT and aldrin are still widely used as insecticides in many countries, although they have been banned in most developed countries. In addition to acute toxicity, HCH can cause hormonal disorders and liver and kidney failure in humans and other animals. Aldrin belongs to a group of organochlorides most of which are banned from use in the developed world. Aldrin, however, is still used in the United States of America as a termite pesticide.

Other chemical risk factors

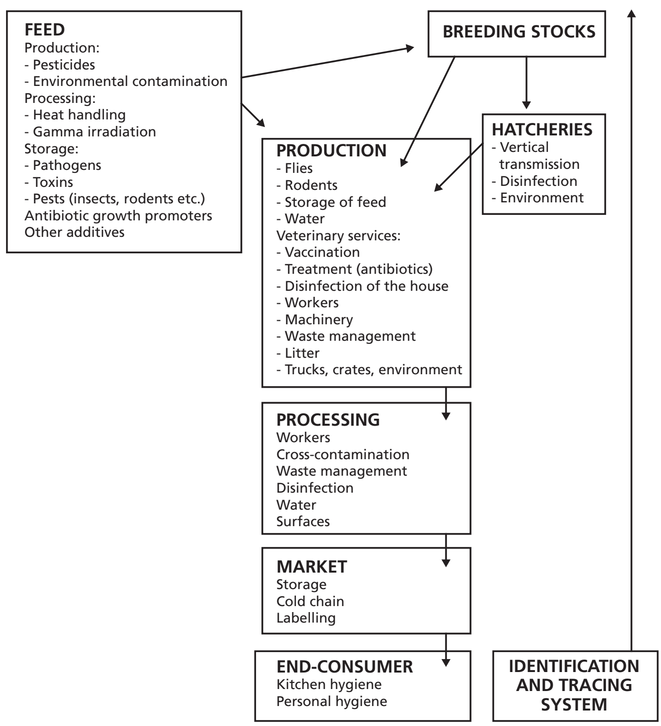
Disinfective agents used in production establishments and processing plants are also risk factors. Chlorinated water used in rinsing the carcasses has also raised concerns among consumers. In the EU the use of chlorinated water is banned, but in the United States of America it is a common practice. The use of disinfectants to clean the equipment in production and processing establishments might, as mentioned above, also give rise to a problem of resistance.

4 THE VERTICAL CHAIN

The different steps of the food production system need specific regulations. However, food-safety interventions should optimally be considered as a whole, i.e. should be coordinated through the whole vertical system (see Figure 1). The chain from "farm to fork" starts with feed production, and continues through the hatcheries to the slaughterhouses, processing plants, wholesalers, retailers and the end consumer. Between these steps there is transport and storage, during which maintaining the cold-chain is crucial. The hygienic behaviour of the end consumer, such as washing hands and kitchen utilities after handling raw poultry meat or eggs, is the final factor in avoiding the food-borne illnesses related to poultry products.

WHO formulated a three-step approach to mitigating the risk posed by *Salmonella* spp. (WHO, 1980); the terms used are also relevant for other microbiological hazards. The first step is pre-harvest control, which focuses on the feed and poultry producers. The second step is harvesting control, which covers hygiene measures at the time of slaughter; these are described in the Codex HACCP model (see Table 2 for an example). The third step is post-harvest control, which covers the product from the processing establishment all the way to the end-consumer. Each of these three stages has to be taken into consideration in order to prevent risk factors entering the chain.

FIGURE 1
The vertical chain of poultry food-products and examples of possible hazard points



It is suggested that the first step, pre-harvest control, is the most important means to prevent infection with pathogens such as *Salmonella*, as traditional control systems are unable to control for these pathogens later in the chain. Singer *et al*. (2007) describe three reasons why it is important to process only healthy animals – thus emphasising the importance of pre-harvest measures. First, a sick animal will shed pathogens into the surroundings and onto other animals; second, processing a sick animal may require additional handling in order to separate the infected parts from the carcass, which may add to the risk of cross-contamination; and third, certain illnesses lead to pathological changes in the carcass which may cause increased fragility of specific organs. *E. coli*-originated airsacculitis, which causes adhesions of the inner organs and therefore increased risk of ruptures during mechanical processing and increased risk of cross-contamination, is mentioned as an example of the latter problem (ibid.).

Poultry producers have an important role in preventing risk factors from entering the food chain. In the developed world this role has become more or less clear to the farmers as a result of official regulations and increased hygiene demands originating from consumers and retailers. The enforcement of these regulations is done through control visits by governmental authorities to production establishments, and by continuous control on the part

TABLE 2
Generic HACCP model for raw chicken: process flow diagram for slaughterhouse

INPUTS	PROCESS STEPS	EDIBLE OUTPUTS
Live birds	1. Receipt of live birds	
	2. Hanging	
	3. Stunning	
	4. Killing	
	5. Bleeding	
	6. Scalding	
	7. Defeathering	
Water (possibly with bactericidal agent)	8. Washing	
	9. Head pulling	Head
	10. Hock cutting	Feet
	11. Venting	
	12. Evisceration	Edible offal (liver, gizzard, heart)
Water (possibly with bactericidal agent)	13. Washing	
	14. Crop removal	
	15. Neck cracking/cutting of neck flap	Necks
Water (possibly with bactericidal agent)	16. Washing (inside/outside)	
Water with ice (possibly also with bactericidal agent)	17. Chilling	
	18. Re-hanging	
	19. Conveying to secondary processing area	
	20. Portioning	
	21 a. Storage	
	22 b. Deboning	
Packaging materials	22. Packaging	
	23. Chilling/freezing	
	24. Storage	
	25. Dispatch	Packed whole chicken or chicken portions

Source: MAF (2000).

of the establishments themselves. An efficient traceability system linking the food product to the farm has enabled efficient and rapid intervention measures in the event of an out-break of a food-borne disease. It has been shown that improvements made to the health of production animals have positive effects on the safety of animal-derived food products for humans. Singer *et al*. (2007) showed that there is a strong correlation between the health of production animals and level of food-related human illnesses. Veterinary services are also important. The non-regulated use of antibiotics as veterinary treatment might be a link to the appearance of resistant strains of pathogens posing a threat also to human health. The antibiotics used for veterinary treatment can in some cases overlap with crucial ones used to treat human illnesses.

Slaughterhouses and food-processing establishments are the next links in the chain of food safety. The post-slaughter poultry carcass is a suitable growing medium for many pathogens, including human pathogens. Hygiene procedures when handling the carcass are, therefore, crucial and should be carefully planned and monitored to avoid contamination and cross-contamination of the food products. Packaging, transport, shelf-life and storage, as well as the maintenance of the cold-chain are important considerations. The cleaning and disinfecting of the premises and transport vehicles involved in these processes should be controlled. Resistance issues should be considered in the choice of the products used. Food products are then transported to wholesalers, retailers and finally to the consumers. Many cases of food-borne illnesses could be avoided by applying good hygiene practices in the home or in restaurants. Consumer information and education is, therefore, crucial, especially in developing countries where hygiene standards are poor.

4.1 Responsibility for control

Three major stakeholders can be identified in an industrial poultry production chain– the producer, the consumer, and the government. In industrialized countries, there are strong consumer-protection organizations which directly, or indirectly through governmental institutions, put pressure on the producer to supply safe products. A shift of legal responsibility from the government to the producer has been the common trend in developed countries (FAO, 2007). According to this mindset, the optimal role of the government is as a guarantor of the system through administrative and regulatory methods – the producer being the one managing the systems. A major factor in the prevention of food-borne illnesses is to ensure that stakeholders from all sides understand their responsibilities and voluntarily introduce good hygiene practices.

5 FOOD-SAFETY REGULATIONS AND RISK ANALYSIS

5.1 Risk-analysis tools

In order to set up food-safety strategies for countries or regions, some basic frameworks have been designed by international regulators. The modern approach is to use risk analysis tools. Briefly, such tools include the following steps (Adams and Moss 2000):

- identification of the hazards (i.e. the risk factors described above);
- exposure assessment – estimating the likely intake of the agents;
- hazard characterization – quantitative and qualitative analysis of the risk factors; and
- risk characterization – estimating the probability and severity of the possible food-borne illness.

This approach has to a large extent been successfully implemented in the developed-country food production sector. However, the proper implementation of risk-analysis tools requires certain basic components. These include efficient public health institutions, sufficient laboratory facilities, properly trained human resources and functional infrastructure

(FAO, 2007). Obviously, many countries are weak with respect to one or more of these components. A careful analysis of the country or region should, therefore, be implemented before considering the application of such tools.

5.2 The international regulatory environment

Large parts of developed-world markets follow international sets of rules. The major players in the international rule-setting forum are the FAO/WHO Codex Alimentarius Commission with its Hazard Analysis and Critical Control Point (HACCP) guidelines; the World Organisation for Animal Health (OIE) with its Terrestrial Animal Health Code, and the World Trade Organization (WTO) which sets the sanitary and phytosanitary (SPS) framework for international trade. The Codex Alimentarius Commission has also set out guidelines for good agricultural practices (GAPs), good manufacturing practises (GMPs) and good hygiene practices (GHPs). These sets of rules and practices are widely accepted in developed countries and international markets.

In addition to the main rule setters mentioned above, there are several other international and regional bodies. Internationally, there is for example, the International Atomic Energy Agency (IAEA) which sets regulations concerning irradiation of food and feed, etc. Regionally, there are organizations such as the European Food Safety Authority (EFSA) and the African Regional Standardization Organization (ARSO). Regulations set by private industry should also be taken into consideration. These regulations are sometimes more stringent than those described above. Moreover, they often include regulations related to quality aspects not considered to influence human health.

The international rules are set to protect the consumer, but have been criticized for setting trade barriers that prevent developing countries from entering international markets because of the high costs associated with implementation. In particular, the private standards imposed by some parts of the industry are the target of such criticisms. Another consideration is that the international rules may be of little relevance to poor developing countries that are not involved in the international livestock trade. According to Randolph *et al*. (2007) 90 percent of the world's livestock trade is within domestic markets.

In the developed world, food products are mostly sold in large marketing systems, such as supermarkets. However, in the developing world there is a vast informal sector involving live-markets and street vendors of food. The production and slaughter systems in the developing world also differ greatly from the industrial model described above. This poses complications for the implementation and enforcement of food-safety regulations: how can the informal and the formal sectors be linked, and how can homogenous food-safety policies be implemented throughout the market?

6 FOOD-SAFETY CONCERNS IN DEVELOPING COUNTRIES

Food-borne diseases are major health problems throughout the world. According to statistics from WHO, 1.8 million people died of diarrhoeal diseases in 2005 (WHO, 2007). Motarjemi *et al*. (1999) estimate that up to 70 percent of such cases are associated with contaminated food (though not restricted to livestock products). In addition, the WHO report states that in industrialized countries up to 30 percent of the population is reported to be affected by a food-borne disease each year, implying that the proportion in developing countries might be much higher.

In developed countries, the control of food-borne illnesses has been relatively successful with the help of measures described above. Public-sector measures, such as vaccination of animals, vector control, medication, slaughter inspection, risk analysis and consumer education, have been used to advance food safety in these countries (Blancou, 2005). However, in many developing countries, attempts to use such measures have been less successful.

The public sector in developing countries faces various constraints, including poor financial resources, infrastructure and information. Mills *et al*. (2004) point out that some public health projects have failed, despite proper funding and the help from international community, as a result of a weak public sector and poor infrastructure.

Many countries, including many developing countries, have officially introduced food-safety regulations in order to meet the demands of international markets and global agreements. However, such efforts have often remained theoretical or have only been implemented in large industrial establishment that have international customers. Small producers have often not been integrated within the regulatory framework, and hence are left to operate in the informal market sector. Azevedo and Bankuti (2002) describe the situation in Brazil, where the implementation of stricter regulations has led to a growth of the informal market, resulting in more "unsafe" food being sold to the consumers. This effect is a result of the increased costs associated with producers having to upgrade to the new safety regulations (ibid.). The poor populations of developing countries are described as having a high price-sensitivity, and consequently they will readily switch to buying products from the informal market if the prices of food products in the formal, regulated, market rise.

Azevedo and Bankuti (2002), however, also describe positive experiences from Brazil: in addition to the federal regulations implemented in the export sector, other, more lenient, regulations have been introduced at state and municipality level. Establishments that follow these regulations are allowed to supply state and municipal markets, respectively. This has inevitably resulted in food produced according to different hygiene standards being sold in the national market, but it has decreased the share of the informal market as a whole. A significant number of informal slaughterhouses have moved into the formal market as a result of the introduction of the less strict state-level and municipal-level measures (ibid.).

The other major problem in developing countries is a lack of information among consumers. There are many consumer interest groups working in the developed countries, but these groups are absent, less visible or weaker in developing countries (see discussion of Bangladesh in the following section).

The implementation of international food-safety standards, such as the FAO/WHO Codex standards described above, may not seem relevant to non-exporting developing countries. However, as Randolph *et al*. (2007) point out, alarm over a zoonotic disease can quickly affect the domestic market for livestock products. For example, in Bangladesh the mere news of highly pathogenic avian influenza outbreaks elsewhere caused a temporary drop of 70 percent in the consumption of poultry products (ibid).

Even if these international regulations were to be implemented in the industrial production plants, the average developing country consumer might not benefit. Ayieko *et al*. (2005) reported that even in the more developed cities in Africa, such as Nairobi, only 8 percent of meat products were bought form supermarkets. This implies that live markets and home-slaughtering remain widespread. Another study (Omore *et al*., 2005) shows that lack of proper controlling institutions leads to a high prevalence of food-safety hazards, even in products sold in supermarkets.

Large regional differences exist with respect to the consumption of different livestock products, as a result of differences in culture and eating habits. This can affect the focus of food safety-related measures. For example, in Bangladesh, where fish is the most important animal product, this particular sector has been the focus of food-safety policies, while development in other sectors, such as poultry, has been slower.

7 LESSONS FROM BANGLADESH

Production of poultry meat and eggs in Bangladesh has been growing quite rapidly over the last 15 years. Poultry meat production increased from 66 000 tonnes in 1990 to 102 000 tonnes in 2005, and egg production increased from 85 000 tonnes to 160 000 tonnes over the same period (FAOSTAT). Quasem and Islam (2004) estimated the growth rate of chicken production in Bangladesh to be 5.3 percent *per annum*, and predicted that consumption of broiler meat and eggs would grow by 95 percent and 78 percent, respectively, in the period to 2020. This growth is being driven by the growth in market demand – the same pattern that is seen globally.

As poultry is not an internationally marketed commercial product in Bangladesh, few organized vertical production systems have been established. One exception is the Aftab Poultry Ltd., which produces processed poultry for the few supermarkets that exist in Dhaka and Chittagong. Most poultry is sold in live bird markets, and about 90 percent of the rural families keep small numbers of chickens (Das *et. al.*, 2008). This means that, apart from the Aftab farms, there are no processing plants or organized slaughtering. Aftab operates a system of contract farms – a total of 560 in 2005 (Begum, 2005).

In 1999, there were only two laws related to slaughter and meat – the Animal Slaughter and Meat Act (1957) and the Municipal Corporation Ordinance (1983). These two laws define animal categories allowed for slaughtering, provisions for meatless days, etc. However, they do not set out minimum procedures for slaughter (Svendsen, 1999). Moreover, they do not cover guidelines for pre-slaughter and post-slaughter inspection (ibid.) . In 2005, the Animal Disease Act and the Animal and Animal Products Quarantine Act were approved by the country's parliament.[2] However, it remains to be seen how successful the implementation of these laws will be.

One factor contributing to the slow implementation of international regulatory tools such as HACCP in the poultry sector in Bangladesh is extremely high start-up costs. For example, the cost of implementing HACCP in the shrimp industry to meet EU standards was equivalent to more than 9 percent of annual sales, which represents quite an overwhelming figure for the small producer (Cato *et al*., 1998).

A study in 1997 recorded a 10 percent prevalence of *Salmonella* in commercial poultry farms in Bangladesh (from 1 200 farms tested) (Hoque *et al*., 1997). *Salmonella* is in fact endemic throughout the country. Official records for the prevalence of *Campylobacter* are lacking (personal communications with P. Biswas, University of Chittagong, Bangladesh).

[2] Ministry of Fisheries and Livestock: http://www.mofl.gov.bd/MoFL_laws.aspx

The prevalence of other major microbiological risk factors such as clostridia, *Listeria, E. coli*, and *Staphylococcus aureus* is also largely undocumented.

With regard to chemical risk factors, the use of antibiotics is widespread throughout the poultry sector. Antibiotics are used for therapeutic purposes and as growth promoters in feed. The antibiotics used include oxytetracycline, amoxycillin, co-trimoxazole, gentamicin and ciprofloxacin (personal communication with P. Biswas, University of Chittagong, Bangladesh).

Despite the efforts made by the government, there are major deficiencies with respect to food safety in poultry production of Bangladesh. Consumer awareness of food-borne illnesses is quite elementary. Consumer organizations of the type that in industrialized countries exert pressure on producers to apply food-safety measures are weak or non-existent in Bangladesh (personal communication with Dr. Giassudin, University of Chittagong, Bangladesh). This may contribute to a lack of implementation of existing policies. A recent critical overview (Amjad, 2007) assessed the consumer protection legislation in Bangladesh and concluded that the main public-health problems were similar to those found in other developing countries. One of the main issues is a lack of awareness among consumers. Illiteracy is a factor. There is also a lack of awareness of consumer rights and food-safety risks. Another problem is evidently financial. Even if awareness were greater, financial limitations would still affect consumers' choices and promote the consumption of poorer quality products. Despite efforts to establish consumer-protection legislation, enforcement remains poor (ibid.). Moreover, according to some reports (e.g. Harboe, 1998), the vertical links from the government to the villages are quite weak; a given village may lack the information or the incentives necessary to apply the food-safety regulations passed by parliament.

8 DISCUSSION AND CONCLUSIONS

It is quite difficult to define a best model for food-safety practices applicable to the developing world as a whole. More country-specific data on risk factors throughout the vertical chain are needed. The political environment, the state of infrastructure and so forth should also be carefully assessed before policies are formulated.

Surveillance and data collection systems are often lacking or not functional, meaning that reliable data about risk factors are unavailable. Restructuring or establishing food-safety services may require substantial education of veterinary and the health inspectors at all levels.

A market-driven approach could be a way to achieve success in food safety, but this would need interest and large investments from the industry. There would definitely be difficulties in implementing a thorough control system, because of the existence of the vast informal sector in which animals are not slaughtered in the abattoirs but in homes or at the markets. The Brazilian model, mentioned above, might offer a way forward for some countries. The evidence presented from Bangladesh, suggests that efforts to improve food safety in poultry production should start at the local union or village level with simple regulations directed towards addressing the most prominent deficiencies in the food-safety system. Clearly, this would, again, require identification of the major risks and their entry points into the food chain. Village-level education campaigns, directed at community workers such as teachers, and thus reaching the consumers, as well as at restaurants, would be essential. The main message is clear. Investment in basic education, and thus increasing consumer awareness, should be seen as a key element of food-safety strategies in developing countries.

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Risks caused by bio-aerosols in poultry houses

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SUMMARY

Aerial pollutants in confined animal houses are widely recognized as detrimental to the respiratory health of animals kept in these facilities. Primary and opportunistic microbial pathogens may directly cause infectious and allergic diseases in farm animals, and chronic exposure to some types of aerial pollutants may exacerbate multi-factorial environmental diseases. There are, however, few international field surveys paying attention to the health of the farmers and the farm personnel working in such atmospheres, and to the spread of pathogens from farm buildings. Studies reveal that up to 20 percent of farmers and farm workers report work-related symptoms of respiratory affections, such as coughing, sputum and wheezing. Some develop asthma, others develop diseases that are described as ODTS (organic dust toxic syndrome). There are indications that various pathogens can survive in ambient air for several minutes and can be distributed over long distances, (e.g. foot-and-mouth disease (FMD) virus more than 50 km, and staphylococcae up to 500 m).

This paper describes the complex nature and composition of the aerial pollutants, such as gases, dust, micro-organisms and other compounds, present in the air of farm animal houses, their potential role in the development of respiratory diseases in humans and animals, and their distribution in the surroundings of farms. Future-oriented sustainable farm animal production should (in addition to improving animal welfare, consumer protection, economy and occupational health) enhance standards aimed at preventing or reducing the aerial spread of pathogens.

Key words: air pollutants, bio-aerosols, poultry farming, disease transmission, occupational health, dust, gases, bacteria

1 INTRODUCTION

The air in modern poultry production systems contains a large variety of air pollutants, such as gases like ammonia and carbon dioxide, dust, micro-organisms and endotoxins. These pollutants, also referred to as bio-aerosols, are increasingly regarded as both aggravating and environmentally harmful. The pollutants give cause for concern for several reasons.

Animal respiratory health may be compromised by pollutants such as gases, dust, micro-organisms and endotoxins (Baekbo, 1990; Hamilton *et al.*, 1993; Hartung, 1994).

It is well documented that livestock buildings, manure storage facilities, manure spreading and even free range systems are major sources of gaseous pollutants such as ammonia, methane and nitrous oxide, which contribute to soil acidification and global warming (Jarvis and Pain, 1990; Hartung *et al*., 1990; Ecetoc, 1994).

There is epidemiological evidence that the health of farmers working in animal houses may be harmed by regular exposure to air pollutants such as ammonia, dust, micro-organisms and endotoxins (Donham, 1987; Whyte *et al*., 1994; Donham *et al*., 1995; Radon *et al*., 2002; Hartung, 2005). Providing a safe and healthy work environment for employees is an important objective for any industry – including animal farming (Cargill and Hartung, 2001).

A major reason for concern are bio-aerosol emissions, such as dust and micro-organisms, from farm buildings, which are believed to play a role in respiratory affections in people living in the vicinity of animal enterprises (Müller and Wieser, 1987; Hartung, 1995; Seedorf, 2004), and which can be transmitted between poultry houses and farms via the air (Schulz *et al*., 2005). Scientific assessment of the risk of aerial transmission of pathogens between flocks is hampered by the fact that there is still little knowledge about the nature and composition of bio-aerosols, the tenacity (resistance) of bacteria and viruses in an air-borne state, and their survival times in ambient air.

This paper briefly defines the term bio-aerosol, gives some quantitative data on air pollutants in poultry houses, presents examples of the health effects of this pollution on humans and animals, discusses the survival times of bacteria and viruses in air and the possible extent of their spread in the surroundings of farms, and reflects on "safe distances" between flocks.

2 COMMON POLLUTANTS FOUND IN FARM ANIMAL HOUSES, AND DEFINITION OF "BIO-AEROSOL"

The key pollutants recognized in the airspace of livestock buildings are particles including dust, micro-organisms and their toxins, and gases such as ammonia, carbon dioxide and more than 100 trace gases such as volatile fatty acids (Table 1). Under commercial production conditions the airborne particles will contain a mixture of biological material from a range of sources, with bacteria, toxins, gases and volatile organic compounds adsorbed to them. Hence, a more descriptive term for these airborne particles is bio-aerosol (Cargill and Banhazi, 1998). The typical character of bio-aerosols is that they may affect living things through infectivity, allergenicity, toxicity, pharmacological or other processes. Their sizes can range from aerodynamic diameters of 0.5 to 100 µm (Hirst, 1995).

TABLE 1
Common air pollutants in poultry houses

Type of pollutant	Examples
Gases	Ammonia, hydrogen sulphide, carbon monoxide, carbon dioxide, 136 trace gases, osmogens
Bacteria/fungi	100 to 1 000 colony-forming units (CFU)/litre air 80 percent staphylococcaceae/streptocococcaceae
Dust	inhalable dust can reach levels of 10 mg/m^3; approximately 90% is organic matter; particles can carry antibiotic residues
Endotoxin	339 to 860 ng/m^3 inhalable endotoxin in poultry houses

TABLE 2

Bio-aerosol concentrations in livestock buildings

	Cattle	Pigs	Chickens
Inhalable dust (mg m^{-3})	0.38	2.19	3.60
Respirable dust (mg m^{-3})	0.07	0.23	0.45
Total bacteria (log CFU m^{-3})	4.4	5.2	5.8
Total fungi (log CFU m^{-3})	3.8	3.8	4.1
Inhalable ETOX (ng m^{-3})	23.2	118.9	660.4
Respirable ETOX (ng m^{-3})	2.6	12.0	47.5

ETOX = endotoxin; 1 ng = approx. 10 EU (endotoxin units); CFU = colony forming unit.
Sources: Seedorf *et al.* (1998): Takai *et al.* (1998).

Several studies have recorded the concentrations of key components of bio-aerosols in farm animal buildings, with particular high levels recorded in poultry production (e.g. Seedorf *et al*., 1998).

Table 2 summarizes the results of a broad European Union-wide study on bio-aerosols in pig, cattle and poultry farms. The results show that the lowest concentrations were found in cattle production and the highest in poultry houses (ibid.). However, there are considerable differences between production systems within a given species. The highest dust concentrations regularly occur in houses for laying hens. These concentrations often exceed the occupational health limit for the workplace (in Germany) of 4 mg/m³, particularly at times of high animal activities (Saleh, 2006). These pollutants are emitted into the environment by way of the exhaust air through the ventilation system.

3 WORK-PLACE HEALTH EFFECTS OF BIOAEROSOLS IN FARM ANIMAL HOUSES

Complaints about respiratory symptoms during and after work in animal houses have risen among farmers and employees in recent years. The number of employees who were granted an insurance pension because of work-related obstructive airway diseases caused by allergic compounds rose from about 90 in 1981 to approximately 700 in 1994, a slightly smaller increase from 8 to 50 was observed for obstructive diseases caused by chemical irritants or toxic compounds (according to the statistic of the German occupational health board in agriculture, 1996). In a study comprising 1 861 farmers in northern Germany, about 22 percent of the pig farmers, 17 percent of the cattle farmers and 13 percent of the poultry farmers admitted airway problems (Nowak, 1998). The data are detailed in Table 3. Although the causes of the relatively high incidence of health problems, associated particularly with pig farming are not yet completely understood, it seems that factors such as high concentrations of air pollutants, the composition of pig house bio-aerosols, insufficient ventilation, and poor system management may play a role. The results may also be biased by the fact that most pig farmers in Germany work on their own farms, which they do not easily abandon even in the event of health problems, while poultry farm workers can more easily change their workplace or profession.

Numerous studies have demonstrated links between dust and human ill-health in a number of livestock-related industries (Donham *et al.*, 1995). A survey of 69 full-time poultry stockpersons in the United Kingdom found that although occupational health and safety guidelines were adhered to, 20 percent were exposed to levels of dust 2.5 times higher than the 10 mg/m3 recommended under occupational health and safety guidelines (Whyte *et al.*, 1994). Findings such as these have led to the introduction of strict codes to protect people involved in the intensive livestock industries in several countries including Denmark and Sweden. Guidelines have also been recommended to the Australian pig industry (Jackson and Mahon, 1995).

The first reports indicating health hazards for humans working in intensive livestock production systems were published over 20 years ago (Donham *et al.*, 1977). A number of syndromes have been recognized in workers in the intensive animal industries. They range from an acute syndrome, which develops within a few hours to days of exposure to animal sheds, and which is accompanied by a variety of clinical signs including lethargy, a mild febrile reaction, headaches, joint and muscle aches, and general malaise, to more chronic responses. In some cases, the initial attack is so severe that the employee terminates his or her employment within a matter of days. In general, episodes last 12 to 48 hours, with chronic fatigue and congested respiratory passages being reported as the most common clinical signs. The condition has been referred to as organic dust toxic syndrome (ODTS) or toxic alveolitis. The prevalence of ODTS has been quoted as ranging from 10 to 30 percent of workers, depending on the type of intensive animal production and the facilities used (Donham, 1995).

A range of acute respiratory symptoms, described by employees following contact with their work environment, but not necessarily associated with a generalized clinical syndrome, have also been documented (Brouwer *et al.*, 1986). The more common clinical signs include an acute cough, excess sputum or phlegm, a scratchy throat, discharging or runny nose, and burning or watery eyes. Other more generalized clinical signs that may or may not be present include headaches, tightness of the chest, shortness of breath, wheez-

TABLE 3
Frequency of workplace-related respiratory symptoms in livestock farmers/employees in Lower Saxony, Germany

Animal species		Number of persons surveyed	Percentage of persons with complaints
Pigs	Sow	619	22.7
	Fattening	799	21.9
	Weaner	551	23.0
Cattle	Cow	1 245	17.4
	Beef	895	17.2
	Calf	1 190	17.8
Chickens	Laying hens	279	14.7
	Broilers	47	12.8

Source: Nowak (1998).

ing and muscle aches. In several studies in North America, and Sweden, the prevalence of acute symptoms was found to be 1.5 to 2 times higher than chronic symptoms. However, in a similar study in the Netherlands, the prevalence of chronic and acute symptoms was reported to be similar (ibid.).

Exposure to dust produces a variety of clinical responses in individuals. These include occupational asthma due to sensitization to allergens in the airspace, chronic bronchitis, chronic airways obstructive syndrome, allergic alveolitis and ODTS (Iversen, 1999).

The suggestion that the primary clinical problem is an obstruction of the airways is supported by various studies in which workers have been subjected to lung function tests. Although the forced expiratory volume-in-one-second (FEV1) was not changed in most people studied, decreases in the FEV1/forced vital capacity (FVC) ratio and flow rates support this hypothesis. In a series of studies of workers over a period of time, the greatest decrease (4 to 12 percent) occurred in forced expiratory flow rates (Hagland and Rylander, 1987). In both Swedish and American workers, significant changes were also recorded in FEV1 and flow rates. Although the changes reported in these studies were modest on a population basis, a significant clinical reduction in FVC was recorded in 14 percent of Canadian workers (Dosman *et al*., 1988) and 20 percent of Dutch workers (Brouwer *et al*., 1986).

Exposure to bio-aerosols has also been shown to cause broncho-constriction, hyper-responsiveness and increased inflammatory cells in bronchial alveolar lavage fluids in naïve subjects (Malberg and Larsson, 1992). It is assumed that broncho-constriction followed by reduced ventilation of the lungs can be caused by inhaled endotoxin. Experiments using nasal lavage show that pig-house dust containing different concentrations of endotoxins increases the inflammatory reaction of the nasal mucous membranes of humans, distinctly (Nowak *et al*., 1994). The broncho-constrictive effects of bio-aerosols have also been demonstrated in guinea pigs (Zuskin *et al*., 1991) as well as in stockpersons in Sweden and North America (Donham, 1995).

Further studies are needed to improve understanding of the building features and animal husbandry practices that increase the concentration of airborne pollutants in buildings housing animals, and to determine the key pollutants involved. The evidence collected in farm animal buildings suggests that issues such as hygiene and stocking density (kg biomass/m^3) are key factors, but that the composition of pollutants or bio-aerosols may vary significantly from shed to shed depending on a range of factors (Banhazi *et al*., 2000); these factors include hygiene, dietary composition, as well as the type of bedding and effluent disposal system used. The severity of specific occupational health problems might be more affected by the composition of bio-aerosols within an animal-house atmosphere than just by the concentration of airborne particles.

4 TRANSMISSION DISTANCES OF BIO-AEROSOLS

There are few experimental data available on transmission distances of bio-aerosols from animal houses. From epidemiological studies, it is known that FMD virus can travel over distances of more than 50 kilometres (e.g. Donaldson and Ferries, 1975; Gloster *et al*., 2005). Experiments around farms revealed elevated levels of dust particles and bacteria between 50 and 300 m downwind of animal houses compared to upwind control meas-

TABLE 4
Reported transmission distances of bio-aerosols emitted from livestock buildings

Component	Distance (m)	Reference
Dust particles	50	Schmidt and Hoy (1996)
	115	Hartung *et al.* (1998)
Bacteria	50	Platz *et al.* (1995)
	100	Sarikas (1976)
	200	Köllner and Heller (2005)
	200–300	Müller and Wieser (1987)

urements (Table 4). These figures are far from being safe distances, because they do not reflect the spread of specific pathogens or allergenic components (e.g. feather fragments), which may be transported much longer distances, and which can cause health risks even in small quantities.

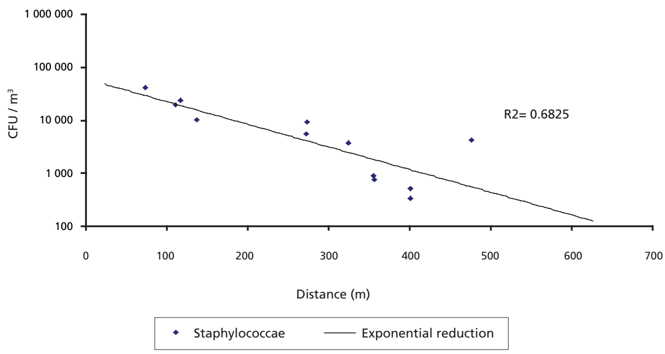
Most important for the possible transmission of a pathogen is its ability to survive in an airborne state over a longer period. Table 5 presents some data showing that micro-organisms are strongly influenced by environmental conditions such as temperature and humidity of the air; other factors include radiation, sunlight and additional chemical compounds in the air.

Recent investigations in and around broiler houses have shown that the travel distance of staphylococcae downwind can be more than 500 m from the source. Under stable wind

TABLE 5
Loss of viability of various pathogens in air at varying temperature and humidity

Pathogen	Relative. humidity (%)	Temperature (°C)	Loss of viability after 250 seconds in air (%)
Escherichia coli (O78)	15–40	22	14
Mycoplasma gallisepticum	40–50	25	up to 3
Salmonella enteritidis	75	24	up to 20
S. newbrunswick	30	10	38
S. newbrunswick	70	21	11
S. typhimurium	75	24	up to 20
Staphylococcus aureus	50	22	up to 1
Influenza A virus	50	21	more than 70
Influenza A virus	70	21	more than 66
Newcastle disease virus	10	23	No loss detectable
Newcastle disease virus	35 and 90	23	20

FIGURE 1
Decreasing concentrations of staphylococcae with increasing distance downwind from a broiler barn with 30 000 birds



Notes: Sampling 1.5 m above ground. Animals in second half of production cycle. Air temperature about 16 °C, wind speed between 1.7 m/s and 6.3 m/s. n = 12. CFU = Colony forming unit.
Source: Seedorf *et al.* (2005).

conditions more than 4 000 CFU/m³ were found 477 m downwind of the barn (Seedorf *et al*., 2005). Staphylococcae are typical bacteria in broiler house air (Figure 1). They can probably serve as indicators for bacterial pollution, because they do usually not appear in relevant concentrations in normal outside air.

These results show that there is a considerable distribution of micro-organisms from poultry houses into the surroundings.

5 STRATEGIES TO MINIMIZE THE RISK FOR EMPLOYEES AND ANIMALS

Several approaches to reducing air pollution in animal houses and protecting employees on the job are available. These include wearing protective gear, reducing exposure levels within the buildings, and eliminating pollutants at source. Employees should be encouraged to wear dust masks (or ventilators) and eye protection when working in sheds, particularly in straw-based shelters when handling or moving animals. As a minimum, a mask that can be shaped for individual nasal structures, with two head straps (above and below the ears) should be used. Reliable protection requires the use of ventilated masks. The disadvantage is the weight of the helmet with the filter system and the battery-powered ventilator. Employees who wear glasses may need to consider contact lenses while wearing a mask and eye protection. A recent survey is given in the book KTBL Schrift 436 (Anonymous, 2005).

Various strategies have been recommended for reducing the concentrations of air-borne pollutants in animal houses. These include management measures as well as strict hygienic rules and direct reduction techniques such as fogging sheds with oil and water (Pedersen, 1998; Banhazi *et al*., 1999). All these methods have to be carefully investigated as to whether they may cause side effects in the animals, the environment or meat quality (Cargill and Hartung, 2001). End-of-pipe techniques such as biofilters and bioscrubbers, which filter the exhaust air and reduce the pollution of the surroundings of the farm, are recommended in some countries. These techniques are, however, still rather expensive, and are presently largely restricted to sensitive situations such as when farms are located very close to residential areas.

Reducing air pollutants in animal houses is an urgent requirement for the development of future poultry production. It will provide a safer and healthier work environment for employees, and a better atmosphere for the animals – improving their health, welfare and performance. Reducing emissions will at the same time reduce the risk of transmission of pathogens indoors as well as between neighbouring farms. Future-oriented sustainable farm animal production should (in addition to improving to animal welfare, consumer protection, economy and occupational health) also enhance standards aimed at preventing or reducing the aerial spread of pathogens via the air.

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Veterinary services for poultry production

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SUMMARY

The current highly pathogenic avian influenza (HPAI) crisis has brought poultry production to the focus of public attention. Poultry production takes place in two basic systems: the industrial sector and the small-scale production system at village level. The level of involvement of veterinary services differs greatly between the two systems. While private veterinary services are important in the industrial sector, there is only limited provision of veterinary services in small-scale production systems. This has consequences for the success of disease control measures.

As HPAI is a zoonotic disease, its control is undoubtedly a public good and ultimate responsibility for this should lie with the official veterinary services. However, as both public and private sectors are contributing to disease control, this paper suggests strengthening national animal health systems and ensuring that all service providers have clearly defined roles and responsibilities under the leadership of the official veterinary services. Evidence gained during Newcastle disease control projects at village level, indicates that a paradigm shift in disease control is needed, promoting strong involvement of communities in policy development. This requires a multidisciplinary approach that enables a better understanding of this specific sector to be obtained. The Food and Agriculture Organization of the United Nations (FAO) is implementing pilot projects in different countries to better understand virus spread, value chains, the role of poultry in livelihoods, and the species and breeds kept. Broader knowledge, will allow the impact of control measures in this sector to be assessed, and national HPAI preventive and control policies to be adjusted as needed.

Key words: disease control, poultry, multidisciplinary, small scale

1 INTRODUCTION

Since the outbreak of highly pathogenic avian influenza (HPAI) H5N1 in poultry, in 2003/2004, in Southeast Asia, and its subsequent spread to more than 50 of the world's countries, poultry production has come sharply into the focus of the international community's attention. This heightened awareness is in large part due to the zoonotic potential of HPAI H5N1-V. The present virus strain has a relatively low ability to spread from poultry to humans, but evidence shows that once this transfer occurs the virus causes a very high mortality rate. More importantly, there is a fear that a new strain will emerge and cause a human flu pandemic.

Right from the beginning, the challenge for governments and technical agencies was to ensure early detection and control of the disease. Even with the improvements in detection achieved over the last three years, there is still need to strengthen surveillance systems further and institutionalize them within national animal health systems.

In this paper, existing poultry health systems are described and an outlook is tentatively given as to how to improve the linkage between poultry owners, and private and public veterinary services.

2 VETERINARY SERVICES IN POULTRY PRODUCTION

Two basic systems of poultry production can be identified and are present in most countries: an industrial poultry sector and a small-scale production system. It is recognized that other classification systems exist (see Rushton and Ngongi (1998) for early versions and more recently FAO (2004) for a classification based on a notional idea of biosecurity). The approach and level of involvement of veterinary services in poultry production differ greatly between the industrial sector and the small-scale production system.

The industrial sector, which often operates in international markets, has a high use of variable inputs, mainly concentrate feed, and significant investments in infrastructure. This sector has developed its own poultry health schemes to ensure the productivity and health of the birds, a development crucial to avoiding production losses resulting from diseases and ensuring that disease-related market shocks are minimized. These requirements apply at farm level, but in the case of diseases that are notified under international agreements, also apply at national level. Notification to the World Organisation for Animal Health (OIE) generally entails international market bans, and in the case of zoonotic diseases also gives rise to internal market shocks. Another relevant consideration is that companies often use their poultry health schemes as a sales argument when negotiating with their clients.

Even though private poultry health schemes may vary in their details, implementation is organized mostly in the same way in all countries. The schemes are conceived for all participants in the chain – hatcheries, producers (broilers, pullets and layers), slaughterhouses, transporters and feed mills. It includes biosecurity (bioexclusion) measures at farm level, sampling at critical control points in the chain, vaccination schemes and other prophylactic measures for the animals. These activities and the results of control measures are internally recorded. The veterinary services (diagnostic, prophylactic and therapeutic) are generally provided by private veterinarians, either employed by the company or contracted with specific terms of reference. It is common for diagnostic work (detection of pathogens and residues) to be carried out in laboratories that are often owned by the poultry companies. In an integrated poultry chain it is mandatory for poultry producers to be part of a poultry health scheme, whatever their contractual status. This approach ensures maximum consistency in the quality of the produce and the services provided; it allows a fast and targeted reaction in the case of hazards. It also maintains high levels of productivity as the large quantities of inputs involved (mainly feed) are used by healthy flocks.

The role of the official veterinary services in this context is mainly to ensure that moral hazards affecting consumers are kept to a minimum and that there is an effective framework for research and dissemination of knowledge that has a strong public good nature. The responsibilities of the official veterinary services can be derived from agreements such as the World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement)[1]. There are defined responsibilities set out in the *Animal Health Codes* of OIE for disease surveillance[2]; prevention, control and eradication of highly contagious diseases; and movement controls and quarantining. The diseases covered by these provisions have serious consequences in terms of socio-economic impact, trade and public health. Regarding food and feed safety, the basic roles of the state are defined in the Codex Alimentarius[3] which covers official inspections regarding food hygiene, including controls on residues.

For some aspects of the above-described animal health system in the industrial poultry sector, the respective roles of service providers can be clearly defined. For example, flock treatments to increase flock productivity have a strong private good component and are best left to private veterinary services. However, the maintenance of low levels of drug residues in food is clearly a moral hazard issue, which state veterinary services need to address to protect consumers. Some other issues are less clear, and require careful coordination between public and private veterinary services. For example, there are strong incentives for producers to prevent the entry of a disease agent, but if a disease agent enters a flock, the private incentives for containment are not clear and the state needs to play a strong role. Dividing tasks between private and public services requires a close relationship between the two sectors to ensure appropriate roles, cooperation and implementation.

The small-scale/backyard sector operates in a completely different setting. The most important differences with regard to disease control are as follows:

- very diverse organization of the sector in different regions;
- minimal or no external inputs;
- poultry flocks that are generally managed by women, who may well own the birds and market the produce;
- production exclusively for household consumption, or local or national trade; and
- no integration of the associated market chains.

The use of veterinary products and services are limited in this sector because:

- losses due to diseases are common and often considered inevitable; and
- many poultry producers are poorly connected to veterinary product distribution and advice networks – making the transaction costs involved in obtaining such goods very high.

Where there is a possibility to get regular access to markets and therefore to generate income, small-scale poultry producers will make investments in inputs, including veterinary services. Such services are frequently provided by non-veterinarians, such as trained paravets or other knowledgeable people in the villages. In some countries where private veterinary services are under development, the official veterinary services may provide clinical services at village level.

The roles and responsibilities of public and private sectors in animal health service delivery have been described by Leonard (2000) and Ahuja (2004). The latter author provides a useful analysis of the public and private good nature of animal health services, which has

1 http://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm (December 5, 2007).

2 http://www.oie.int/eng/normes/en_mode.htm?21d10 (January 22, 2008).

3 http://www.codexalimentarius.net/web/index_en.jsp (December 5, 2007).

been used to develop a list of the roles and responsibilities of public and private sectors in animal health delivery (see Table 1).

According to the classification set out in Table 1, non-zoonotic, highly contagious poultry diseases, such as Newcastle disease or duck plague, should only be part of official control programmes when they may endanger international trade. This is the case, for example, in the European Union, North America and Japan. These regions/countries have important market interests in the international poultry sector, and trade bans have consequences for their economies. In other regions of the world, there is no official programme to control these diseases although they are notifiable to the OIE. Their control is generally not considered a public good according to the above-described classification (Ahuja, 2004).

TABLE 1
Suggested channels for animal health functions

Animal health function	Appropriate delivery channel		Economic characteristic
	Public	Private	
Disease surveillance, prevention, control and eradication of highly contagious disease with serious socio-economic, trade and public health consequences	√	√	Public good
Disease surveillance, prevention, control and eradication of diseases of low contagion		√	Private good with externalities
Quarantine and movement control	√		Measures to correct for externalities
Emergency responses	√		Public good
Veterinary inspection	√		Measures to correct for "moral hazard"
Wildlife disease monitoring	√		Public good
Zoonosis control	√		Measures to correct for externalities
Disease investigation and diagnosis	√	√	Private good with externalities
Drug/vaccine quality control	√		Require measures to correct for "moral hazard"
Production and distribution of drugs and vaccines		√	Private good
Vaccination and vector control	√	√	Private good with externalities
Research, extension and training	√	√	Public and private
Clinical diagnosis and treatment		√	Private good
Food hygiene and inspection	√		Measures to correct for "moral hazard"
Residue testing	√		
Food safety tasks	√		Public good
Compliance and monitoring	√		Public good

Source: modified from Ahuja (2004).

3 EXPERIENCE IN COMBATING NEWCASTLE DISEASE AT VILLAGE LEVEL

As poultry production can be considered an important development tool for promoting food security at household level, there have for a many years been various initiatives to improve production and to provide veterinary services such as vaccination to protect animals from Newcastle disease (Copland, 1987; Sagild and Haresnape, 1987; Ideris *et al*., 1990; Jagne, 1991; Rweyemamu *et al*., 1991; Spradbrow, 1993; Rushton in FAO, 1993; Rushton in FAO, 1995; Rushton in FAO, 1996; Bell *et al*., 1995; Alders and Spradbrow, 2001) and other diseases (Permin and Pedersen, 2002).

International development agencies and NGOs have initiated extended activities to control Newcastle disease in village poultry (e.g. French initiative in West-Africa, the initiatives of the Australian Centre for International Agriculture Research). Key elements in these initiatives are vaccination, communication and information, and monitoring and evaluation (Dolberg in FAO, 2007). Although the design of such programmes may differ, success depends in all cases largely on the involvement of the national government and its veterinary service, and of producers and their veterinary services provided by private veterinarians or paravets.

As the programmes mainly address very poor people, national governments and public veterinary services have to be involved. Their role is to provide an adequate policy framework – for example, introducing village poultry production into national poverty eradication programmes, designing and conducting information campaigns, and initiating vaccination campaigns (including making the decision as to the type of vaccine to be used).

The producers and their associated veterinary services have to recognize the programme as something that adds value to their poultry production. This requires medium- to long-term programme implementation in order to build up trust and ensure sustainability.

A Newcastle disease control programme will only be successful and sustainable if there is a win–win situation for both sides. Therefore, there is a need for reliable national policies and commitment from the public sector. One way to meet this requirement would be to integrate the programme in national livestock policy. In addition, there is a need to involve the international donor community and the development agencies. These actors will be required to assist the programme, at least at the beginning, especially in developing the initial vaccination and information campaigns – including training, logistics (procurement and distribution of the vaccine, and monitoring the success of the vaccination) and disseminating the results. This requires the mobilization of additional funds.

The experience gained in developing and implementing Newcastle disease control programmes could be utilized for the control of HPAI, even though the nature of the disease requires the use of other control tools.

4 THE EMERGENCE OF HPAI H5N1

HPAI H5N1 has changed the situation for the poultry sector tremendously. This virus is panzootic, zoonotic and has the potential to become pandemic. All the criteria for a public good apply to the animal disease caused by this virus. Therefore, there is urgent need for national veterinary services to be involved in the control of this disease. While this occurs more or less successfully in the industrial system, it appears to be very difficult in the small-scale sector.

The classical tools utilized to control highly contagious diseases (biosecurity at farm level, movement bans/restrictions, culling and vaccination) first require some basic planning data on the poultry sector:

- species and approximate numbers of birds;
- type of production;
- marketing and distribution systems;
- slaughterhouses; and
- locations of production and marketing, including hatcheries, slaughterhouses and wet markets.

These data are generally available for the industrial sector, but rarely for the small-scale sector. Moreover, as in most of the affected countries there is no official registration system for small-scale production units (in some, registration does not exist even for the industrial sector), they are unlikely to become available in the short or medium term.

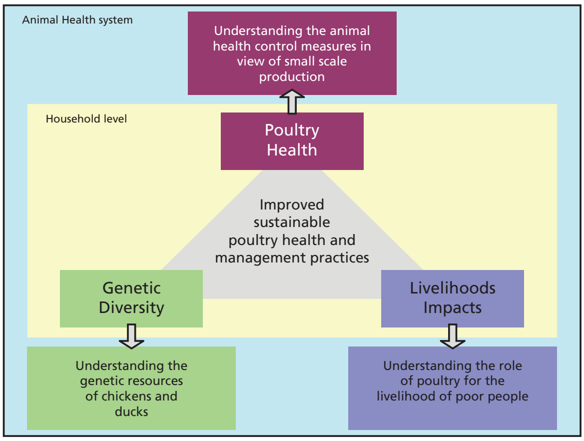
The lack of data and surveillance for the small-scale sector might be one reason why the control of HPAI in the industrial sector is quite successful, while the virus persists for longer in the small-scale sector. In addition, small-scale/backyard producers regularly experience substantial losses in their flocks due to contagious diseases such as Newcastle disease, but also malnutrition, parasites and predation. As they rarely receive help to prevent such losses, they will generally not report an event even if it might be an HPAI outbreak. Even worse, experience teaches the villagers that if by chance the official veterinary services become aware of an HPAI outbreak, birds are destroyed, production and marketing is limited, and access to any sort of compensation maybe limited or non-existent. For these reasons, possible outbreaks in backyards are rarely reported by the poultry owners and are often only detected after investigation of outbreaks in commercial farms, as the result of an active surveillance exercise ("Participatory Disease Search" programme in Indonesia, market surveillance in Viet Nam) or when a human case occurs.

It is obvious, therefore, that a paradigm shift is needed in approaches to combating HPAI in small-scale/backyard systems and to create a win–win situation in which both the needs of producers at community level and the concerns of the international community are addressed (BMELV/GTZ, 2006).

5 MULTIDISCIPLINARY APPROACHES TO DISEASE CONTROL

Based on experience of poultry development programmes for villagers (including the above-described Newcastle disease campaigns), and experience of HPAI control to date, it can be concluded that the classical disease control measures (biosecurity at farm level, movement controls, culling and vaccination) will have only limited impact on the disease in this sector. Rushton and Ngongi (1998) note that interventions rarely work if they are implemented in isolation. Interventions need to be supported by a package of measures covering health, husbandry and marketing. As in the implementation of Newcastle disease control programmes, long-term strategies developed through a multidisciplinary approach and involving the communities will be critical for HPAI control. This was acknowledged by the Technical Meeting on Highly Pathogenic Avian Influenza and Human H5N1 Infection, held in Rome in June 2007.

FIGURE 1
Conceptual framework[4] for the Animal Health, Breed Diversity and Livelihoods (AHBL) project



A contribution to this new approach is a project, funded by Germany[5] and currently being implemented by FAO in three pilot countries: Cambodia, Egypt and Uganda. The project aims to promote policies and strategies for prevention and control of HPAI that are sensitive to the needs of smallholder producers, especially poor rural families, and to poultry genetic resources. It considers, in a multidisciplinary manner, three main fields of concern: animal health, poultry breeds and livelihoods. The project will contribute to creating a safe production environment for smallholders, which supports sustainable livelihoods and poultry genetic diversity.

The knowledge needed to implement the approach will be generated during the pilot studies which aim to increase understanding of how animal disease control measures affect livelihoods and poultry genetic resources at country level.

Three main objectives for the studies have been identified:

- understanding chicken and duck genetic resources in the respective country;
- understanding animal health control measures from the perspective of small-scale poultry production; and
- understanding the role of poultry in the livelihoods of poor people.

The focus of the studies will be on the communities involved, collecting information through participatory methods and sampling of birds. This will allow characterization of the breeds and assessment of the disease situation in the village sector. Based on the resulting comprehensive data on the livelihood impacts of animal health control measures, including impacts on poultry genetic diversity, it is planned:

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4 Developed by Karin Schwabenbauer, Badi Besbes, Jonathan Rushton and Olaf Thieme (FAO).

5 GCP/INT/010/GER "Promoting strategies for prevention and control of HPAI that focus on smallholder livelihoods and biodiversity"

- to propose improved sustainable poultry health and management practices at household level;
- to define the involvement of the smallholder sector in national animal health systems; and
- to contribute to strengthening veterinary services through public–private partnership.

It is intended that this will provide a baseline for improved reporting and surveillance systems for HPAI.

6 CONCLUSIONS

Poultry production takes place in two different settings: the industrial sector, operating nationally, regionally and in some cases globally; and the small-scale sector, operating with minimal inputs and with products mainly aimed at household consumption or local markets. The types of veterinary services demanded by and provided to these two basic types of poultry production are very different. This influences the effectiveness of disease control measures. The classical tools (biosecurity at farm level, movement control, culling and vaccination) are likely to have an impact in the case of an outbreak in the industrial sector, but are far less successful in the small-scale sector.

It is argued in this paper that in order to strengthen national animal health systems, institutional arrangements for animal disease control need to reflect the incentives of the public and private sectors in the different components of poultry production systems. This requires well-defined roles and responsibilities which take into account the fact that animal health measures generate both public and private goods, but also that the leadership for the animal health system should rest with the official veterinary services.

In addition, improvements in animal disease control in small-scale village poultry production require a better understanding of this sector, regarding virus spread, value chains, the contribution of poultry to livelihoods, and the species and breeds kept. Based on broader knowledge, the impact of control measures in this sector can be assessed and the national HPAI prevention and control policy adjusted, as needed. Building trust in improved veterinary services based on a public–private partnership is critical for this process. This will not be realized at short notice, and requires strong involvement of communities in policy development and strong commitment from the public sector. This is a major challenge.

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Risks and opportunities for poultry production

SUMMARY OF DISCUSSIONS

The threat posed by highly pathogenic avian influenza (HPAI) gave rise to numerous comments. Particularly emphasized were the challenges of ensuring communication and cooperation among stakeholders (particularly across the dividing line between human and animal health) and of developing effective strategies for small-scale production systems and for locations where the infrastructure for disease control is inadequate. It was noted that inappropriate media coverage of HPAI can sometimes present a problem for those working on the control of the disease. Cooperation between the public and private sectors was considered to be essential for effective disease control, and some positive developments in this area were mentioned. It was also noted that there are lessons to be learned from the control of other diseases such as Newcastle disease. Communication among all stakeholders, including the consumers, was emphasized as a means to foster trust and openness. The need to clarify the role of vaccination in the control of HPAI was noted, as was the need for a better understanding of the roles of wild birds and the transport and trade of poultry in the spread of the disease.

The future of small-scale poultry production was also discussed. Its important contribution to the livelihoods of the poor was recognized, as were the challenges of controlling diseases such as HPAI in this production system. It was noted that there is a need to learn more about the livelihoods and priorities of poor poultry keepers – without this understanding, attempts to introduce new technologies would have little impact in terms of poverty reduction. There was a call for improvement of community-based animal health systems, backed by adequate training and community participation in the financial aspects of such schemes. The need to develop effective early-warning systems at the community level was noted.

With regard to the environmental impacts of poultry production, it was argued that the real problem is not a lack of technologies to deal with the problems, but the costs of implementing them and a lack of incentives and regulations to enforce their use. It was also suggested that pollution costs and other externalities should be taken into account when assessing the relative efficiency of different production systems.

Other challenges brought up during the discussion included food safety, changing consumer demands (possible future increase in consumer demand for breast meat in developing countries), rising input costs, the use of feed crops for biofuel production, and loss of genetic diversity in the poultry population.