The project: This publication is part of a series developed to support decision-making for the prevention and control of highly pathogenic avian influenza through the use of risk mapping, and is an output of the Early Detection Response and Surveillance of Avian Influenza in Africa (EDRS-AIA) project, implemented by the International Livestock Research Institute (ILRI) in collaboration with African Union Interafrican Bureau for Animal Resources (AU/IBAR).

Researchers and writers: A joint research team from the Royal Veterinary College (RVC) in London and ILRI prepared this publication series under the guidance of Professor Dirk Pfeiffer. Team members included Solenne Costard, Kim Stevens, Raphaelle Metras, Wachira Theuri, Russ Kruska, Tom Randolph, Delia Grace, and Saskia Hendrickx.

Editor: Carole Douglis

Graphic Design: Lilian Ohayo, Eric Ouma

Photographer: Stevie Mann/ILRI

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Risk Mapping for HPAI H5N1 in Africa
Improving surveillance for bird flu

Initial Bird Flu Risk Map Report
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Introduction

Why risk maps?

Risk maps are tools that decision-makers can use to help focus their disease surveillance efforts on areas at greatest risk of disease outbreak.

The aim of this risk mapping project is to identify areas at higher risk for the introduction and spread of highly pathogenic avian influenza (HPAI) H5N1—commonly called “bird flu”—in Africa. “Introduction” refers to a first occurrence in a place; “spread” refers to disease movement once introduced.

We lack adequate knowledge so far about the epidemiology of bird flu in Africa, concerning both introduction and spread. Better information is essential since more than 85 percent of households in rural Africa raise poultry. An epidemic could therefore devastate both livelihoods and food sources, as well as raise the risk of disease transmission to humans.

The risk map project for bird flu in Africa

This project presents risk maps which have been generated for bird flu for the African continent and sub-regions. Project staff have used state-of-the-art techniques for creating the best maps possible based on the data currently available. These maps will be refined as our knowledge of the epidemiology of bird flu improves.

The maps in this report were created using multicriteria decision modelling (MCDM). MCDM combines observations and knowledge from numerous sources including published studies, known outbreaks, geographic representation of a wide range of risk factors, direct field observation and experts’ experience to produce a risk map.

Bird flu status so far in Africa

The first outbreak of bird flu in Africa occurred in 2006. Since then the disease has affected 11 countries: Burkina Faso, Niger, Nigeria, Togo, Benin, Ghana, Ivory Coast, Sudan, Egypt, Cameroun and Djibouti. In March 2009, Egypt still reported ongoing outbreaks (see Figure 1, page 1-5).
This Initial Report presents

- The rationale and methodology for risk mapping of bird flu in Africa
- The risk-factor layers from which the risk maps are generated
- The first generation of risk maps, for the continent and several sub-continental regions.

The Final Report will feature risk maps improved through incorporation of improved data, field work, and expert validation.

Use of risk maps: some words of caution

Decision-makers and map users should always exercise caution when interpreting risk maps.

- Maps cannot predict an outbreak; they can only indicate where the risk of an outbreak is higher or lower than other areas.
- So far we have only a limited understanding of the epidemiology of the disease in Africa.
- Maps are imperfect since important data are sometimes unavailable, and other data may be inaccurate.
- Possibly important risk factors cannot be mapped. These include beliefs and cultural practices regarding poultry.
Methodology

The methodology for generating the risk maps is based on multi-criteria decision modelling (MCDM) (Pfeiffer et al., 2008). It combines knowledge and observations from numerous sources including published studies, direct field observation, experts’ experience and geographical representation of risk factors associated with the introduction and spread of the disease. It is driven by our best epidemiological understanding of the different factors associated with an increased risk of the disease.

Figure 1:
Countries in Africa affected by bird flu between 2006 and March 2009, and their current status with regards to the disease.
MCDM involves the following steps:

1. Define the objective(s) of the mapping exercise. (In this case they are to map the risk of introduction and risk of spread of bird flu in Africa.)

2. Identify risk factors and how they are associated with the risk of disease. (e.g. a risk factor for the spread of bird flu may be poultry density; the association between the risk factor and the outcome is that the higher the poultry density in an area, the more likely the virus will spread.)

3. Find publicly available maps of risk factors and create a map ‘layer’ for each. (Researchers identified 12 layers representing risk factors associated with poultry trade and transport, and migratory flyways.)

4. Digitally manipulate the maps so that they are in the correct format for inclusion in the MCDM.

5. Define the relative importance of each factor in relation to the objective. (e.g. in Africa it appears that the poultry trade may pose a greater risk to the introduction of bird flu than migratory birds.)

6. Combine risk-factor layers to produce a final, weighted estimate of relative risk for each location in the study area. This process results in a risk map.

7. Perform a sensitivity analysis. This analysis is a statistical check on the calculations underlying the risk maps.

8. Validate the maps. This process is ongoing. We will validate the risk maps with field observations of actual outbreaks in Africa, and also with expert opinion.

The process in more depth

Step 1
Defining the objective(s)

The objectives of the multicriteria decision model are to:

a) To identify areas in Africa with a high or low likelihood for the introduction of bird flu

b) To identify areas in Africa with a high or low potential for bird flu to spread, once introduced into the continent.

Step 2
Defining the risk factors

A systematic search of peer-reviewed, published studies on avian influenza helped researchers identify risk factors for the introduction and spread of bird flu in Africa. Of the risk factors that emerged, the team selected those that can be mapped. For instance, proximity to waterbodies and main roads can be mapped, while cultural beliefs regarding poultry cannot be mapped.
Searches were performed on two comprehensive databases of journals and other scientific literature:

1) PubMed/Medline, a widely used general medical database, and

2) ISI Web of knowledge (Athens), which includes a wealth of literature on veterinary medicine and public health.

Key words for the searches were standardised across the two databases to produce comparable searches (Table 1).

Table 1:
Standardised key words used in the literature search of two databases

<table>
<thead>
<tr>
<th>Key words</th>
<th>PubMed (Field specified: MeSH terms)</th>
<th>ISI Web of knowledge (Field specified: Topic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>avian Influenza</td>
<td>influenza in birds</td>
<td>avian Influenza</td>
</tr>
<tr>
<td>HPAI</td>
<td>influenza in birds</td>
<td>HPAI</td>
</tr>
<tr>
<td>H5N1</td>
<td>Influenza A Virus, H5N1 Subtype</td>
<td>H5N1</td>
</tr>
<tr>
<td>Africa</td>
<td>Africa</td>
<td>Africa</td>
</tr>
<tr>
<td>risk assessment</td>
<td>risk assessment</td>
<td>risk assessment</td>
</tr>
<tr>
<td>wild bird*</td>
<td>wild animal</td>
<td>wild birds</td>
</tr>
<tr>
<td>legal import*</td>
<td>commerce</td>
<td>trade</td>
</tr>
<tr>
<td>illegal import*</td>
<td>commerce</td>
<td>trade</td>
</tr>
<tr>
<td>risk*</td>
<td>risk</td>
<td>NOT USED</td>
</tr>
<tr>
<td>risk factor*</td>
<td>risk factors</td>
<td>risk factor*</td>
</tr>
<tr>
<td>establish*</td>
<td>epidemiology</td>
<td>establish*</td>
</tr>
<tr>
<td>endemic*</td>
<td>epidemiology</td>
<td>endemic*</td>
</tr>
<tr>
<td>transmiss*</td>
<td>disease transmission</td>
<td>transmiss*</td>
</tr>
</tbody>
</table>

More specific terms (e.g. “biosecurity,” “markets,” “fomites,” “ducks,” etc.) were assumed to be covered by the above search strategy, since the key words refer to broader concepts.

The keyword search produced several hundreds of articles published as of 5th March 2009. Researchers screened all (some were listed on both databases), then read the 136 most relevant ones. Of these, 48 identified risk factors for introduction and spread of bird flu (Figure 2).

Using the list of risk factors (Table 2), those suitable for mapping were extracted, and classified according to their relevance for introduction or spread of disease (Tables 3 and 4).
Two selection criteria were used to identify risk factors useful for mapping activities:

a) Ability of the risk factor to be mapped.
   
   Example 1: “Owner lives off farm” (Kung, Morris et al. 2007) is a risk factor for spread that cannot be represented on a map.
   
   Example 2: “Water area” (Ducatez 2006) is a risk factor that can be represented on a map.

b) Importance of the risk factor according to the number of times reported in the literature review.

Figure 2:
Flow chart diagram indicating the screening and selection of relevant papers selected from the two databases.
Initial Bird Flu Risk Map Report

Part One: The Why and How of Risk Mapping
### Table 2:
Risk factors for the occurrence of bird flu as identified in a review of 136 articles published on PubMed or ISI Web of Knowledge

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Comments</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Markets/ trade</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days open (7 days) LPAI*</td>
<td>New Jersey</td>
<td>Bulaga, 2003</td>
</tr>
<tr>
<td>Live poultry market</td>
<td>China</td>
<td>Cheung et al., 2007</td>
</tr>
<tr>
<td>Sale of poultry at live bird markets</td>
<td>Vietnam, farm level</td>
<td>Soares-Magalhaes, 2006</td>
</tr>
<tr>
<td>Live bird markets</td>
<td>Vietnam</td>
<td>Nguyen et al., 2005</td>
</tr>
<tr>
<td>Live poultry market</td>
<td>Korea</td>
<td>Choi et al., 2005</td>
</tr>
<tr>
<td>Retail marketing of live poultry</td>
<td>HK, farm level</td>
<td>Kung et al., 2007</td>
</tr>
<tr>
<td>Unprotected trade</td>
<td>Nigeria</td>
<td>Ducatez, 2006</td>
</tr>
<tr>
<td>Importation of day old chicks</td>
<td>Ethiopia</td>
<td>Soares-Magalhaes, 2007</td>
</tr>
<tr>
<td>Legal and illegal trade of poultry</td>
<td>Global</td>
<td>Gauthier-Clerc, 2007; Vannier, 2007</td>
</tr>
<tr>
<td>Trade of poultry</td>
<td></td>
<td>Kilpatrick et al., 2006</td>
</tr>
<tr>
<td>Proximity to road / highway</td>
<td>Romania, China</td>
<td>Fang et al., 2008; Ward et al., 2008</td>
</tr>
<tr>
<td>Major cultural festivals with peak sale / consumption</td>
<td>Vietnam</td>
<td>Pfeiffer et al., 2007</td>
</tr>
<tr>
<td>Reducing distances to higher human population density aggregation</td>
<td>Vietnam, farm level</td>
<td>Pfeiffer et al., 2007</td>
</tr>
<tr>
<td><strong>Migratory/ wild birds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Migratory birds route</td>
<td>Europe</td>
<td>Pfeiffer et al., 2006; Feare, 2007; Sabirovic et al., 2007</td>
</tr>
<tr>
<td></td>
<td>Ethiopia</td>
<td>Goutard et al., 2007</td>
</tr>
<tr>
<td></td>
<td>Egypt</td>
<td>Saad, 2007</td>
</tr>
<tr>
<td></td>
<td>America/ South Africa</td>
<td>Abolnik, 2007</td>
</tr>
<tr>
<td></td>
<td>Global</td>
<td>Kilpatrick et al., 2006; Staiknecht, 2007; Weber and Stilianakis, 2007; Gaidet et al., 2008b; Keawcharoen et al., 2008</td>
</tr>
<tr>
<td><strong>Farm practices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Distance cases - susceptible</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Movements of poultry between holdings</td>
<td>Vietnam, farm level</td>
<td>Soares-Magalhaes, 2006</td>
</tr>
<tr>
<td>Direct distance to the nearest case farm</td>
<td>Japan, farm level</td>
<td>Nishiguchi et al., 2007</td>
</tr>
<tr>
<td>Proximity of infected premises &lt; 1.5km</td>
<td>Italy, farm level</td>
<td>Mannelli et al., 2006</td>
</tr>
<tr>
<td><strong>Biosecurity / Sanitary measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of housing (4 systems duck raising)</td>
<td>Thailand, farm level</td>
<td>Songserm, 2006</td>
</tr>
<tr>
<td>Backyard/small scale/free range systems</td>
<td>Nigeria, farm level</td>
<td>Cecchi et al., 2008; Joannis et al., 2008</td>
</tr>
<tr>
<td>Incomplete biosecurity measures of farm visitors</td>
<td>Japan, farm level</td>
<td>Nishiguchi et al., 2007</td>
</tr>
<tr>
<td>Owner lives off farm</td>
<td>HK, farm level</td>
<td>Kung et al., 2007</td>
</tr>
<tr>
<td>Use of non-family caretakers</td>
<td>US, farm level</td>
<td>McQuiston, 2005</td>
</tr>
<tr>
<td>Relative working in poultry industry</td>
<td>HK, farm level</td>
<td>Kung et al., 2007</td>
</tr>
<tr>
<td>Farm managed by employees (not owner)</td>
<td>Korea, farm level</td>
<td>Yoon et al., 2005</td>
</tr>
<tr>
<td>Sharing of farms equipment among farms</td>
<td>Japan, farm level</td>
<td>Nishiguchi et al., 2007</td>
</tr>
<tr>
<td>Carboards eggs trays (fomites?)</td>
<td>The Netherlands</td>
<td>Thomas et al., 2005</td>
</tr>
<tr>
<td>Movements of fomites into the poultry holdings</td>
<td>Vietnam, farm level</td>
<td>Soares-Magalhaes, 2006</td>
</tr>
<tr>
<td>Risk factors</td>
<td>Comments</td>
<td>References</td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>----------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Wild birds in feed trough</td>
<td>HK, farm level</td>
<td>(Kung et al., 2007)</td>
</tr>
<tr>
<td>Disposal of dying and dead birds</td>
<td>Vietnam, farm level</td>
<td>(Soares-Magalhaes, 2006)</td>
</tr>
<tr>
<td>Disposal of dead birds</td>
<td>US, farm level</td>
<td>(McQuiston, 2005)</td>
</tr>
<tr>
<td>Presence of mammalian wildlife on the farms</td>
<td>US, farm level</td>
<td>(McQuiston, 2005)</td>
</tr>
<tr>
<td>Use of untreated water for animal consumption</td>
<td>Vietnam, farm level</td>
<td>(Soares-Magalhaes, 2006)</td>
</tr>
<tr>
<td><strong>Husbandry practices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age group of highest death rate at &gt; 30 days old</td>
<td>HK, farm level</td>
<td>(Kung et al., 2007)</td>
</tr>
<tr>
<td>Birds of &gt; 10 weeks old</td>
<td>US, farm level</td>
<td>(McQuiston, 2005)</td>
</tr>
<tr>
<td>Introduction of end-of-lay chickens</td>
<td>Japan, farm level</td>
<td>(Nishiguchi et al., 2007)</td>
</tr>
<tr>
<td>Increasing chicken density</td>
<td>Vietnam, farm level</td>
<td>(Pfeiffer et al., 2007)</td>
</tr>
<tr>
<td>Increased poultry flock density</td>
<td>Vietnam</td>
<td>(Henning et al., 2009)</td>
</tr>
<tr>
<td>Increased number of chicken house in use on farm</td>
<td>Korea, farm level</td>
<td>(Yoon et al., 2005)</td>
</tr>
<tr>
<td>Number of chickens on farms and stock density</td>
<td>HK, farm level</td>
<td>(Kung et al., 2007)</td>
</tr>
<tr>
<td>Keeping poultry over or near ponds and rice fields</td>
<td>Vietnam, farm level</td>
<td>(Soares-Magalhaes, 2006)</td>
</tr>
<tr>
<td>Increasing domestic water birds density</td>
<td>Vietnam, farm level</td>
<td>(Pfeiffer et al., 2007)</td>
</tr>
<tr>
<td><strong>Agriculture / crop / ducks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greater % of rice paddy fields</td>
<td>Vietnam, farm level</td>
<td>(Pfeiffer et al., 2007)</td>
</tr>
<tr>
<td>Increasing % of aquaculture</td>
<td>Vietnam, farm level</td>
<td>(Pfeiffer et al., 2007)</td>
</tr>
<tr>
<td>Increased NDVI rainy season</td>
<td>Vietnam</td>
<td>(Henning et al., 2009)</td>
</tr>
<tr>
<td>Rice crop production (agriculture) and calendar</td>
<td>Thailand ducks</td>
<td>(Gilbert et al., 2006; Gilbert, 2007)</td>
</tr>
<tr>
<td>Abundance of free-grazing ducks</td>
<td>Thailand ducks</td>
<td>(Gilbert et al., 2006; Gilbert, 2007)</td>
</tr>
<tr>
<td>Domestic ducks</td>
<td>Asia</td>
<td>(Hulse-Post et al., 2005)</td>
</tr>
<tr>
<td>Domestic and wild ducks</td>
<td>Asia</td>
<td>(Sturm-Ramirez et al., 2005)</td>
</tr>
<tr>
<td><strong>Aggregation site</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wetlands / seasonality, hydrology: during dry season</td>
<td>Thailand ducks</td>
<td>(Gilbert et al., 2006; Gilbert, 2007)</td>
</tr>
<tr>
<td>Resting sites for wild birds</td>
<td>Germany</td>
<td>(Hlinak et al., 2006)</td>
</tr>
<tr>
<td>Wetlands (Camargue): places of aggregation</td>
<td>France</td>
<td>(Jourdain et al., 2007)</td>
</tr>
<tr>
<td>Water inland area</td>
<td>Nigeria</td>
<td>(Ducatez, 2006)</td>
</tr>
<tr>
<td>Wetlands / water birds/ waterfowl</td>
<td>Africa, Nigeria, Spain</td>
<td>(Gaidet et al., 2007; Cecchi et al., 2008; Martinez et al., 2009)</td>
</tr>
<tr>
<td>Proximity to wetlands</td>
<td>Romania, China</td>
<td>(Fang et al., 2008; Ward et al., 2009)</td>
</tr>
<tr>
<td>Proximity to river</td>
<td>Romania</td>
<td>(Ward et al., 2008)</td>
</tr>
<tr>
<td><strong>Scavenging animals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vultures eating dead birds</td>
<td>Burkina Faso</td>
<td>(Ducatez et al., 2007)</td>
</tr>
<tr>
<td>Dogs carriers</td>
<td>Thailand</td>
<td>(Cleaveland et al., 2006)</td>
</tr>
<tr>
<td>Cats</td>
<td>Burkina Faso, Germany,</td>
<td>(Tiensin et al., 2005; Editorial-team, 2006; Ducatez et al., 2007; Desvaux et al., 2009)</td>
</tr>
<tr>
<td></td>
<td>Thailand, Cambodia</td>
<td></td>
</tr>
</tbody>
</table>

*LPAI: Low Pathogenic Avian Influenza*
Table 3: Factors associated with the introduction of bird flu into Africa, and the hypothesized relationship between each factor and the introduction of disease

<table>
<thead>
<tr>
<th>Potential risk factors for the introduction of HPAI H5N1</th>
<th>Hypothesized relationship between potential risk factor and the introduction of HPAI H5N1 in Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyways</td>
<td>For the MCDM risk mapping, it was assumed that migratory birds constitute a risk for the introduction of HPAI H5N1 into Africa. The migratory flyways covering areas in Africa represent areas expected to be at higher risk of introduction of bird flu. The role of migratory birds in long distance transmission of HPAI H5N1 has been considered in several studies, but still remains controversial due to many knowledge gaps. Wild birds (esp. wild ducks) were identified as potential long distance vectors for the virus in various studies (Kilpatrick et al., 2006; Stailknecht, 2007; Gaidet et al., 2008b; Keawcharoen et al., 2008), while other authors considered it unlikely (Feare, 2007; Saad, 2007; Weber and Stilianakis, 2007). Different risk assessments of the introduction of HPAI H5N1 into different regions have concluded that the role of migratory birds was low but not negligible, with high uncertainty (Pfeiffer et al., 2006; Goutard et al., 2007; Sabirovic et al., 2007).</td>
</tr>
<tr>
<td>Surface water: wetlands and waterbodies</td>
<td>Increasing distance from surface water is expected to be associated with decreasing risk of introduction of the disease in Africa. Wetlands are considered as aggregation sites for migratory and resident wild birds and therefore constitute potentially higher risk areas for introduction and transmission of HPAI virus (Hlinak et al., 2006; Jourdain et al., 2007), as was suggested for Nigeria (Ducatez, 2006). Surveillance studies conducted in several major wetlands of Africa isolated AI viruses in Eurasian and Afro-tropical species of wild birds (Gaidet et al., 2007; Gaidet et al., 2008a). Distance to wetland areas containing migratory waterfowl species has also been hypothesised as a risk factor for the introduction of disease in Spain (Martinez et al., 2009).</td>
</tr>
<tr>
<td>International poultry trade: cross-border roads, ports and airports</td>
<td>For the MCDM risk mapping, it was hypothesized that international poultry trade occurs via roads, ports and airports, and that increasing density of ports, airports and roads is associated with a higher risk of introduction of HPAI H5N1. Poultry trade has been identified as a risk factor for introduction of HPAI (Ducatez, 2006; Kilpatrick et al., 2006). A study published in 2007 stressed the importance of formal and informal trade for the introduction of the disease in previously unaffected areas, as it seems was the case in Nigeria (Vannier, 2007). In addition, proximity to highways was found associated with risk of HPAI outbreak in China (Fang et al., 2008), and this is likely to be due increased movements of poultry and poultry products for trade.</td>
</tr>
</tbody>
</table>
Table 4: Factors associated with the spread of bird flu in Africa, and the hypothesized relationship between each factor and the spread of disease

<table>
<thead>
<tr>
<th>Potential risk factors for the spread of HPAI H5N1</th>
<th>Hypothesized relationship between potential risk factor and the spread of HPAI H5N1 in Africa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>Increasing density of roads is expected to be associated with increasing movements of poultry and poultry products for trade, and thus higher risk of spread of disease. Outbreak risk was associated with proximity to major roads in Romania (Ward et al., 2008) and China (Fang et al., 2008). This is likely to be due to transport of poultry for trade via road.</td>
</tr>
<tr>
<td>Navigable rivers</td>
<td>Increasing distance from navigable rivers is expected to be associated with decreasing risk of spread of the disease. There is no published evidence for the direct role of navigable rivers in the spread of HPAIV, however given the identification of roads as a risk factor (Fang et al., 2008; Ward et al., 2008), such a role can be hypothesized for important rivers in Africa known to be used for transport of consumption goods and livestock.</td>
</tr>
<tr>
<td>Poultry density</td>
<td>Increasing density of poultry is expected to be associated with a higher contact rate between susceptible and infected birds and therefore greater risk of spread. It was found that H5N1 persistence in Nigeria was correlated with backyard chicken and duck numbers (Cecchi et al., 2008). Proximity to an infected farm has been shown to be an important factor in the spread of low pathogenicity influenza viruses (Mannelli et al., 2006) as well as distance to the nearest case farm (Nishiguchi et al., 2007). Conversely, (Fang et al., 2008) found no association between poultry density and the risk of HPAIV infection in China, arguing that this unexpected finding was due to a greater proportion of industrialised chicken production at higher poultry densities, with associated higher biosecurity standards and vaccination protocols. Henning et al. (2009) found that poultry density was a risk factor for HPAIV outbreaks in Vietnam, but only at medium population densities. High poultry density was postulated as a risk factor for HPAIV occurrence in Thailand (Tiensin et al., 2005) and in Hong Kong (Kung et al., 2007), although this has been shown to be associated more with duck density alone than total poultry density (Gilbert et al., 2006).</td>
</tr>
<tr>
<td>Presence of poultry markets/cities</td>
<td>Increasing density of cities is expected to be associated with increasing risk of spread of HPAI H5N1. Cities are associated with higher demand for poultry products and therefore the presence of trading areas providing live or freshly slaughtered birds. Low pathogenicity viruses have been isolated from poultry in live bird markets in the USA (Bulaga, 2003), China (Cheung et al., 2007) and Korea (Choi et al., 2005), and HPAI has been isolated from a live bird market in Vietnam (Nguyen et al., 2005). Sale of chicken at retail markets was also identified as a risk factor for HPAI infection of farms in Hong Kong (Kung et al., 2007). The risk of HPAI outbreak was found to be negatively associated with increasing distance from higher density human population areas (Pfeiffer et al., 2007), and this is likely to be due to increased intensity of production and trade of poultry in highly populated areas.</td>
</tr>
<tr>
<td>Natural wetlands and water bodies</td>
<td>Increasing distance from wetlands and waterbodies is expected to be associated with decreasing risk of spread of the disease. Proximity to wetlands has been shown to be a risk factor for the occurrence of HPAI in poultry in South-East Asia (Gilbert et al., 2006; Fang et al., 2008), as has proximity to rivers and wetlands in Romania (Ward et al., 2008; Ward et al., 2009). Distance to wetland areas containing migratory waterfowl species has been hypothesised as a risk factor for disease in Nigeria (Cecchi et al., 2008).</td>
</tr>
<tr>
<td>Irrigated areas</td>
<td>Proximity to irrigated areas is expected to be associated with increased risk of spread of HPAI H5N1. Rice crop production has been found to be associated with HPAI in Vietnam and Thailand (Gilbert, 2007; Pfeiffer et al., 2007), as has aquaculture (Pfeiffer et al., 2007).</td>
</tr>
</tbody>
</table>
Part Two

Risk Factor Layers
Methodology continued

Risk factor layers for introduction of bird flu

Risk factor layers for spread of bird flu once introduced
Methodology continued

Step 3
Producing risk-factor layers

After identifying the major risk factors, the risk-map team sourced maps for them, in the public domain when possible. They produced 9 layers representing risk factors associated with poultry trade and transportation, and migratory flyways.

Risk-factor layers

1. Major global flyways for migratory birds
2. Location of ports in Africa
3. Location of airports in Africa
4. Main roads in Africa
5. Location of lakes (waterbodies) in Africa
6. Location of standing water (wetlands) in Africa
7. Location of irrigated areas in Africa
8. Poultry density in Africa
9. Location of major cities in Africa

Step 4
Converting the layers into “raster” maps.

A digitized raster map allows researchers to assign relative importance or “weight” of the risk factor at any particular point or “pixel.” Raster maps of risk factor layers can be combined to show how risk changes when more than one risk factor is present.

The complexity of the conversion varied greatly: sometimes it was simple, but in some cases the risk factor maps required extensive manipulation to produce raster maps (Table 5 for risk factors for introduction, Table 6 for spread.)
### Table 5:
Manipulation required to convert risk-factor layers into risk-factor raster maps (for risk of introduction of bird flu into Africa)

<table>
<thead>
<tr>
<th>Risk factor map</th>
<th>Manipulation</th>
<th>Raster map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyways for migratory birds (Vector map, FAO 2005)</td>
<td>Extraction of Black Sea flyway</td>
<td>Presence/absence of Black Sea flyway</td>
</tr>
<tr>
<td></td>
<td>Extraction of East Africa Flyway</td>
<td>Presence/absence of East Africa Flyway</td>
</tr>
<tr>
<td></td>
<td>Extraction of East Atlantic flyway</td>
<td>Presence/absence of East Atlantic flyway</td>
</tr>
<tr>
<td>Location of surface water: Water bodies (Vector map, RWDB-USGS) Wetlands (Vector map, Lehner and Döll 2004) Irrigated areas (Vector map, Siebert et al. 2007)</td>
<td>Calculate and map distance from: (1) Lakes and impoundments, (2) irrigated areas, (3) swamps and marshes, (4) salty lakes, (5) lagoon, mangroves, and (6) salt pan</td>
<td>Distance from surface water</td>
</tr>
<tr>
<td>Location of ports (Vector map, FAO)</td>
<td>Calculate and map density of ports per 1000 square kilometers</td>
<td>Density of ports</td>
</tr>
<tr>
<td>Location of airports (Vector map, RWDB-USGS)</td>
<td>Calculate and map density of airports per 1000 square kilometers</td>
<td>Density of airports</td>
</tr>
<tr>
<td>Location of roads (Vector map, CIESIN 2004)</td>
<td>Calculate and map linear density of roads per 100 square kilometers</td>
<td>Density of roads</td>
</tr>
</tbody>
</table>

### Table 6:
Manipulation required to convert risk-factor layers into risk-factor raster maps (for risk of spread of bird flu in Africa)

<table>
<thead>
<tr>
<th>Risk factor map</th>
<th>Manipulation</th>
<th>Raster map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of roads: (Vector map, CIESIN 2004)</td>
<td>Calculate and map linear density of roads per 100 square kilometers</td>
<td>Density of roads</td>
</tr>
<tr>
<td>Location of rivers (Vector map, ESRI 2005)</td>
<td>Calculate distance (km) to navigable rivers</td>
<td>Distance to navigable rivers</td>
</tr>
<tr>
<td>Location of cities (pop &gt; 50000) (Vector map, GRUMP 2005)</td>
<td>Calculate and map density of cities per 100 square kilometers</td>
<td>Density of cities</td>
</tr>
<tr>
<td>Location of surface water: Water bodies (Vector map, RWDB-USGS) Wetlands (Vector map, Lehner and Döll 2004) Irrigated areas (Vector map, Siebert et al. 2007)</td>
<td>Calculate and map distance (km) from: (1) Lakes and impoundments, (2) irrigated areas, (3) swamps and marshes, (4) salty lakes, (5) lagoon, mangroves, and (6) salt pan</td>
<td>Distance from surface water</td>
</tr>
<tr>
<td>Poultry density (Raster map, Wint and Robinson 2007)</td>
<td>No manipulation required (Resolution 0.05 x 0.05 degrees)</td>
<td>Poultry density</td>
</tr>
</tbody>
</table>
Risk factor layers for introduction of bird flu

This section presents the risk-factor layers: digitized maps showing the distribution of risk factors associated with the introduction of bird flu in Africa. For each risk factor, the raster map is presented with a brief description of what it represents; its limitations and possible inherent biases when used for risk mapping, and consequent recommendations for its use and further refinement.

These risk-factor layers are not intended for use on their own, they will be included in the MDCM model to produce the risk maps.
**Flyways**

This shapefile identifies seven major global flyways for migratory birds. The (i) East Atlantic, (ii) Black Sea / Mediterranean, and (iii) East Africa / West Asia flyways are the three crossing the African continent, and are included in the MCDM as risk factors for the introduction of H5N1 by migratory birds.

**Caveats**

These flyways are summary routes for all migratory bird species. Yet not all migratory species can carry bird flu, so this map may overstate the risk in some areas. On the other hand, some high-risk species have specific pathways within these areas, which are associated with a higher risk of bird flu. Also, seasonal variation in risk is not represented.

**Recommendations for use**

This layer can be used as a preliminary indicator to assess the annual risk of introduction via migratory birds.
Ports

What this layer represents
Live poultry and poultry products enter the continent through ports, in both legal and illegal trade. Infected poultry or poultry parts can cause an outbreak.

Caveats
Data are insufficient on port size and activity. The number of ports is likely to be underestimated since the map shows only major ports, but smaller ones also handle poultry.

Recommendations for use
Without more data on their relative importance, err on the side of caution and consider all ports equally risky regardless of size.

Strategy for further development
- Include ports for river and lake traffic, not currently taken into account.
- Sources may include various trade-related, transport and shipping associations. Poultry-sector studies could also provide relevant information.
Airports

What this layer represents
Legally traded live poultry can enter through airports, so infected poultry could bring bird flu to the continent through this route. Airports are classified as Civilian/Military or Others.

Caveats
- The number of airports is likely to be underestimated: Smaller airports may not show up on this map.
- Little information is available on type or size of airports, or the volume of birds handled, so this layer does not show these factors.

Recommendations
In the absence of additional information, give same weight of importance to all airports for the risk mapping.

Strategy for further development
Additional data sources will be sought on airport locations and characteristics (i.e. use, origin, and volume of poultry, poultry products and poultry-related goods handled). Poultry sector studies could also provide relevant information for some countries.
Main transboundary roads

What this layer represents
This layer shows major transboundary roads—potential entry points for poultry in legal or illegal trade. Major roads presumably handle larger, long-distance volumes.

Caveats
- Smaller roads are not represented, though they may carry smaller, shorter-distance trade between and within countries.
- Volume of poultry is not available for every entry point.
- No information is available on presence, type, or quality of border control.

Recommendations for use
Give same weight of importance to all entry points if no additional data are found on poultry import volumes.

Strategy for further development
Additional data sources on poultry imports will be sought.
Waterbodies

What this layer represents
Migratory birds often congregate at lakes and other waterbodies. Since waterbodies overlap with wetlands to some extent, care was taken not to increase risk artificially by counting the same location twice (see 1.6 below).

Caveats
- These are not the only areas at risk for the entry of the virus via migratory birds.
- Seasonality of waterbodies is not shown.

Recommendations for use
Use waterbodies data as potential locations for high risk each year during swan, geese, duck migrations.
Wetlands

What this layer represents
Migrating birds congregate at wetlands, whether the water is standing or flowing. Therefore wetlands represent a risk factor for introduction of bird flu into Africa from other continents via migratory birds.

Caveats
- Some wetlands are permanent, some are seasonal; this level of detail is not displayed on the risk factor layer.
- There are other areas at risk for entry of the virus via migratory birds.

Recommendations for use
Wetlands represent important risk areas during annual migrations of wild birds that could carry bird flu.

Use combined wetlands and waterbodies data as potential locations for high risk each year during swan, geese, duck migrations.

Source: Lehner and Döll 2004
Risk factor layers for spread of bird flu once introduced

This section presents risk factors associated with the spread of bird flu after it has been introduced into a given area. As in the preceding section, a source map is presented for each risk factor along with a brief description of what it represents, caveats—limitations and possible inherent biases—and recommendations for its use and further refinement.
Waterbodies

**What this layer represents**

Waterbodies are risk factors for spread as well as introduction. The same data can be used to assess the risk of both.

At waterbodies, migratory birds mix with resident wild birds and local domestic birds. An introduced virus can therefore spread between populations.

**Caveats**

- This layer shows only the spatial distribution of the risk factor, it does not quantify the risk of transmission between wild birds and poultry populations.
- Seasonality of waterbodies as permanent or seasonal is not available, so seasonality of risk is not displayed on this layer.

**Recommendations for use**

Use combined data from wetlands, waterbodies and irrigated areas to show potential locations for the annual risk of introduction and spread of the virus between migratory birds, resident wild birds and local domestic birds.
Wetlands

What this layer represents

Wetlands are risk factors for spread as well as introduction. The same data can be used to assess the risk of both.

At wetlands, migratory birds mix with resident wild birds and local domestic birds. An introduced virus could therefore spread between populations.

Caveats

- These data cannot quantify the risk of transmission between migratory birds and resident wild birds or domestic poultry.
- Seasonality of wetlands is not available. Seasonality of risk can not be inferred.

Recommendations for use

Use combined data for wetlands, waterbodies and irrigated areas to indicate potential locations for the annual risk of introduction and spread of the virus between migratory birds, resident wild birds and local domestic birds.

Source: Lehner and Döll 2004
Irrigated areas

What this layer represents
Irrigated areas typically lie close to human settlements and domestic bird populations. Wild birds, migratory or resident, also use them as resting and feeding sites. They therefore represent a risk for the mixing of domestic birds, and possibly domestic and wild birds.

Caveats
- These data cannot quantify the risk of transmission between migratory birds and resident wild birds or domestic poultry.
- Seasonality of wetlands is not available. Seasonality of risk cannot be inferred.

Recommendations for use
Use combined data from wetlands, waterbodies and irrigated areas to indicate potential locations for the annual risk of introduction and spread of the virus between migratory birds, resident wild birds and local domestic birds.

Source: Siebert et al. 2007
Poultry density

What this layer represents
The map represents the number of poultry per km2. We assume that poultry density represents primarily the distribution of small-scale and backyard poultry production. High-density poultry areas are therefore likely to be associated with an increased risk of spread, via direct contacts, fomites, and interactions between stakeholders.

Caveats
The map does not represent density of poultry production units. At the moment, no information is available on how the poultry density was derived, or on the types of production units considered for deriving density estimates.

Recommendations for use
This raster map will be used to compare the density of poultry and human population and assess the risk of spread for bird flu within the poultry population.

Strategy for further development
Information on how the poultry density was derived will be sought in order to check the assumptions underlying this map. In particular, information on the spatial distribution of small- versus large-scale production units will inform whether this layer can be used to represent the distribution of small-scale and backyard poultry population (though not the distribution of large-scale production units). Potential overlap between human population density and poultry density will be checked.
Major roads

What this layer represents

Major roads likely carry the bulk of the poultry trade and are therefore a potentially important risk factor for spread of bird flu.

Caveats

- Not all roads used for poultry trade can be represented.
- This layer leaves out small, local trade routes.

Recommendations for use

These data will be completed with data on smaller roads, and used to represent potential for spread via poultry trade.

Strategy for further development

Researchers are seeking more information on the poultry trade and the relative importance of the roads traders use.
Major cities

What this layer represents

Major cities represent a risk factor for spread via the large poultry trade. This includes markets where live animals and poultry products are exchanged and consumed, industrial poultry plants, and associated waste.

Caveats

- This layer assumes that major cities see the highest density of bird trade.
- The map does not represent small, local markets.

Recommendations for use

These data will be used to represent main poultry markets and centres of activities related to poultry production, trade and consumption.

Strategy for further development

Researchers are seeking more field information on poultry markets and their relative importance.
Part Three

Preliminary Risk Maps
Methodology continued

Limitations of the risk maps

Initial Risk Maps

Risk factors for introduction and spread of bird flu

Identification of areas at risk of introduction of bird flu and
Identification of areas with the potential for spread of
bird flu, once the disease has been introduced
Step 5
Defining the relative importance of each risk factor in relation to the objective

To weight the relative importance of risk factors, five members of the project team weighted risk factors in pairs*: specifying first whether Factor A was more or less important than Factor B regarding the introduction or spread of bird flu in Africa and second, the degree of importance.

Factor A could be (i) Equally, (ii) Moderately, (iii) Strongly or (iv) Very Strongly, more or less important than Factor B.

These weightings were based on each team member’s expert opinion, and were performed for each pairwise combination of factors. The five sets of weightings were then compared: where three or more of the five team members had given the same weighting, it was accepted.

Where there were discrepancies between team members’ weightings for any pair of factors, the weighting was discussed and a final weighting agreed upon.

The agreed pairwise weightings were used to calculate a weight for each risk factor, and these weights incorporated into the multicriteria decision model.

The agreed weightings for each pairwise comparison of the risk factors for the introduction Africa are presented in Table 7; those for spread are presented in Table 8. For the pairwise comparison, risk factors in the rows are weighted relative to the risk factors in the columns. For example, reading from Table 7, the risk factor density of airports is considered to be moderately more important than distance from waterbodies for the introduction of bird flu into Africa.
Table 7: Agreed weightings of pairwise comparison of risk factors for the introduction of bird flu into Africa.

<table>
<thead>
<tr>
<th></th>
<th>Black Sea flyway</th>
<th>East Africa flyway</th>
<th>East Atlantic flyway</th>
<th>Distance from waterbodies</th>
<th>Density of ports</th>
<th>Density of airports</th>
<th>Density of roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence/absence of Black Sea flyway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence/absence of East Africa flyway</td>
<td>Equal importance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence/absence of East Atlantic flyway</td>
<td>Moderately less important</td>
<td>Moderately less important</td>
<td>Strongly more important</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from waterbodies</td>
<td>Moderately more important</td>
<td>Moderately more important</td>
<td>Strongly more important</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of ports</td>
<td>Strongly more important</td>
<td>Strongly more important</td>
<td>Strongly more important</td>
<td>Moderately more important</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of airports</td>
<td>Strongly more important</td>
<td>Strongly more important</td>
<td>Very strongly more imp.</td>
<td>Moderately more important</td>
<td>Equal importance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of roads</td>
<td>Very strongly more important</td>
<td>Very strongly more important</td>
<td>Extremely more important</td>
<td>Strongly more important</td>
<td>Moderately more important</td>
<td>Moderately more important</td>
<td></td>
</tr>
</tbody>
</table>

For the pairwise comparison, risk factors in the rows are weighted relative to the risk factors in the columns. For example, the risk factor density of airports is considered to be moderately more important than distance from waterbodies for the introduction of bird flu into Africa.

Table 8: Agreed weightings of pairwise comparison of risk factors for the spread of bird flu in Africa.

<table>
<thead>
<tr>
<th></th>
<th>Density of roads</th>
<th>Density of cities</th>
<th>Distance from waterbodies</th>
<th>Distance from irrigated areas</th>
<th>Poultry density</th>
<th>Distance to navigable rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of roads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of cities</td>
<td>Equal importance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from waterbodies</td>
<td>Moderately less important</td>
<td>Moderately less important</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from irrigated areas</td>
<td>Strongly less important</td>
<td>Strongly less important</td>
<td>Moderately less important</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry density</td>
<td>Equal importance</td>
<td>Equal importance</td>
<td>Moderately more important</td>
<td>Strongly more important</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to navigable rivers</td>
<td>Equal importance</td>
<td>Equal importance</td>
<td>Moderately more important</td>
<td>Strongly more important</td>
<td>Equal importance</td>
<td></td>
</tr>
</tbody>
</table>

For the pairwise comparison, risk factors in the rows are weighted relative to the risk factors in the columns.
Step 6
Combining all factors to produce a final weighted estimate of risk for each location in the study area. This process produces a risk map.

The raster maps for individual risk factors were combined using weighted linear combination (WLC). Factors with a higher weight exert greater influence on the final risk estimate. This combination is done for each individual pixel in the map (a pixel = 1000 km²), which generates a numeric risk score on a scale of 0 (lower risk) to 255 (higher risk). The resulting risk maps identify areas at highest risk of introduction and spread of bird flu in Africa (Figures 3 and 4, pages 3-10 and 3-11).

Step 7
Performing a sensitivity analysis.

This analysis is a statistical check on the calculations underlying the risk maps. It showed that even if weighting for any individual risk factor was changed by 25 percent, (in other words, was “off” by 25 percent), the results in terms of risk level for the regions remained the same.

Sensitivity analysis in more detail: For each factor, two new weights were calculated by (i) adding and (ii) subtracting 25% from the original weight. Each of the newly calculated weights was then individually incorporated into the multicriteria decision model, while holding all other factor weights constant.

The risk score was measured at 10,000 randomly selected locations on each of the maps, and the average change in the risk score as a result of altering the different factor weights was calculated (Tables 9 and 10). From the results in Tables 9 and 10, it can be seen that increasing or decreasing the weights of the individual risk factors resulted in negligible changes to the individual pixel risk scores. The highest average change in the risk score was 3.91 ± 2.29 as a result of decreasing the weight assigned to tertiary road density in the spread of disease. In other words, changing the weight assigned to tertiary road density by 25% would be expected to change the final overall risk score for the spread of avian flu by only 2 to 6 points on a scale of 255. At the aggregate level, regions identified as being at higher or lower risk for the introduction or spread of disease would therefore remain as such even when the weights of the different risk factors are increased or decreased by as much as 25%.

Risk scores for both disease introduction and spread were therefore highly robust, showing little change as a result of the altered weights.
Table 9: Sensitivity analysis of the factors and weights used to estimate and map the risk of introduction of bird flu into Africa. The average change in risk scores was calculated from 10,000 randomly selected locations.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Average change in risk score (+ std. dev)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Factor weight increased by 25%</td>
</tr>
<tr>
<td>East Africa Flyway</td>
<td>0.10 ± 0.54</td>
</tr>
<tr>
<td>East Atlantic Flyway</td>
<td>0.02 ± 0.52</td>
</tr>
<tr>
<td>Black Sea Flyway</td>
<td>1.26 ± 0.67</td>
</tr>
<tr>
<td>Airport density</td>
<td>1.05 ± 0.57</td>
</tr>
<tr>
<td>Port density</td>
<td>1.09 ± 0.51</td>
</tr>
<tr>
<td>Primary road density</td>
<td>2.05 ± 0.82</td>
</tr>
<tr>
<td>Secondary road density</td>
<td>1.94 ± 0.85</td>
</tr>
</tbody>
</table>

Table 10: Sensitivity analysis of the factors and weights used to estimate and map the risk of spread of bird flu in Africa. The average change in risk scores was calculated from 10,000 randomly selected points on the map.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Average change in risk score (+ std. dev)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Factor weight increased by 25%</td>
</tr>
<tr>
<td>Primary road density</td>
<td>3.46 ± 1.10</td>
</tr>
<tr>
<td>Secondary road density</td>
<td>3.40 ± 1.11</td>
</tr>
<tr>
<td>Tertiary road density</td>
<td>3.61 ± 2.13</td>
</tr>
<tr>
<td>Density of cities</td>
<td>2.74 ± 2.03</td>
</tr>
<tr>
<td>Distance to waterbodies</td>
<td>1.12 ± 0.89</td>
</tr>
<tr>
<td>Distance to irrigated land</td>
<td>0.39 ± 0.64</td>
</tr>
<tr>
<td>Distance to navigable rivers</td>
<td>2.51 ± 2.30</td>
</tr>
</tbody>
</table>
Step 8
Validating and improving the maps.

This process is ongoing. We will validate the risk maps with field observations of actual outbreaks in Africa, and also with expert opinion.

Geographical data will be refined and cross-checked with information from the field.

Information derived from expert workshops, extensive consultations and field surveys will also be incorporated into the maps.

Feedback and updates will be solicited from all those involved or interested in the Bird flu Risk Mapping Project. The project team will welcome your observations and thoughts!

Initial Risk Maps

The following dozen risk maps are guides to locations where bird flu is most likely to be introduced into Africa, and where it has more potential for spread once introduced.

The risk maps are based on our current understanding of risk factors and their relative importance. They are only guides: they do not incorporate all possible risk factors and should always be used in conjunction with ground-truthing and other tools such as risk assessment.

Risk factors for introduction and spread of bird flu

The maps take into account known risk factors that can be mapped, and the degree of risk that each represents at any one point. The risk factors include:

Places where poultry is imported, traded (legally or illegally), produced, and consumed:

- Main roads
- Major markets and major metropolitan areas—places of dense human populations where a lot of poultry is likely to be concentrated
- Ports
- Airports

Major global flyways for migratory wild birds

At their resting places, wild birds that might carry the virus could transmit it to domestic birds, including poultry. The higher the concentration of birds, the more likely this is to happen. Places of concern include:

- Wetlands
- Lakes, rivers and other waterbodies, whether standing or flowing
- Irrigated fields
Limitations of the risk maps

Data considerations

- **Data quality**: The quality of the data used as geographical inputs for the model varies. For example, we suspect that data pertaining to the number of ports and airports underestimates the actual number of those facilities. In addition, available road maps displayed only primary, secondary and tertiary roads; data on minor roads, which could play an important role in the illegal trade of poultry, were unavailable.

- **Proxies**: When data for specific risk factors were unavailable, proxy data were used. For example, as there are no available data on the location of markets in Africa, cities with human populations of more than 50,000 were used as proxies for the location of markets. This may bias the results since rural markets or collection points, too, might play an important role in legal or illegal trade.

Weighting considerations

- **Influence**: Weighting of the different risk factors was performed by only five people who have, of necessity, been involved in all aspects of the development of these risk maps from the outset. The participants may have therefore influenced each other’s opinion regarding weighting of the risk factors.

- **Lack of knowledge**: There is a general lack of knowledge regarding the introduction and spread of bird flu, not only in Africa, but worldwide. However, our access to the most up-to-date scientific information on the subject translates, we hope, into a better assessment of the risk factors involved and their relative importance in the introduction and spread of bird flu in Africa.

Each of these considerations should be taken into account when interpreting the risk maps.

Key findings

*Areas at higher risk of introduction of bird flu (Figure 3)*

Areas identified as having the highest risk of introduction of bird flu include the Nile Delta, the coastline of Northern Africa, Western Africa, and parts of South Africa.

Areas identified as having the lowest risk include Northern Africa, Somalia, Ethiopia and Botswana.

*Areas with the potential for spread of bird flu once the disease has been introduced (Figure 4)*

Most of sub-Saharan Africa was identified as having the highest risk for the spread of bird flu. In other words, most areas of the continent are more vulnerable to spread than to initial introduction of bird flu.

Regions with the lowest risk of spread include Northern Africa, Somalia, Angola, Namibia and the south-west parts of South Africa.
Identification of areas at risk of introduction of bird flu
and
Identification of areas with the potential for spread of bird flu, once the disease has been introduced
1) Identification of areas in Africa at risk of introduction of bird flu

**Figure 3:**
Map showing relative likelihood of introduction of bird flu in Africa

**Note**
This map shows only relative likelihood of introduction. It cannot predict where actual outbreaks will occur. Although it is based on our current understanding of the risk factors involved in the introduction of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still only partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

**Key findings for risk of introduction at the continental level**

Areas identified as having the highest risk of introduction of bird flu include the Nile Delta, the coastline of Northern Africa, Western Africa, and parts of South Africa.

Areas identified as having the lowest risk include Northern Africa, Somalia, Ethiopia and Botswana.
2) Identification of areas in Africa with the potential for spread of bird flu, once the disease has been introduced

Figure 4:
Map showing relative potential for spread of bird flu in Africa, once the disease has been introduced

Note
This map shows areas with potential for spread (once the disease has been introduced), but not the extent of spread in any one area. Although it is based on our current understanding of the risk factors involved in the spread of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

Key findings for risk of spread at the continental level
Most of sub-Saharan Africa was identified as having the highest risk for the spread of bird flu.

Regions with the lowest risk of spread included Northern Africa, Somalia, Angola, Namibia and the south-west parts of South Africa
3) Identification of areas in southern Africa (SADC) at risk of introduction of bird flu

Note

This map shows only relative likelihood of introduction. It cannot predict where actual outbreaks will occur. Although it is based on our current understanding of the risk factors involved in the introduction of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still only partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

Use

Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
4) Identification of areas in southern Africa (SADC) with the potential for spread of bird flu, once the disease has been introduced.

**Figure 6:**
Map showing relative potential for spread of bird flu in southern Africa, once the disease has been introduced.

**Note**
This map shows areas with potential for spread (once the disease has been introduced), but not the extent of spread in any one area. Although it is based on our current understanding of the risk factors involved in the spread of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

**Use**
Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
5) Identification of areas in eastern Africa (EAC) at risk of introduction of bird flu

![Map showing relative likelihood of introduction of bird flu in eastern Africa](image)

**Figure 7:**
*Map showing relative likelihood of introduction of bird flu in eastern Africa*

**Note**

This map shows only relative likelihood of introduction. It cannot predict where actual outbreaks will occur. Although it is based on our current understanding of the risk factors involved in the introduction of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still only partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

**Use**

Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
6) Identification of areas in eastern Africa (EAC) with the potential for spread of bird flu, once the disease has been introduced

Figure 8:
Map showing relative potential for spread of bird flu in eastern Africa, once the disease has been introduced

Note
This map shows areas with potential for spread (once the disease has been introduced), but not the extent of spread in any one area. Although it is based on our current understanding of the risk factors involved in the spread of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

Use
Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
7) Identification of areas in western Africa (ECOWAS) at risk of introduction of bird flu

![Map showing relative likelihood of introduction of bird flu in western Africa](image)

**Figure 9:**
Map showing relative likelihood of introduction of bird flu in western Africa

**Note**
This map shows only relative likelihood of introduction. It cannot predict where actual outbreaks will occur. Although it is based on our current understanding of the risk factors involved in the introduction of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still only partial. In addition, the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

**Use**
Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
8) Identification of areas in western Africa (ECOWAS) with the potential for spread of bird flu, once the disease has been introduced

Figure 10:
Map showing relative potential for spread of bird flu in western Africa, once the disease has been introduced

Note
This map shows areas with potential for spread (once the disease has been introduced), but not the extent of spread in any one area. Although it is based on our current understanding of the risk factors involved in the spread of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

Use
Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
9) Identification of areas in Nigeria at risk of introduction of bird flu

Figure 11:
Map showing relative likelihood of introduction of bird flu in Nigeria

Note

This map shows only relative likelihood of introduction. It cannot predict where actual outbreaks will occur. Although it is based on our current understanding of the risk factors involved in the introduction of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still only partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

Use

Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
10) Identification of areas in Nigeria with the potential for spread of bird flu, once the disease has been introduced

*Figure 12: Map showing relative potential for spread of bird flu in Nigeria, once the disease has been introduced*

**Note**

This map shows areas with potential for spread (once the disease has been introduced), but not the extent of spread in any one area. Although it is based on our current understanding of the risk factors involved in the spread of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

The map shows areas at risk of spread, but not the extent of spread in any one area. Bird flu has already been introduced and is spreading through Nigeria, but researchers’ knowledge of current extent of the disease is incomplete.

**Use**

Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
11) Identification of areas in Uganda at risk of introduction of bird flu

![Map showing relative likelihood of introduction of bird flu in Uganda](image)

**Figure 13:**
Map showing relative likelihood of introduction of bird flu in Uganda

**Note**
This map shows only relative likelihood of introduction. It cannot predict where actual outbreaks will occur. Although it is based on our current understanding of the risk factors involved in the introduction of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still only partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

**Use**
Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
12) Identification of areas in Uganda with the potential for spread of bird flu, once the disease has been introduced

Figure 14:
Map showing relative potential for spread of bird flu in Uganda, once the disease has been introduced

**Note**

This map shows areas with potential for spread (once the disease has been introduced), but not the extent of spread in any one area. Although it is based on our current understanding of the risk factors involved in the spread of bird flu in Africa and the relative importance of each factor, our understanding of the epidemiology of bird flu in Africa is still partial. In addition the data needed to produce such maps are frequently incomplete, out of date, and in some cases flawed. The risk map will be validated during the next step of the project.

**Use**

Use this map to help focus areas where veterinary health officials and workers target their surveillance efforts, in conjunction with complementary tools considering other risk factors.
References


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Initial Bird Flu
Risk Map Report