<table>
<thead>
<tr>
<th>Methodology continued</th>
<th>3-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitations of the risk maps</td>
<td>3-8</td>
</tr>
<tr>
<td>Initial Risk Maps</td>
<td>3-7</td>
</tr>
<tr>
<td>Risk factors for introduction and spread of bird flu</td>
<td>3-7</td>
</tr>
<tr>
<td>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</td>
<td>3-9</td>
</tr>
</tbody>
</table>
Methodology continued

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>Risk Factor</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>Equal importance</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></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>Risk Factor</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

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

**Figure 5:**
*Map showing relative likelihood of introduction of bird flu in southern 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.
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

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

![Map showing relative potential for spread of bird flu in eastern Africa, once the disease has been introduced](image)

**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

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

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

![Map showing relative potential for spread of bird flu in Uganda, once the disease has been introduced](image)

**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.