Chapter 30

General discussion and conclusions

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1. Research objectives of the project

The main target of the Healthy Poultry project was to develop a scientific basis for future decision making regarding strategies to prevent the introduction and dissemination of epizootic poultry diseases, in particular Avian Influenza (AI). The Healthy Poultry project was based on three strategic research objectives:

1. The development and standardization of data and methods to identify poultry production areas according to their density, organizational and economic structure and contact structure, or in other words, according to their 'general or base risks' for epizootic poultry disease introduction and spread;
2. Identification and quantification of risk factors for introduction and spread of AI at regional and farm level, i.e. AI specific risk factors;
3. Definition and epidemiological and economic analysis of strategies for monitoring, prevention and control of AI and formulation for guidelines for implementation of new AI policies.

Each objective was organized within one specific research Task, which was furthermore subdivided into separate Work Packages. Within this chapter, for each of these Tasks and WPs, the main findings will be summarized and discussed.

2. Overall results and deliverables of the project

2.1. Task A: Development and standardization of data and methods to identify poultry production areas according to their density, organizational and economic structure and contact structure.

Within the overall project, Task A had to deal with the development and standardization of data and methods to identify poultry production areas according to their density, organization of egg and poultry meat production, and the contact structure existing in the European poultry production. Within Task A, the following four work packages were defined.

<u>WP 2: Spatial, structural and demographic issues</u>. Partner P2, the Institute of Spatial Analysis and Planning in Areas of Intensive Agriculture (University of Vechta, Germany) was in charge of this work package. WP 2 focused on the collection of data based on geographical coordinates in all participating countries related to poultry production structure and demography.

<u>WP 3: Organisational and economic issues</u>. Parter P5, the LEI (Wageningen University, The Netherlands) was in charge of this work package. WP 3 had the task to collect data related to the organization of poultry production, such as different types of production chains and their share of overall poultry production within regions and countries.

<u>WP 4: Migratory bird issues</u>. Partner P7, the Istituto Nazionale per la Fauna Selvatica (Italy) was in charge of this work package. The work package focused on the collection of data on species, location, and routes related to migratory birds. This data pool should provide basic statistical information for the evaluation of the risk of AI dissemination.

WP 5: Integration of databases in a GIS, spatial analysis and toolbox development. The toolbox was developed by the Institute of Spatial Analysis and Planning in Areas of Intensive Agriculture (University of Vechta, Germany). The work focused on the development of a standardized and harmonized database, the implementation and visualization of the dataset in a geographical information system (GIS), and the transformation of the GIS-based information into a web-based and user-friendly system for decision makers.

Overall, scientists working in Task A could perform all scheduled activities and complete the reports in due time. Bilateral project cooperation and collaboration was initiated and occurred to be very successful. Within task A, all partners met in several bilateral meetings in Italy, Wageningen, and Vechta. Between the partners P1 (University of Wageningen) and P2 (University of Vechta), intensive collaboration took place to conduct the farm level analysis and to develop regional risk maps for introduction (P2) and spread (P1) (Grabkowsky et al, this report). Some of the results of the work packages have already been published in journals and been presented on national and international conferences. Other reports will be submitted for publication in peer reviewed scientific journals.

The main deliverables of Task A were:

1. Spatial parameters and conversion tables;
2. An organizational and economic database;
3. A farm economic analysis of poultry production;
4. A spatial, structural and demographic database of poultry production;
5. A database on migratory birds issues;
6. A descriptive analysis of migratory birds issues;
7. A GIS-based toolbox for spatial, structural, demographic and basic disease risk analysis;
8. A spatial and geo-statistical analysis of poultry production.

Most of these separate deliverables were integrated: deliverables 1, 2, 4, and 5 were integrated in the GIS-based toolbox (deliverable 7), and used for spatial and geo-statistical analyses purposes (deliverable 8). The other deliverables 3 and 6 became available as separate reports respectively chapters in this report.

2.2. Task B: Identification and quantification of risk-factors for introduction and spread of Avian Influenza at regional and farm level

Within the project Task B focused on the identification and quantification of risk factors for introduction and spread of AI at regional and farm level. Within Task B, the following two work packages were defined.

WP6: Epidemiological analysis of the Italian data set on Avian Influenza. Partner P3, the Istituto Zooprofilattico Sperimentale delle Venezie (IZSV) was in charge of this WP. It included (1) the development of a common analysis framework and approach to be used by WP6 and WP7, (2) the development of a database from disease control data of epidemiologically relevant information regarding the Italian epizootics, such as type and size of holding, geographical coordinates, diagnosis, mortality and risk factors, and (3) a statistical-epidemiological analysis of these data applying various techniques such as regression, logistic regression and survival analysis focused on (1) risk factors for introduction and spread of AI, (2) spatial and time depending dynamics of the spread of the AIV and the effect of prevention and control measures, and (3) the effect of prevention and control measures.

WP7: Epidemiological analysis of the Dutch data set on Avian Influenza. Partner P4, the University of Utrecht, was in charge of this WP, which included the same activities as in WP6, but then for data on the Dutch epizootic of AI. During the course of the project,

additional research was included with regard to transmission experiments focused on the estimation of important transmission parameters for AI.
P3 (IZSVe) developed analytical methods to estimate the contribution of different factors related to the poultry production to the risk of infection at farm level, in case of both High (HP) and Low (LP) pathogenic AI epidemics. Moreover, the efficacy of the different control measures implemented for the control of HP and LP AI epidemics was estimated, with particular emphasis on the use of vaccination.
P4 (Utrecht University) developed an approach based on the epidemiological modeling of within- and between-farm spread of HPAI, with particular emphasis on the estimate of the date of HPAI introduction into a farm and the experimental evaluation of the efficacy of AI vaccination in turkeys.
For the final part of the project, a more integrated approach was defined and common analyses mainly on the Italian HP and LP AI epidemics data were performed.
This second part allowed to develop a broader approach, including the evaluation of the role of different poultry species and productions (e.g. meat turkeys that are important in Italy but less relevant for the Netherlands), and different control strategies. The integrated approach was carried out by the exchange of data and information between the two partners and by hosting the Dutch PhD student for three months at the IZSVe. In this activity, particular emphasis was on the application of the models developed by the Utrecht University to the Italian epidemics, in order to validate them in different conditions and to compare the results obtained using different approaches in the analysis of the same data.
Overall, the task B performed all the scheduled activities and met all the objectives established. In support of the quality of the work performed, some of the results obtained by IZSVe and Utrecht University have been already published in peer reviewed scientific journals, or presented in national and international scientific meetings (see the report). The integrated work performed in the final part of the project is going to be submitted for publication to peer reviewed scientific journals.
Other results of the Healthy poultry project, and in particular of the Task B, are the strengthening of the cooperation and the networking between the different partners involved.
The main deliverables of Task B were:

1. An epidemiological analysis of Italian data on AI;
2. An epidemiological analysis of Dutch data on AI.

These deliverables were achieved and are described in various chapters of the report.
Moreover, another deliverable was achieved, also described in this report: results of experiments focused on the estimation of important transmission parameters for AI.

2.3. Task C: Definition, epidemiological and economic analysis of strategies for prevention, monitoring and control of Avian Influenza

Task C focused on (1) qualitative regional risk assessment for AI and (2) epidemiological and economic simulation of prevention and control of AI. The main aim was to provide integrated information to support decisions on prevention and control of AI. Task C included the following four WPs.
<u>WP8: Qualitative regional risk assessment for Avian Influenza</u>. This WP was a collaborative activity of P1 (Wageningen University) and P2 (ISPA), with important support by P5 (LEI) and P7 (INFS).Within this WP, the GIS-based toolbox developed in WP5 was extensively used, focused on a descriptive analysis poultry regions within the EU regarding qualitative risk assessment on introduction and spread of AI. The aim was to identify regions with higher respectively lower risks for introduction and spread of AI.

WP9: Economic analysis of monitoring systems for AI. Partner P6 (SIU) was in charge of this WP, during the course of the project P1 (Wageningen University) gradually took over the lead. This WP focused on modeling monitoring of AI, with the aim to identify key-factors for improvement of monitoring systems, both from an epidemiological and economic point of view.
WP10: Epidemiological and economic modeling of AI to analyze prevention and control strategies. Partner P1 was in charge of this WP, however extensive use was made of inputs and expertise of other project partners, particularly P2 (ISPA), P4 (Utrecht University) and P5 (LEI). Within this WP, data and information generated by various other WPs of the project was integrated in several simulation models, both epidemiological and economic ones. Various prevention and control strategies for AI were analyzed on their epidemiological and economic impact in various situations (e.g. poultry density, control measures and measures for economic mitigation of the AI impact).
WP11: Development of integrated monitoring, prevention and control strategies for AI. Partner P1 (Wageningen University) was in charge of this WP, with assistance of all other project partners. Within this WP, the knowledge generated by the project was assembles, aimed at formulation of guidelines for future prevention and control of Avian Influenza.
The main deliverables of Task C were:
1. An analysis of monitoring systems for AI;
2. A qualitative regional risk assessment for AI;
3. An epidemiological-economic analysis of prevention and control strategies for AI;
4. The provision of guidelines for management of AI.

Deliverable 1 has been achieved with the remark that availability of required data from certain member states was sometimes a problem, which hampered the final outcomes. Deliverable 2 could not be achieved completely, however a framework and first analysis results could be provided. Deliverable 3 could be achieved, although during 2009 additional work on this topic will be made in order to fully utilize the potential of the work already carried out. For all these three deliverables, chapters are included in this report describing the main features. Deliverable 4 could be achieved, and is included in this report.

2.4. Dissemination of project results

The results of the project were disseminated as follows:
- To the European Commission via partner meetings, progress reports and a final scientific report;
- To the scientific community via scientific publications in peer-reviewed journals and more popular journals, presentations and contributions at conferences and seminars, teaching in regular curricula and post graduate courses at universities and the organization of a scientific course;
- To the decision makers and policy makers in control of Avian Influenza via regular contacts and meetings (at the level of individual member states), the provision on request of the toolboxes and models developed, the organization of a meeting with stakeholder representatives;
- The provision of four synthesis publication of the entire project in a peer-reviewed scientific journal;
- The possibility of organization of a meeting with policy makers (particularly of the EU) to present the final project results and conclusions.

3. Summary of results and conclusions per research objective

3.1. Task A: Development and standardization of data and methods to identify poultry production areas according to their density, organizational and economic structure and contact structure

3.1.1. Production, consumption and trade of poultry meat

Production of poultry meat faced a period of growth for three decades. However, the number of produced broilers, turkeys, ducks, and geese decreased between 2000 and 2006 due to the impacts of Avian Influenza outbreaks and an over-supply on the turkey meat market.
For poultry meat, the main producing countries within the EU-27 are France, The United Kingdom, Spain, Germany, Italy, Poland and the Netherlands. For turkey meat, France and Italy are important producers and for duck production France is producing more than half of the total EU production.
The main exporting countries within the EU of poultry meat are (in order of self sufficiency rate) the Netherlands, Belgium, Denmark, France and Poland. Between EU member states there are only minor differences in productions costs, hence intra community trade must be explained by other marketing factors.
In general, broilers are kept in closed, controlled housing systems in which broilers are kept on litter. Only France has substantial broilers production in which the birds have access to an outdoor range.
The production chain for poultry meat works with a very strict organizational model, in which contract growing plays a dominating role. This means that if one or more links within the production chain are blocked, the production of the end-product (i.e. poultry meat) will stop very quickly. An example can be the situation with AI in which hatcheries cannot deliver day old chicks to broiler farms and within one or two months the production will have come to an end until restocking is permitted again.
In the EU (27), a close correlation between the population of a member state and its poultry flocks as well as its poultry meat production can be observed; the only exception is The Netherlands: in spite of a comparatively low population they rank in top positions with regard to production and exports
The consumption of poultry meat will show further growth in the coming years. Consumers appreciate local fresh poultry meat. Further growth will be realized through the use of poultry meat in convenience products (‘ready to eat’) and through diversification of places of consumption (out of home consumption).
With regard to the trade of live poultry for meat production, the main trade flows are between the three neighbouring countries Belgium, The Netherlands and Germany. In addition France is exporting live birds to Belgium. A large part of these numbers are broilers transported for slaughter to a neighbouring country. As long distance transport of live broilers is not economic feasible in general the distance in most cases most likely will not exceed 200 km.

3.1.2. Production, consumption and trade of eggs

As in poultry meat production, a similar downward trend of layer flocks can be observed. However, this trend could be stopped except in France, Germany, The Netherlands and in some East European and Baltic countries. For egg production, the main producing countries within the EU-27 are France, Spain, UK, Germany, Italy, The Netherlands and Poland.
The main exporters within the EU are (in order of self sufficiency rate) The Netherlands, Spain, Finland and Poland. Within the EU there are only minor differences in production cost and, as a result, there is limited amount of international trade. The main trade flow in eggs is from the Netherlands to Germany. Associated with egg production is the trade of day old

chicks from a hatchery to a broiler farm in another country. The smaller trade flows are mainly from France and the Netherlands to there neighbouring countries. Especially France is a main actor in poultry breeding for layers, but also for ducks, geese and some slow growing broilers.
The production chain for egg production is less integrated than the chain for broiler meat production. The egg sector in most European countries is working with independent layer famers. These independent entrepreneurs buy the pullets and feed and sell the eggs to a packing station.
There are various housing systems for layers: cages, barn systems (indoor) or free range systems with an access to an outdoor run. The percentage layers in alternative systems (non cage) is in general higher in North-Western Europe. Of the main egg producing countries, the percentage of layers in free range systems is high in the UK (32%), France (18%), the Netherlands (16%) and Germany (15%). In the UK, France and Germany this percentage is expected to increase in the coming years.
The combination of a high density of poultry in an area and free range production of poultry can be a risk factor for avian influenza. Within the EU the poultry density is high in (parts of) the Netherlands, Belgium, Germany, France, UK, Italy and Greece. In the Netherlands, Germany (Lower Saxony), parts of the UK and France (Brittany), a high density of poultry is combined with free range layer production.

3.1.3. Contact structure of broiler and layer farms

The results of the studies on production, consumption and trade provide a general view on movements of live animals and products between countries. In order to obtain information on risky contacts at the farm level, a detailed study was conducted on the contact structure of layer and broiler farms in The Netherlands. Since this study examined the contact structure during a normal, non-epidemic situation, it gives an indication about the possibilities for contact-based spread of AI during the High Risk Period (HRP).
The frequency of many professional contacts is strongly dependent on the production cycle in broiler and layer farms and therefore shows little variation between farms. Direct contact with poultry (entering poultry sheds) is generally thought to be a more likely way of AI transmission than contact with the poultry farm premises only. Contacts entering the sheds appear to be mainly those necessary for normal business operations; this may reflect increased bio-security efforts in the Dutch poultry production sector.
Based on the contact information in the logbook, it is more likely that contact-based transmission occurs within a sector (i.e. egg and poultry meat production) than between sectors. Moreover transmission to other species is unlikely.
Distances travelled by the contacts were highly variable and many records in the logbook were missing or unreadable. Distances travelled are regionally dependent due to location of slaughterhouses, packing stations, hatcheries, etc. Since only a low number of farms joined the logbook study and no data on the Gelderse Vallei (a main egg producing DPPA) was available, the data on distances might not be representative for The Netherlands as a whole. However, the ranges indicate that contact(s) could result in virus spread between the two distinct densely populated poultry areas in The Netherlands (i.e. the Gelderse Vallei and East Brabant/Norht Limburg) and that this would most likely be due to professional contacts. Private contacts, sale of farm products and employees are more likely to account for neighbourhood spread.

3.1.4. The role of wild birds in the introduction and spread of Avian Influenza in the EU

In this study, attention was focused on target species involved, which are mainly migratory ducks and waders, and on sites valuable for their presence. The main sources of information were on the Important Bird Areas (IBA) and the International Waterbird Census (IWC). The information was for all EU member states, however the degree of precision varied amongst these countries. A total of 1,883 IBAs were identified spread of the entire continent. These areas could be sub-divided into: 490 wintering, 510 breeding, 657 passage and 226 wintering and breeding. A substantial clustering could be observed in North-Western Europe, particularly Denmark, North-Western Germany, The Netherlands, Belgium, North-Western France and the United Kingdom. However, when scoring important features of the IBAs was included (type of the site, extension and abundance of birds) potentially important sites are concentrated in the Mediterranean basin between Turkey, Greece and Italy and in the Nordic and Baltic retions. The data collected was included in the GIS based toolbox and further analyzed.

3.1.5. Database development within a WebGIS based toolbox for poultry production

The collection of poultry data from all of the 27 EU member states was accompanied with a variety of problems. Especially in regard to the national survey frequencies and data collection standards, a long-term harmonisation is appreciated but a solution in the near future will not be provided. Therefore, Eurostat represents an important connection between the national statistical offices and the user of European data. But to date, Eurostat does not offer appropriate data on the field of poultry production. Although this system has the capability to provide useful information, which is representative for all of the European members, there is still the need to develop and improve the system in regard of standardisation, harmonisation, and documentation. Therefore, the statistical offices were approached and a new, standardized poultry database was developed. Implemented in the toolbox, the data supply essential information for various research fields. To keep it up-to-date, every statistical office of the EU-27 needs to be approached regularly and a continuous implementation of the new releases is required.

Within this study, the data were collected for different purposes. One of them was to define risk areas for the introduction and spread of AI. Therefore the most actual data with a high spatial resolution were required. Since the European data server Eurostat does not provide poultry data in the quality and detail needed, all national statistical offices of the 27 European member states where approached to provide the data.

For the visualisation of the poultry data, two different variables were selected. On the one hand, the distribution of the poultry stocks on regional level was depicted by graduated symbols. On the other hand, maps showing the regional poultry density were generated. The geodata were transformed into mapfiles and implemented in an internet compatible client-server-model, in which all components are open source products. The core part of the system is a development environment for building spatially-enabled internet applications called MapServer. The final toolbox provides all information available in a web-based mapserver database, where the scientific user can conduct several semantic queries in the field of European poultry production.

The toolbox was used for analysis purposes on qualitative regional risk assessment for AI. It appeared that he toolbox is a powerful tool to visualise and analyse poultry production in Europe in general, and risk assessment in particular. Its user-friendliness provides an easy and comprehensible access to a statistical database, which is especially of use for decision makers and other important stakeholders. To enrich the system, further information such as the location and type of poultry farms, feed mills, and rendering plants as well as additional analysis tools could be easily implemented. The use of this toolbox is possible on request.

3.2. Task B: Identification and quantification of risk factors for introduction and spread of Avian Influenza at regional and farm level

3.2.1. Transmission parameters of, risk factors for and spatial analysis of Highly Pathogenic Avian Influenza H7N1 in northern Italy in 1999-2000

The analysis were carried out using a data-base of poultry farms of Lombardy and Veneto. The database included dates of stocking and of slaughter of bird farms, and dates of detection of clinical signs of highly pathogenic avian-influenza (HPAI). In addition to clinical signs, isolation of HPAI virus and post-mortem lesions were criteria for case definition that were applied according to the EU legislation. Moreover, spatial analysis were based on precise location of poultry premisis in Veneto and Lombardy regions of northern Italy, expressed in the coordinates in the National Projection System.

The between-farm transmission parameters were estimated of the HPAI epidemic that struck the poultry industry of northern Italy (including turkeys, layer hens, broilers, gamebirds, and waterfowl) from December 1999 through April 2000. The average number of susceptible farms that were infected with HPAI virus by each infectious farm during a day (b) were estimated with a generalised linear model (GLM). The HPAI's reproductive ratios (Rh, the average number of new infected farms (IFs) that were caused by an infectious farm) were calculated separately for the regions of Lombardy and Veneto, where 382 out of 413 (92.5%) of IFs were located. In both regions, Rh decreased to <1 during the second month of the epidemic (showing that its containment had been initiated). Subsequently, during the last two months of the epidemic, b and Rh were reduced to 0.04/day and 0.6, respectively, in Veneto and to 0.07/day and 0.8 in Lombardy. The reduction of the susceptible population was achieved through strict control measures, which included: (1) pre-emptive slaughter of at-risk poultry flocks (within less than 1 km from an IF and other risky contacts), (2) a ban on restocking and (3) an earlier slaughtering than ususal. This reduction was implemented to the greatest extent in Veneto and this might have been associated with a more rapid control of the epidemic in this region than in Lombardy.

With regard to the analysis for risk factors, a Cox regression model that included spatial factors such as the G index was used. The results confirmed the relationship between risk of infection and poultry species, production type and size of the farms. The effectiveness of pre-emptive culling was confirmed. It was shown that the risk of infection progressively increased with farm size, possibly because on larger farms there is a higher number of risky contacts. An increased risk of infection was observed for poultry farms located near an infected farm, which was supported by the effects of pre-emptive culling. Another finding was the increased risk of infection of farms at altitudes below 150 m above sea level. The importance of using appropriate statistical methods that take into account time at risk for individual farms in areas with high farm density when evaluating AI risk factors is highlighted. Moreover, the measures for the control and eradication of AI infection need to consider species differences in susceptibility, the types of production and the density of poultry farms in the affected areas.

The spatial analysis included the infected farms with regard to the epidemic that was caused by H7N1 subtype of type-A influenza virus, and which originated from a low-pathogenic AI virus which spread among poultry farms in northeastern Italy in 1999 and eventually became virulent by mutation. More than 90% of 413 infected premises were located in Lombardy and Veneto regions; of 382 outbreaks 60% occurred in Lombardy and 40% in Veneto region. Global and local spatial statistics were used to estimate the location and degree of clustering of cases with respect to the population at risk. Outbreaks were spatially clustered primarily in Lombardy, with a large cluster in Brescia province and another in Mantua province, on the border with Veneto. Time series analysis was used to assess the temporal clustering of outbreaks. Temporal aggregation increased during the first five weeks and decreased thereafter (probably due to eradication measures enforced in Veneto region). Spatio-temporal clustering was assessed considering the Temporal Risk Window (TRW), the time period during which premises remain infectious and infection can spread to neighboring premises. The clustering pattern was similar to the one detected when considering spatial clustering, i.e., the larger clusters were identified in Brescia and Mantua provinces of Lombardy. These results highlight the role of proximity in the spread of AI virus, and, when considering the TRW, indicate the possible direction of virus spread.

3.2.2. Evaluation of vaccination efficacy in the control of Low Pathogenic Avian Influenza in Italy

The four LPAI epidemics which occurred in the DPPA in North-East Italy from 2000 to 2006 were analysed and compared in order to evaluate the outcome of the implemented vaccination policies.

Emergency vaccination was implemented to control and eradicate the 2000-2001 and 2002-2003 LPAI infections, with different outcomes. In both the epidemics, vaccination coverage of meat turkey flocks reached 95% at the end of the epidemic period. In 2000-2001, the start of the vaccination campaign coincided with the end of the epidemic in the vaccination area and the spread of the virus to unvaccinated neighbouring areas (provinces of Padua and Vicenza). Nevertheless, the epidemic was eradicated and only 20 flocks were infected outside the vaccination area. In 2002-2003, the start of vaccination was delayed and the incidence peak occurred when coverage was still low (44%), involving at that time only unvaccinated poultry farms. The incidence of AI infection started decreasing when about 65% of meat turkey flocks had been vaccinated and, apart from the late outbreaks occurring in vaccinated turkey flocks (April-June, 2003), it remained low until the end of the epidemic.

The observed survival probability of vaccinated and unvaccinated flocks in the two epidemics was different: about 100% in 2000-2001 for vaccinated flocks (only one vaccinated flock was infected) but decreased to 77% in 2002-2003. A possible explanation could be that in 2000, vaccination of replacements was carried out after complete depopulation of poultry farms due to the 1999-2000 H7N1 HPAI epidemic, the start of the vaccination program was correctly planned and farm restocking was carried out accordingly. This induced a homogeneous immunological status in the population. Conversely, in 2002-2003, vaccination of replacements was applied in the presence of active virus circulation, and the start of the vaccination campaign was delayed due to the unavailability of vaccine, inducing a heterogeneous immunological status in the population. Furthermore, in 2000 poultry density in the area was lower, less infected birds were marketed, and a smaller area was involved than in 2003. Motivation in the industry and among farmers was high in 2000 but only limited in 2003, probably influencing the application of biosecurity and vaccination measures.

Some risk factors related to the LPAI infection at farm level were investigated in meat turkeys. In general turkeys are highly susceptible to AI infections, and taking into account all the LPAI epidemics analysed in this study, meat turkeys accounted for 87.5% of the outbreaks (447 out of 511 infected flocks). In 2002-2003 meat turkey farms had the lowest survival probability (42.3%) of the various poultry species and production types in the study area, probably because of relatively lower levels of biosecurity.

Regarding AI vaccination of laying hens, no cases were observed in vaccinated flocks irrespective of the number of vaccine administrations, confirming that chickens are less susceptible to AI viruses than are turkeys and that AI vaccines provide better protection in this species compared to turkeys. Farm size was confirmed to influence the risk of LPAI infection at farm level. In the 2002-2003 epidemic, a progressive decrease in survival probability was observed in meat turkeys with increase in farm size. This might be due to the higher number of at-risk contacts in larger farms, because of the more frequent movement of feed trucks and the presence of additional temporary staff, especially during specific phases of the production cycle (e.g., debeaking, vaccine administration, individual drug treatment, and loading for slaughter). Our findings on the effect of proximity to an IP during its infectious period (TRW) on the risk of infection were consistent with observations on the H7N1 HPAI epidemic in Italy. In the 2002-2003 LPAI epidemic too, having an IP within 4.5 Km was a risk factor for AI infection at farm level. Nevertheless, the effect of proximity provided slightly different results compared to our observations during the 1999-2000 HPAI epidemic. In the HPAI epidemic there was a progressive increase in risk with decrease in distance from an IP. Conversely, during the LPAI epidemic survival probability was almost the same for farms within 4.5 Km of an IP but then increased dramatically for more distant farms. The difference observed in the HPAI and LPAI epidemics could be due to differences in spread capability from an IP to the contiguous farms of HP compared to LPAI viruses. It has been demonstrated that HP viruses have higher infectivity than do LP ones, on the basis of transmission parameters calculated in experimental infections, and this evidence could highlight the importance of radial dispersion for HPAI viruses.

Prophylactic vaccination was practiced in 2004 and 2005, when the re-emergence of the H7N3 LPAI virus and the introduction from the wild reservoir of an LPAI virus of the H5N2 subtype in vaccinated poultry populations was observed. The increased resistance to the field virus challenge of vaccinated birds and the reduction of virus shedding, combined with restrictions, biosecurity and appropriate surveillance, resulted in a rapid eradication of the two outbreaks. Considering the number of affected farms and the duration of the 2004 and 2005 epidemics, we observed that although it was not possible to avoid the introduction of AI viruses in vaccinated meat turkey flocks, the spread of the infection was limited, with a marked reduction in the economic impact of the epidemics.

A general conclusion is, that both emergency and preventive vaccination, associated with restrictions, bio-security and active surveillance for the prompt identification and the appropriate management of any AI outbreaks in vaccinated flocks, could support the control and eradication of LPAI infections in DPPAs. Preventive vaccination provided better results in terms of reduction of the number of outbreaks and duration of the epidemic. These findings could help in the setting up of contingency plans for AI that include decision-making patterns under different scenarios and also take into account vaccination.

3.2.3. Effectiveness of control measures, risk factors for introduction and within-flock transmission of Highly Pathogenic Avian Influenza (H7N7) virus in The Netherlands in 2003

An epidemic of HPAI virus subtype H7N7 occurred in the Netherlands in 2003, affecting 255 flocks and leading to the culling of 30 million birds. To evaluate the effectiveness of the control measures, the between-flock transmission characteristics of the virus were quantified in two affected areas, using the reproduction ratio R_h. The control measures markedly reduced the transmission of HPAI virus: R_h before detection of the first infected flock was 6.5 (95% confidence interval 3.1-9.9) in one area and 3.1 in another area, and decreased to 1.2 (95% CI 0.6-1.9) after detection of the first outbreak in both areas. The observation that R_h remained greater than 1 suggests that the containment of the epidemic was probably due to the reduction in the number of susceptible flocks by complete depopulation of the infected areas rather than to the reduction of the transmission by the other control measures. These results indicate that outbreaks of HPAI viruses are difficult – if not impossible – to control in poultry-dense areas with usual control measures, and could only be achieved by depopulation of the whole affected area. Moreover, new outbreaks can be expected because the wild fowl population is endemically infected with AI virus strains. It might be worthwhile to consider reducing the flock density in order to reduce the probability of an epidemic of this size, or to consider vaccination of poultry as an additional control measure which may reduce virus

spread in an infected area, thereby reducing the risk of human exposure. The risk of introduction of AI virus from wild fowl might be reduced by keeping poultry indoors. However, this might be unacceptable to the general public, which prefers the idea of free-range poultry for (presumed) welfare reasons.
With regard to the risk factors for introduction, for each risk factor available for analysis, the Mantel-Haenszel odds ratio was calculated (stratified on farm size and housing type). An increased risk of HPAI virus introduction in layer finisher type poultry was found: OR = 2,05 (95% CI = 1.29-3.27). An explanation for this increased risk is the high number of contacts between these farms, especially via cardboard egg trays used for removal of eggs during the epidemic. The analysis did not indicate significant differences between the infected and uninfected farms with regard to housing type, presence of cattle or pigs. Since layer finisher type farms are assumed to be at higher risk for HPAI virus introduction, more specific control measures might be applied in future outbreaks.
Some factors expected to be important for the introduction of AI virus did not show up in the analysis. E.g. an increased risk of HPAI virus introduction in free-range systems was not found. However, this lack of finding may well have been caused by the obligation to keep all poultry inside after the first outbreak was diagnosed. Mixed farms with cattle or pigs were not significantly associated with a higher risk of HPAI virus introduction. Possibly, the hypothesis of transmission via vermin or contiguous contact was not appropriate, or the hygienic measures on these farms were more stringent. Another possibility is that a certain number of the contacts were not poultry-related.
Farm size and housing type were identified as possible confounders in this study. In this study, farm size was found as a risk factor for introduction of HPAI virus. The number of houses was significantly associated with the presence of HPAI virus (OR=1.93, 95% CI=1.34-2.79), and also the number of animals (OR=2.08, 95% CI=1.45-3.00). The mechanism behind this risk factor is that although the probability of infection of an individual bird as such is generally very small, on large farms with many animals and many animal contacts, the chance of actual infection of the herd is greater than on small farms with a limited number of animals. Therefore farm size was expected to be a risk factor, and a source of confounding, which it was as it altered associations. Housing type could be of specific interest, because 75% of layer type poultry in the Netherlands are in ground floor systems of which 58% are in free-range systems. In this study, housing type was a risk factor, and no source of confounding. Possibly, farmers with ground floor systems realised they were more at risk for introduction of AI virus and took appropriate hygiene measures to prevent it or the number or type of contacts did not differ between battery or ground floor systems. Moreover, poultry was housed inside immediately after the first outbreak was detected, reducing the probability of this introduction route.
For future outbreaks of HPAI, the results suggest that the contacts between layer type farms should be limited as much as possible, and might be a first step in a more sophisticated approach to eradication of the AI virus from the poultry population. In practice, if the current depopulation policy is upheld, either prioritisation of high-risk farms and their contacts at depopulation in a certain radius around infected farms or prohibition of the collection of eggs might decrease mechanical transmission.
With regard to the estimation of within-flock transmission of HPAI (H7N7 and H7N1) a study was carried out to estimate the transmission rate parameter (β) and the influence of various risk factors on within-flock transmission. Field data of the epidemics in Italy (1999-2000; H7N1) and The Netherlands (2003; H7N7) were used. The estimation is based on back-calculation of daily mortality data to fit a susceptible-infectious-removed format, and these data are analysed with a generalized linear model. For H7N7 virus transmission an infectious period of four days was used, whereas for H7N1 virus the infectious period was set at two days. The transmission

rate parameter (β) from these field data was estimated at 4.50 per infectious chicken per day (95% CI: 2.68 – 7.57) for the Dutch data (H7N7), which was lower than reported from experimental data. For the Italian data (H7N1) the β was estimated at 1.43 (1.17 – 1.74) in turkeys. In contrast to general belief, none of the studied risk factors (housing system, flock size, species, age of the birds in weeks and date of depopulation) had significant influence on the estimated β.
With regard to the role of backyard a study was carried out to quantify the epidemiological contributions of backyard flocks using data from the H7N7 HPAI epidemic in the Netherlands in 2003. A dataset was constructed in which flocks in the affected area were classified as susceptible (S), infected but not yet infectious (E), infectious (I), and removed (R). The analyses were based on a two-type SEIR epidemic model, with the two types representing commercial poultry farms and backyard poultry flocks. The results show that backyard flocks were considerably less susceptible to infection than commercial, while estimates of the relative infectiousness of backyard flocks varied widely. These results indicate that, from an epidemiological perspective, backyard flocks played a marginal role in the outbreak of highly pathogenic avian influenza in the Netherlands in 2003.

3.2.4. Estimation of the day of HPAI (H7N7) virus introduction into a poultry flock based on mortality data

The goal of this study was to develop a model to back-calculate the day HPAI virus is introduced into a flock, based on within-flock mortality data. The back-calculation method was based on a stochastic SEIR (susceptible (S) – latently infected (E) – infectious (I) – removed (= dead; R)) epidemic model. The latent and infectious period were assumed to be gamma distributed. Parameter values were based on experimental H7N7 within-flock transmission data. The model was used to estimate the day of virus introduction based on a defined within-flock mortality threshold (detection rule for determining AI). The results indicate that approximately two weeks can elapse before a noticeable increase in mortality is observed after a single introduction into a flock. For example, it takes twelve (minimum 11 – maximum 15) days before AI is detected if the detection rule is fifty dead chickens on two consecutive days in a 10,000 chicken flock (current Dutch monitoring rule for notification). The results are robust for flock size and detection rule, but sensitive to the length of the latent and infectious periods. Furthermore, assuming multiple introductions on one day will result in a shorter estimated period between infection and detection. It was concluded that this type of model can be a useful tool to back-calculate the day of HPAI H7N7 virus introduction and thus support control measures, but needs to be based on sound data on pathogen transmission. The population should follow homogeneous mixing patterns, therefore the model might not be useful for e.g. caged animals. It is assumed that in battery caged flocks the transmission of H7N7 HPAI will be slower than in loose housed flocks because of spatial separation of the cages. To use this model, it is important to collect daily mortality data and maintain these records at least for the duration of the epidemic.

3.2.5. The impact of vaccination on HPAI and LPAI infections

A transmission experiment was carried out with highly pathogenic avian influenza (HPAI) H7N7 virus in twelve-week-old turkeys. Cloacal and tracheal swabs as well as serum samples were taken to monitor the infection both in inoculated and in susceptible contact turkeys, which were all either unvaccinated, vaccinated once or vaccinated twice with H7N1. Swabs were tested by real-time RT-PCR and serum samples with hemagglutination inhibition test. Unvaccinated contact birds had a mean infectious period of 6.2 days, and an estimated transmission rate parameter of 1.26 per infectious bird per day. However, no virus shedding was found in inoculated vaccinated turkeys. It was therefore concluded that vaccination with

H7N1 protected against challenge with HPAI H7N7 virus, i.e. the important role vaccination could have in controlling an preventing HPAI outbreaks is underlined.
In another study the impact of between-farm spread during LPAI in Italy was studied. Data of four epidemics was available, during which six control measures were implemented: stamping out of infected flocks (1), controlled marketing (2), preventive culling (3), vaccination (4), homogenous areas (5) and reduced density (6). The reproduction ratio between herds (R_h) was estimated. Because various combinations of control measures were implemented, the impact of vaccination both in a univariable and a multivariable model was studied. After implementation of stamping out and controlled marketing the R_h dropped from 2.15 to below 1 during the first epidemic. The second epidemic showed a reduction of R_h below 1 after vaccination started. Vaccination significantly reduced the R_h in the multivariable model, and significantly below 1 in the univariable model. The study showed that vaccination has a clear between-farm spread reducing effect during the second epidemic. This effect is less clear during the first epidemic, where it seems that vaccination worsens the transmission. However, during period 4 there were only 2 cases. In the multivariable analysis (after correction for other measures), vaccination did not seem to reduce R_h below 1, suggesting that vaccination alone is not a sufficient control measure. The analysis of observational studies where control measures are rarely implemented on their own is not straightforward, as opposed to clinical trials. Therefore it is necessary to analyse field data with a combination of multivariable and univariable techniques.

3.2.6. Risk factors for Avian Influenza obtained from literature and expert opinion

A literature study followed by a three-stage Delphi study to elicit the expert opinion of 21 international AI experts was carried out. The results showed that the categories of introduction routes that obtained the highest ratings were by far migratory/wild birds followed by illegal import from third countries. Within the categories for introduction routes, particularly risk factors dealing with movements/trade of live birds (legal and illegal) were considered to be of major importance for AIV introduction. Free-range farming was considered to be the major demographical risk factor for AIV introduction. For spread the categories that obtained the highest ratings were unregistered trade within a region and neighbourhood spread. Similar to introduction, risk factors dealing with movements/trade of live birds (registered and unregistered) obtained the highest weights, but also poultry workers (e.g. catching crews and other service teams) were believed to be important for AIV spread. The number of commercial farms in a region was given the highest ratings among the demographical risk factors for spread.
The results presented are in accordance with the general view that live animal movements, human contacts and high farm densities play an important role in the dissemination of infectious animal diseases. Furthermore, a strong emphasis is laid on possible introductions by wild birds as can be seen from the high weights given to the wild bird category and to risk factors related to free-range farming. However, for some factors, the wild bird category in particular, a relatively high dispersion of values was observed among the experts. Due to a lot of debate about some issues among stakeholders and scarcity of data this is not surprising.

3.3. Task C: Definition, epidemiological and economic analysis of strategies for prevention, monitoring and control of Avian Influenza

3.3.1. Experiences in Italy with control of Avian Influenza

From 2000 to 2005, several *LPAI* epidemics occurred in the Italian poultry population of the Veneto and Lombardia Regions (Northeast Italy). The control strategy included the enforcement of eradication measures, such as the stamping out or controlled marketing of slaughterbirds on infected farms, the prohibition of restocking, and movement restrictions. In order to supplement these disease control measures, a vaccination programme based on the “DIVA” strategy was applied in a well-defined area and targeted to specific types of poultry with long life-span and high LPAI infection risk (meat turkeys and layer). An intensive monitoring programme was implemented to ensure an early identification of field-exposed vaccinated flocks. The collection, storage, and processing of all the vaccination programme data in a centralized database assumed fundamental importance in ensuring the complete control of the epidemiological situation in the vaccination area.

Vaccination proved to be effective in controlling AI. This can be problematic, particularly during the implementation of emergency vaccination programs, whose effectiveness depends mainly on the level of preparedness, the capacity of the veterinary infrastructure, and the level of cooperation with poultry farmers and the other stakeholders. Vaccination is more effective to the extent that the target population (bird species and type of production) is homogeneous. Unfortunately, field conditions are often dissimilar and characterised by many different bird species, various rearing practices, and different levels of disease risk. Effective vaccination and monitoring programmes therefore demand considerable effort and high levels of organisation.

The implementation of the control measures and the emergency vaccination, allowed a significant reduction in the spread of the AI viruses accellerating the end of the epidemics. Interestingly, the epidemics of the 2004 and 2005 that occurred in a vaccinated poultry population were those with the lowest impact in terms of number of affected farms and duration. This effect was also related with the implementation, since 2003, of poultry production management strategies, that reduced the animal density in the areas at higher risk of AI introduction.

The proper application of these measures requires cooperation among poultry producers, poultry farmers and veterinary public health services. Moreover, the control activities, the monitoring programmes associated with the DIVA vaccination strategy and the management measures require financial support in order to ensure their acceptance and application among the different stakeholders.

With regard to the control of *HPAI*, the experiences in Italy showed that the management of a suspected index case is crucial to the subsequent actions aimed at limiting the spread of infection and ultimately in prompt eradication of the virus. Prerequisites for a successful control intervention following an AI suspicion are a prompt disease investigation, aiming at the identification of the time interval from disease introduction to disease detection, tracing of suspect contacts, the implementation of prompt restriction measures on suspected flocks/holdings and prompt stamping out after the disease has been confirmed. Under certain circumstances pre-emptive culling of contact flocks or of flocks at high risk of infection may also be implemented as part of a wider control strategy.

The success of the intervention is related to the level of preparedness and to the degree of communication between the players involved. It is unwise to expect that such a complicated set of measures can be implemented without any preparedness exercise. As field outbreaks have traits in common, but are also unique, dissemination of information on the practical outcome of eradication efforts to relevant parties would result in an improved management of AI outbreaks on a global scale.

3.3.2. Qualitative GIS-based regional risk assessment for Avian Influenza

In this study, a first approach to classify regions of the 27 European Union member states (EU-27) based on expert knowledge and the spatial distribution of AI introduction and spread risk factors is presented. Use was made of the WebGIS based toolbox (see: 3.1.5). Many challenges were faced particularly with respect to data quality and data availability. It was

found that large differences with respect to single AI risk factors in the various regions of the EU-27 exist and that with basic and comprehensible GIS methods these data can be combined into risk maps.
First, single risk factor maps were made including only one risk factor at a time. A distinction was made between risk factors for introduction of AI (e.g. presence of IBAs and import of live animals) and spread (e.g. animal and farm densities). Subsequently, algorithms were developed to combine single risk factors into one risk classification. These overall risk maps were able to identify various regions that consistently have high scores in the various underlying risk maps. This holds particularly for parts of The Netherlands, Germany and France. Germany and The Netherlands have adjacent medium/high risk areas, and on the spread maps a medium/high risk zone across Germany, The Netherlands, Belgium and Northern France shows up. These cross-border risk zones may have serious implications for AI control.
Based on the resulting risk maps, careful conclusions can be made for some regions (e.g. North-Western Europe), whereas for others classification is not yet possible as essential data is lacking. In order to improve the results of future GIS-based risk assessment studies in the EU-27, more attention should be given to the collection of specific AI related risk factors (particularly wild bird data, freerange poultry (farm) data and data related to trade in live birds), to harmonization of data collection, to disclosure of data for research purposes and to adapted sensitivity analysis. Although the risk maps produced in this study cannot be readily used by decision makers, this first approach shows the great potential of GIS-based risk assessment for decision support in animal disease control.

3.2.3. Risk classification of individual farms

This study included 343 poultry farms in Austria, Germany and The Netherlands. The farm data were gathered by using questionnaires and visitor books. The inquiry covers subjects in the categories farm location, management, farm biosecurity, and disease prevention measures. In addition, the farmers documented private and production related visitors for 30 days in a farm's logbook. To evaluate the results, an international expert panel defined and weighted the most important risk factors for AI introduction at farm level within a three-stage Delphi study. Based on this evaluation, all farms were assigned to three classes of risk. To communicate the results to the farmers as comprehensible as possible, a traffic-light scheme was used. The highest risk class represented poultry farms with a high potential for AIV introduction. Comparing the different prevalent structures of poultry production in the three countries, the results can also be used in regard to the EU zoonosis directive.
At the level of individual farms, the study revealed a set of biosecurity gaps, which are related to basic hygiene measures such as hand washing or the disinfection of poultry house equipment. On the one hand, this means that more education of the farmers is necessary and on the other hand it means that most of these security breaches are easy to bridge. Hence, it can be concluded that education and communication are still essential tools within farm management and disease prevention, even in the western part of the European Union, where an invariable high degree of professionalism could be assumed.
Comparing the evaluation results between the countries, it is striking that the Austrian participants received the worst results, followed by the Dutch and the German farmers. An explanation could be the different organisation structures of poultry production in these countries, which could give reasons for variations in farm management and contact structures. With regard to disease prevention, the Austrian and Dutch participants showed a high potential to improve their basic hygiene measurements. This is especially astonishing for the Netherlands since the country already faced a severe AIV outbreak in 2003 and therefore the farmers were expected to provide a high degree of hygiene standard.

Despite the limitations of this study and the relatively small data set used in relation to the size of the countries, the traffic light system for farm risk assessment developed can provide an outline for the prevalent AI introduction risk status of livestock and poultry farms.

3.2.4. Modelling performance of monitoring systems for Avian Influenza

A generic model was developed for studying the performance of monitoring systems for HPAI in broilers. At the moment of reporting, this model was still under further development, i.e. with regard to including different monitoring scenarios and AI and population conditions. Preliminary results however suggest that in some cases the speed of transmission of HPAI is that fast, that improvement of monitoring will not contribute to a substantial reduction of the High Risk Period.

3.2.5. Epidemiological and economic analysis of control strategies for High Pathogenic Avian Influenza

In this study, combined epidemiological and economic modelling is used to compare control strategies for outbreaks of HPAI in densely and sparsely populated poultry areas. The modeling environment used was InterSpread Plus. Parameterization of the model proved to be an extensive job, given the sometimes large and detailed input requirements of InterSpread Plus. Moreover, several adaptations had to be made which are quite specific for EU conditions, e.g. movement restriction zones. Therefore, it was decided to focus on Dutch conditions first as an example for DPPA conditions at country level; SPPA conditions were also included, because in The Netherlands two well-defined DPPA are located, surrounded by areas which can be considered as either MPPA or SPPA.

Detailed parameterization took place with regard to the following issues: (1) farm data (including geographical locations and specific individual data on e.g. production type and size), (2) clinical signs of AI, (3) AI spread mechanisms (with emphasis on local spread and movements, and (4) AI control mechanisms (including various zones of movement restriction and vaccination, AI surveillance, depopulation and vaccination).

A large variety of control strategies was included, which ranged from a basic EU minimum strategy to strategies containing additional measures including pre-emptive culling and/or ring vaccination or preventive vaccination of an area at risk. Strategies are compared according to the 5^{th}, 50^{th} and 95^{th} percentiles of 500 simulated outbreaks for different epidemiological and economic indicators.

The results suggest, that an emergency ring vaccination strategy in combination with pre-emptive culling is an attractive strategy for a DPPA and MPPA. Although two vaccination radii are simulated in this research, the performance of the different radii are dependent on the assumptions regarding local spread. Given the uncertainty surrounding the parameterisation of local spread and the sensitivity of the model to this parameter, it is not possible to draw conclusions about an optimal radius for ring vaccination. Even under an optimistic vaccination scenario, the results suggest large outbreaks are to be expected in densely populated poultry areas. Pre-emptive culling within a larger radius was further able to reduce the expected size of outbreaks in these areas, however this was not considered further in this chapter due to the negative Dutch public perception associated with this measure. Larger vaccination radii were also considered as a proxy for area vaccination of an affected area. These scenarios showed no advantages over the ring vaccination scenarios presented here. However in practical terms, area vaccination may have advantages over ring vaccination, particularly from a logistical perspective.

Although often not seen as necessary for an outbreak in a SPPA, this research suggests that a more intensive strategy (involving vaccination and/or pre-emptive culling) can be implemented for very little extra cost for small outbreaks resulting in significant savings for

larger outbreaks (i.e. outbreaks which would otherwise jump to a DPPA causing a very large outbreak). Clearly the attractiveness of such a strategy would depend on the location of the SPPA in relation to any DPPAs and the potential for contacts between these two areas.
The results of this research suggest that a preventive vaccination strategy targeted at a specific area is relatively expensive compared to ring vaccination strategies. The effectiveness of such a strategy is dependent on the spatial nature of poultry production and the likelihood of the virus jumping between areas. This strategy was epidemiologically attractive for outbreaks in a relatively densely populated area in the Netherlands (the MPPA in this study). In this scenario, the most densely populated poultry area in the Netherlands was preventively vaccinated. This DPPA (the Gelderse Vallei) contains a high proportion of layer farms meaning that a relatively high level of vaccination coverage could be achieved in this area.
A combined strategy of pre-emptive culling and ring vaccination was more attractive than only pre-emptive culling or only ring vaccination. The vaccination strategies simulated had a relatively high level of protection and a capacity of 10 farms per day. It is important to note that it is assumed that pre-emptive culling can begin straight away, while a vaccination programme takes five days to prepare. In addition, not all species are vaccinated which reduces the level of protection at flock level. These aspects are likely to remain as limiting factors for the effectiveness of vaccination.
The results of this research suggest that vaccination capacity (either through more vaccination teams or though alternative administration methods) can be a major impediment to the effectiveness of vaccination strategies.

<u>3.2.6. Market effects of control strategies for High Pathogenic Avian Influenza</u>
In this study, a dynamic and vertically-linked partial equilibrium model of the Dutch layer sector was developed. The model was designed to allow for the implementation of different demand and supply shocks at different levels in the layer production chain which can be associated with simulated HPAI epidemics in the Netherlands; this input was supplied by simulations using the InterSpread Plus model (see 3.2.5).
Shocks which were included in the model were supply shocks associated with the culling of poultry farms and restocking restrictions, domestic and export demand shocks in response to HPAI epidemics or the use of vaccination, trade bans and channelling restrictions on the marketing of poultry and products originating from specified zones. In this way, the most comprehensive exploration of the potential effects of different shocks associated with contagious animal epidemics could be carried out. Moreover, in addition to other studies modeling marketing restrictions on particular products as a result of AI control are included (i.e. table eggs and eggs for industrial processing). Such a comprehensive exploration is particularly useful in the current conditions where (1) a well-defined choice of control of AI is still not available, and (2) studying the Dutch conditions should serve as an example for other EU member states. Hence, a broad exploration would enable to draw first guidelines for economic consequences of various epidemiological and economic approaches of AI control
The results show large differential effects amongst different stakeholder groups as a result of an HPAI epidemic. The relative size of shifts in demand and supply has a major influence on the distribution of these effects. These differences are largest when comparing epidemics in DPPAs and SPPAs, but much smaller when comparing different control strategies for epidemics in a particular area. The temporal pattern of prices and stocks differs according to the epidemic phase. The initial phase (i.e. the first week of the epidemic) is characterised by high uncertainty and is heavily influenced by a total export ban. The outbreak phase (i.e. post-HRP after the first week) is characterised by low prices for live poultry if the number of farms facing restocking restrictions is larger than the number of culled farms. The aftermath phase

(i.e. the period after which AI has been eradicated) is characterised by restocking which generally leads to higher prices (for larger epidemics).

The study shows that the aggregate effect on the welfare of producers disguises very differentiated effects across stakeholder groups, where some stakeholders gain and some lose as a result of HPAI epidemics. Market effects are very different depending on whether epidemics occur in densely or sparsely populated poultry areas. Assuming demand effects do not differ, vaccination and non-vaccination strategies differ according to their epidemiological effectiveness. The distribution of affected farms across the different levels in the production chain has an important effect on the prices of live poultry and eggs.

The results suggest a number of important factors which influence the size and distribution of market effects as a consequence of HPAI epidemics. These include: (1) the location of epidemics in terms of farm density, expected size and length of epidemics, (2) the production structure and degree of vertical integration and market power at the different levels, (3) the nature of and dependency on international trade in live poultry and eggs, in particular the level of intra-EU trade versus inter-EU trade, and (4) the size of any processing or lower quality market and the potential of this market to absorb shocks. Market effects of HPAI epidemics will differ greatly among EU member states since these factors also differ significantly between member states.

3.2.7. Integrated analysis of prevention, monitoring and control of Highly Pathogenic Avian Influenza

First, a conceptual framework appropriate for strategic decision-making regarding AI was developed, which includes potential implications for human health. In this framework the emphasis is placed on the allocation of (financial and other) resources between three important areas of action (i.e. management of AI): prevention, monitoring and control. Within this framework, the objective of decision-makers is to maximise the annual social welfare (or minimise the loss of social welfare) associated with preventing and controlling AI. Social welfare is an aggregation of individual utilities (note: utility is an economic concept reflecting individual welfare and is a combination of both physical impacts and the preferences associated with these impacts).

The conceptual framework illustrates the interrelatedness of prevention, monitoring and control and the trade-offs that exist between these actions. Key characteristics of the decision-problem and the implications for decision-making are explored, such as the issue of risk averseness and ‘dread’ in relation to societal preferences.

The value of this conceptual framework is two-fold: prevention, monitoring and control strategies are considered in an integrated manner allowing for trade-offs between these actions, and a social welfare maximisation approach is used such that not only the size of impacts but also their importance for stakeholders and society is included. Impacts are not restricted to epidemiological and financial-economic impacts but include others such as impacts on human health and animal welfare. This framework realistically captures the decision-making problem and allows for a clear understanding of the trade-offs and critical factors involved.

Secondly, the conceptual framework was further used as a basis for a quantitative analysis of the decision problem using epidemiological and economic modelling aimed at subsequent provision of guidelines for decision-makers. At the time of this study, realistic inputs from epidemiological and economic simulation was not yet available. Therefore, a semi-fictive analysis for the Dutch situation was carried out, specifically aimed at exploring the decision problem.

The results suggest that the effect of epidemic length on profits is more important than the size of the quarantine zone, but this is dependent on the assumption that producers face direct

annual costs for prevention and monitoring but not for control. If the epidemic is short (especially if it is shorter than the average production cycle, which if different between egg and broiler production), then economic losses for producers in the quarantine zone remain small and the size of the quarantine zone is less important. The impact of different cost sharing arrangements requires further investigation, since the results here are dependent on the assumptions regarding cost sharing. A cost sharing arrangement where the costs of prevention and monitoring are spread over all stakeholders and where producers also share in control costs could reduce the conflict between objectives and provide a strategy which is acceptable for all objectives and stakeholders.
If the economic impact on stakeholders is considered, then the case for prevention preferable to cure is less clear cut. In this study, an outbreak does not always lead to welfare losses for producers and consumers. These welfare effects are heavily dependent on price changes. In the current analysis prices are exogenous and the effect of price changes has been explored through potential price scenarios. Endogenising price and trade effects would allow a more thorough analysis of this aspect and should be addressed in further research.
A sensitivity analysis suggests additional findings: optimal levels of prevention and monitoring increase as the base likelihood of introduction increases, the efficacy of control decreases, and the costs of prevention and control fall. However the effects are different for prevention and monitoring. Although prevention and monitoring are both pre-event actions (i.e. actions that take place continuously before AI is notified), prevention reduces the likelihood of the adverse event while monitoring reduces the consequences (cure).
Finally, the results suggest that the optimal combination of actions will be dependent on the objective of the decision maker and that conflict exists between an optimal strategy which minimises costs to the government and one which maximises producer profits or minimises negative effects on human health. From the perspective of minimising the effects on human health, prevention appears preferable to cure but the case is less clear for other objectives.

4. Main conclusions from the research project

In this section, the main conclusions from the research project are summarized per research Task. These conclusions can be regarded as guidelines for (1) implementation of future measures and strategies for prevention and control of Avian Influenza and (2) future research to fill data and information gaps identified which are of prime importance for further improvement of prevention and control of Avian Influenza.

Conclusions with regard to Task A: Development and standardization of data and methods to identify poultry production areas according to their density, organizational and economic structure and contact structure.

With regard to poultry meat, the following can be concluded:

- The main producing countries of poultry meat within the EU-27 are France, the United Kingdom, Spain, Germany, Italy and The Netherlands;
- The main exporting countries of poultry meat within the EU-27 are The Netherlands, Belgium, Denmark, France and Poland;
- In general, broilers are kept in closed housing systems, however in particularly in France substantial outdoor housing occurs;
- Poultry meat is in general produced in very strict organizational models;
- The consumption of poultry meat will show further growth in the coming years;
- The main trade flows with regard to live poultry for meat production occurs between three neighbouring countries Belgium, the Netherlands and Germany.

With regard to eggs, the following can be concluded:

- The main producing countries within the EU-27 are France, Spain, The United Kingdom, Germany, Italy, The Netherlands and Poland;
- The main exporters within the EU-27 are The Netherlands, Spain, Finland and Poland;
- The main trade flows in eggs is from The Netherlands to Germany;
- In general, the production chain of eggs is less integrated than that of broilers, implying more independent actors within the production;
- Various housing systems occur, and free range systems particularly occur in The United Kingdom, France, The Netherlands and Germany; it is expected that with the exception of The Netherlands outdoor housing will increase in the near future;
- Particularly within The Netherlands, Germany (i.e. Lower Saxony), parts of The United Kingdom and France (i.e. Brittany) there is a combination of high density of poultry and free range layer production systems.

With regard to the contact structure in Dutch poultry production, the following can be concluded:

- The frequency of contacts is strongly dependant on the production cycle;
- Contacts entering the poultry sheds are mainly professional contacts;
- It is more likely that contact-based transmission can occur within a sector (i.e. egg and broiler) that between sectors;
- Distances between contact farms can vary very largely, implying that virus spread between two distinct densely populated areas is possible (i.e. the so-called virus jump).

With regard to wild birds, the following was concluded:

- A substantial clustering of Important Bird Areas exists in North-Western Europe, particularly Denmark, North-Western Germany, The Netherlands, Belgium, North-Western France and The United Kingdom;
- Another potentially important concentration of sites with wild birds exists in the Mediterranean basin between Turkey, Greece and Italy, and in the Nordic and Baltic regions.

With regard to the WebGIS-based toolbox, the following conclusions can be drawn:

- The toolbox proved to be a powerful tool to visualize and analyze poultry production within the EU, particularly with regard to qualitative risk assessment;
- Important differences between EU member states with regard to availability and harmonization of data were observed, hence the toolbox could be improved a great deal from standardization, harmonization and documentation of data within the EU.

Conclusions with regard to Task B: Identification and quantification of risk factors for introduction and spread of Avian Influenza at regional and farm level.

With regard to epidemics of High Pathogenic Avian Influenza in Italy, the following was concluded:

- Pre-emptive culling showed to be an effective measure to control HPAI in relatively densely populated poultry areas;
- Reduction of the susceptible population during an epidemic can be achieved through strict control measures which include (1) pre-emptive slaughter of at-risk poultry flocks which are either in close vicinity of infected flocks (less than 1 km) or have had risky contacts, (2) a ban on restocking and (3) an earlier slaughter than usual;
- The risk of infection of a flock progressively increased with farm size, possibly of the larger number of risky contacts;
- The risk of infection was associated with a location close to an already infected farm;

- An association was observed between the increased risk of infection and an altitude below 150 m above sea level.

With regard to epidemics of Low Pathogenic Avian Influenza in Italy, the following was concluded:

- Chickens are less susceptible to AI viruses than turkeys, hence vaccination provides better protection in chicken than in turkey;
- Although vaccination did not completely avoid introduction of AI in turkey flocks, the spread of the infection was limited;
- Farm size was associated with the risk of LPAI infection;
- Vicinity to infected flocks was associated with the risk of infection;
- Both preventive and emergency vaccination associated with restrictions, bio-security and active surveillance for prompt AI identification can support eradication of LPAI in DPPAs.

With regard to the epidemic of High Pathogenic Avian Influenza in The Netherlands, the following conclusions could be drawn:

- HPAI virus are difficult (if not impossible) to control in poultry-dense areas with the standard control measures, hence additional measures are required e.g. depopulation of the whole affected area;
- Layer finisher type poultry was associated with an increased risk for introduction of HPAI, possibly because of the high number of contacts of these farms;
- No significant differences were indicated between infected and uninfected farms with regard to housing type and presence of cattle or pigs, although farm size and housing type were identified as possible confounders;
- Contacts between layer type farms should be limited as much as possible to limit spread of AI virus;
- The within-flock transmission was estimated at 4.50 per infectious chicken per day;
- Approximately two weeks can elapse before a noticeable increase in mortality is observed after a single introduction of AI virus into a flock;
- The model developed is a useful tool to back-calculate the day of HPAI H7N7 virus introduction and in this way can support control measures;
- From an epidemiological perspective, backyard flocks played a marginal role in the outbreak of highly pathogenic avian influenza in the Netherlands in 2003.

With regard to vaccination, the following was concluded:

- Vaccination with H7N1 could protect against challenge with HPAI H7N7 virus in turkeys;
- Vaccination could reduce between-farm spread in LPAI epidemics, however vaccination alone is not sufficient to control the epidemics.

With regard to the expert elicitation study on risk factors for Avian Influenza, the following was concluded:

- Migratory birds and movement and trade of live animals (both legal and illegal) were considered to be the most important risk factors for introduction of AI in a particular region, although there quite some dispersion between experts was observed (particularly with regard to the role of wild birds);
- With regard to risks for spread of AI, unregistered trade of live birds within a region, neighborhood spread (i.e. density) and regular poultry workers were identified as the most important risk factors.

Conclusions with regard to Task C: Definition, epidemiological and economic analysis of strategies for prevention, monitoring and control of Avian Influenza

With regard to the experiences with control strategies in Italy, the following can be concluded:

- In LPAI epidemics, use of vaccination based on the DIVA strategy can be an effective additional control measure;
- Vaccination is more effective in case the target population is more homogeneous;
- With regard to HPAI epidemics the identification and management (tracing of suspected contacts and implementation of control measures) of the suspected index case is a crucial factor for successful disease control;
- In some cases (additional) pre-emptive stamping out is a valuable part of a wider control strategy;
- Preparedness exercises in 'peace time' can contribute to a successful implementation of disease control in case of outbreaks.

With regard to the qualitative regional risk assessment within the EU-27, it was concluded that:

- The methodology of the WebGIS-based toolbox developed within the project has great potential for risk assessment purposes, but that optimal use at this moment is hampered by lacking of essential data in several EU member states (i.e. data on wild birds, free range poultry and trade data);
- Large differences with respect to single AI risk factors in the various regions of the EU-27 exist, implying differences in risks for introduction and/or spread of AI between these regions;
- Parts of The Netherlands, Germany and France have for a number of risk factors higher scores compared to other EU-27 member states;
- Germany and the Netherlands have adjacent medium/high risk areas, i.e. there exist an enlarged cross-border region with higher AI related risks;
- There exists a medium to high risk zone for AI across Germany, The Netherlands, Belgium and Northern France.

With regard to the risk assessment of individual farms in Austria, Germany and The Netherlands, it was concluded that:

- The traffic light system for farm risk assessment developed proved to be a valuable tool both for analysis and extension purposes;
- In most cases practical implementation of basic bio-security (i.e. basic hygiene and cleansing of equipment) on farms can be improved a large deal, which implies that education and communication are still essential tools to improve disease prevention;
- There exist (large) differences in on-farm risks for AI between countries.

With regard to the epidemiological-economic simulations of control of Avian Influenza for Dutch conditions representing DPPAs and SPPAs, the following was concluded that:

- An emergency ring vaccination in combination with pre-emptive culling is an attractive strategy for DPPA and MPPA;
- The combination of ring vaccination and pre-emptive culling is more attractive than only vaccination or only ring vaccination;
- Even under an optimistic vaccination scenario still large outbreaks in DPPAs can occur;
- It is likely that the beneficial effect of area vaccination over emergency ring vaccination in DPPAs is limited;
- Although epidemics of AI in SPPAs can be controlled using the basic control strategies without additional measures (i.e. vaccination and/or pre-emptive culling), implementing

these additional measures can have the advantage that against relatively low additional costs considerable savings can be achieved by preventing 'virus jumps' to MPPAs or DPPAs;
- Preventive vaccination targeted at a specific area is relatively expensive compared to ring vaccination strategies;
- Vaccination capacity (if limited) can be a major impediment to the effectiveness of vaccination strategies.

With regard to the market effects of control of HPAI outbreaks for Dutch conditions representing areas which are net-exporting for poultry products, the following was concluded:
- The aggregate effect for producers disguises very much the differentiated effect across stakeholder groups, and there can be large differential effects amongst these different stakeholder groups;
- The differences in market effects between HPAI outbreaks in DPPAs and SPPAs is much larger than when comparing different control strategies in one area;
- The initial phase of the HPAI outbreak (i.e. first one to two weeks) is characterized by high uncertainty (i.e. fluctuation of prices for example) and is heavily influenced by a total export ban; these effects most likely are independent of the control strategy applied;
- The outbreak phase (i.e. the remaining part of the post-HRP) is characterized by low prices for live poultry if the number of farms facing restocking restrictions is larger than the number of culled farms;
- The aftermath phase (i.e. the time after eradication of AI) is characterized by high prices due to restocking particularly if there was a large epidemic;
- The following important factors that influence the size and the distribution of market effects amongst stakeholders were identified: (1) the location of the epidemic (i.e. DPPA or SPPA) together with the size and duration of the epidemic, (2) the structure and degree of vertical integration and market power at different levels of the production chain, (3) the dependency of international trade of the poultry sector, (4) the size of any processing or lower quality market and the potential of this market to absorb shocks (i.e. the possibilities of channeling parts of the production thereby mitigating the economic impact).

With regard to the integrated analysis of prevention, monitoring and control of Avian Influenza, the following conclusions were drawn:
- The effect of the epidemic length on profits is more important than the size of the movement restriction zone, although this depends on the assumption that producers face direct annual costs for prevention and monitoring but not for control;
- Relatively short epidemics (i.e. relative to the production cycle) result in rather small economic losses for producers in the movement restriction zone and the size of this zone is less important;
- Cost sharing arrangement between producers and stakeholders with regard to prevention, monitoring and control offer the perspective of an attractive economic measure to mitigate potential economic conflicts;
- Preference for prevention and monitoring increases if the likelihood of introduction increases, the efficacy of control decreases and/or the costs of prevention and control fall;
- In choices between prevention, monitoring and control possible conflicts exist between an optimal strategy which minimizes costs to the government and one which maximizes producer profits or minimizes negative effects on human health;
- From the perspective of minimizing the effects on human health prevention appears preferable to control but this case is less clear for other economic objectives.

5. Final remarks and future outlook

The Healthy Poultry research project dealt with various aspects related to the prevention, monitoring and control of Avian Influenza within the EU. Many questions raised at the formulation and the start of the project in 2003/2004 could be answered. Quite obviously, also many other questions could not be answered, at least not to the full extend. Main reasons for this are (1) the limitations in time and resources each research project has to face, (2) the gaps in appropriate data and information (both in size and degree of harmonization within the EU) which were revealed during the course of the project, and (3) the developments with regard to AI that took place over the last five years (i.e. technical developments e.g. with regard to vaccination, and the issue of human health associated with AI).

Prevention and control of AI and other epidemic and endemic poultry disease would greatly benefit from a more harmonized data collection throughout the EU as suggested by this project. Furthermore, it should be mentioned that research activities by various partners of the project in the field of prevention, monitoring and control of AI will continue. This holds for research focused on improved individual prevention and control measures, particularly vaccination. The combined epidemiological-economic analysis also will be continued in the year 2009, with a focus on (1) extension of the current models and approach with other sectors (i.e. broilers) and (2) a further refinement of the integrated analysis of prevention, monitoring and control. Hence, new research results which have a basis in the Healthy Poultry project will become available quite soon.