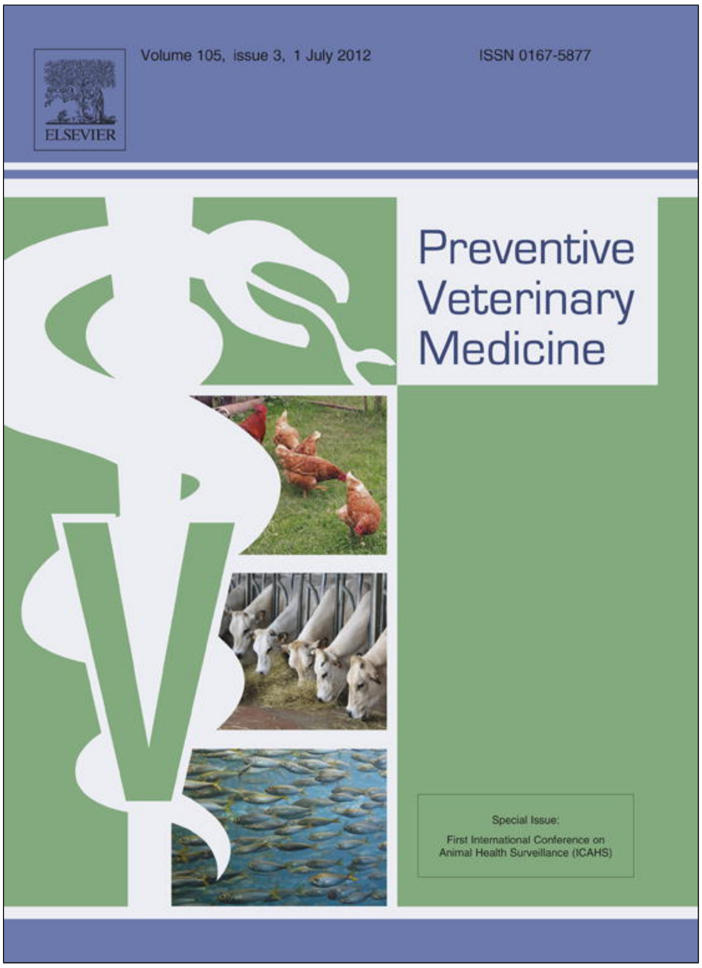
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A qualitative approach to measure the effectiveness of active avian influenza virus surveillance with respect to its cost: A case study from Switzerland

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ABSTRACT

The aim of the project was to apply cost-effectiveness analysis to the economic appraisal of avian influenza virus (AIV) surveillance, using the implemented surveillance programme in Switzerland as a case study. First a qualitative risk assessment approach was used to assess the expected impact of surveillance on the transmission and spread of AIV. The effectiveness of surveillance was expressed as the difference in defined probabilities between a scenario with surveillance and a scenario without surveillance. The following probabilities were modelled (i) transmission of highly pathogenic AIV (HPAIV) from wild birds to poultry, (ii) mutation from low pathogenic AIV (LPAIV) into HPAIV in poultry, and (iii) transmission of HPAIV to other poultry holdings given a primary outbreak.

The cost-effectiveness ratio was defined conventionally as the difference in surveillance costs (ΔC) divided by the change in probability (ΔP), the technical objective, on the presumption that surveillance diminishes the respective probabilities. However, results indicated that surveillance in both wild birds and poultry was not expected to change the probabilities of primary and secondary AIV outbreaks in Switzerland. The overall surveillance costs incurred were estimated at 31,000 €/year, which, to be a rational investment of resources, must still reflect the value policy makers attribute to other benefits from having surveillance (e.g. peace of mind). The advantage of the approach adopted is that it is practical, transparent, and thus able to clarify for policy makers the key variables to be taken into account when evaluating the economic efficiency of resources invested in surveillance, prevention and intervention to exclude AIV.

1. Introduction

Surveillance and intervention are both resource using activities that form part of a mitigation strategy to avoid, contain or reduce the negative consequences of disease. Surveillance helps to offset negative disease effects by promoting successful interventions. The scale and ratios in which the two elements of resources are combined affect the efficiency of mitigation, its costs, benefits, and thus net effect on society's well-being. Surveillance may be active or passive, the former implying active deliberation about the nature and scale of investment necessary to achieve mitigation objectives. Consequently, active surveillance is the focus of this article.

Avian influenza virus (AIV) surveillance in Switzerland aims to document the free status and to provide early warning of an increase in incidence and thereby enable rapid response. If society is to make the best use of its resources,

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the benefits from disease mitigation must be compared to the resource costs for surveillance and intervention with the aim of obtaining the optimal positive net outcome.

In September 2005, the Swiss government implemented an active AIV surveillance programme for migratory birds (Anon., 2005). Because there was a perceived risk in society of highly pathogenic AIV (HPAIV) outbreaks in poultry and the fear of potential transmission to humans with fatal consequences (Anon., 2010a), an international, interdisciplinary project to investigate AIV infections and assess surveillance methods in water birds at Lake Constance (Brunhart et al., 2010) as well as active surveillance in poultry (Wunderwald, 2011) were implemented in 2006. The expected potential benefits of early detection and containment of an AIV outbreak in the animal population are expected to be the avoidance of production losses in the national poultry population, and more importantly, the avoidance of human illness. These are both sources of benefit. In economic terms, therefore, for resource investment in surveillance to be rational and worthwhile, the benefits must be at least commensurate with surveillance costs. Common perceptions about the potential effects of AIV suggest that the value of avoiding them is believed to be very large (Smith, 2005). Indeed, so large relative to the costs incurred that implementation of a mitigation programme to sustain AIV-free status in the poultry population is considered worthwhile under all circumstances. Consequently, the focus of economic analysis becomes one of choosing between the technical options for rapid detection and response should an outbreak occur so as to minimise the mitigation costs.

Given the surveillance objective of early detection, the key question was whether the surveillance programme implemented was cost-effective. Cost-effectiveness analysis (CEA) is a technique for relating the technical outcomes arising from any change to their costs. The technique has been extensively applied and refined in human health economics over past decades (Drummond, 1997; Hutubessy et al., 2003). However, in the veterinary field it has been only occasionally applied to analyse intervention programmes, diagnostics tests and preventive measures, as for example by De Vos et al. (2005) and Knight-Jones et al. (2010). Comparison of the costs and technical outcomes of an existing programme to a scenario of no surveillance allows its classification as cost-effective or cost-ineffective (Hutubessy et al., 2003).

Effectiveness quantifies the extent to which a given technical objective, or target, is achieved. Selection of the appropriate measure for surveillance effectiveness is key to that process, and needs to be determined according to the surveillance objective. For example, it may be a given measurable reduction in the probability of a disease outbreak occurring, the magnitude depending on decision-makers subjective or objective assessment of its value for a particular section of society (e.g. in terms of avoided production losses for farmers, better health protection for vulnerable elderly or infant people) or to society as whole. In general, “CEA is only as valid as its underlying measures of effectiveness and cost” (Weintraub and Cohen, 2009) but, unlike in human health economics, where attempts have been made to harmonise methodologies and encourage comparability of CEA studies (Murray et al., 2000), as yet there are no specific guidelines available for its application in animal health. In the past, there has been a tendency to estimate technical outcomes by increasing the complexity of simulation models (personal communication J. Rushton). The workload to develop such mathematical models is often substantial, and the interpretation of outcomes may be restricted by the use of limited datasets. Thus novel approaches to estimate mitigation outcomes for inclusion in CEA are needed.

The present study was conceived as a CEA approach to investigate the relationship between incremental investment in resources for active surveillance and the changes consequently expected in transmission probabilities for AIV. As will be seen, the outcome was to show that the policy was ineffective, and so calls into question the rationale for active AIV surveillance, at least in Switzerland.

The Swiss active surveillance programme for AIV has two components, one in wild birds and one in poultry (Brunhart et al., 2010; Wunderwald, 2011). Active surveillance in wild birds (including migratory birds) consists of sentinel surveillance of a flock of Mallards kept on Lake Constance in the nature reserve Rhine delta in Austria. Detection of a case of HPAIV may trigger the implementation of preventive measures to reduce the probability of transmission from wild birds to poultry. Active surveillance in poultry aims to detect low pathogenic AIV (LPAIV) infection of the H5 and H7 subtypes. It is based on EU Regulation 2007/268/EEC that requires a sample size that ensures the identification of at least one infected holding with a 95% confidence interval if the prevalence of infected holdings is at least 5%. Since the implementation of the active LPAIV surveillance programme in poultry in 2006, an annually reviewed risk-based sampling strategy has been pursued. In 2009 and 2010, respectively, a total of 66 and 64 layer hen flocks from commercial holdings were tested serologically at the abattoir (10 samples per flock) (Wunderwald, 2011). Positive samples at the abattoir would trigger an epidemiological investigation of remaining flocks at holding level (personal communication R. Hauser). Detection of LPAIV at the farm triggers outbreak response measures as stipulated in the Swiss Animal Health Ordinance (SR 916.401 http://www.admin.ch/ch/d/sr/9/916.401.de.pdf) that impede the spread of LPAIV and so are expected to reduce the probability of mutation of LPAIV into HPAIV in poultry. The outbreak response measures foresee movement restrictions for animals and people, disposal or heat treatment of eggs, the implementation of a restriction zone, and culling of affected birds. Upon suspicion of a HPAIV outbreak in a poultry holding, a movement ban for animals, people and products is put in place. To date, no LPAIV or HPAIV have been detected in Swiss poultry flocks. Until summer 2009, all surveillance results were collected and stored in a central database and presented periodically in short reports that were made available to staff members involved in the AIV mitigation programme (personal communication R. Hauser). Cantonal veterinary services are

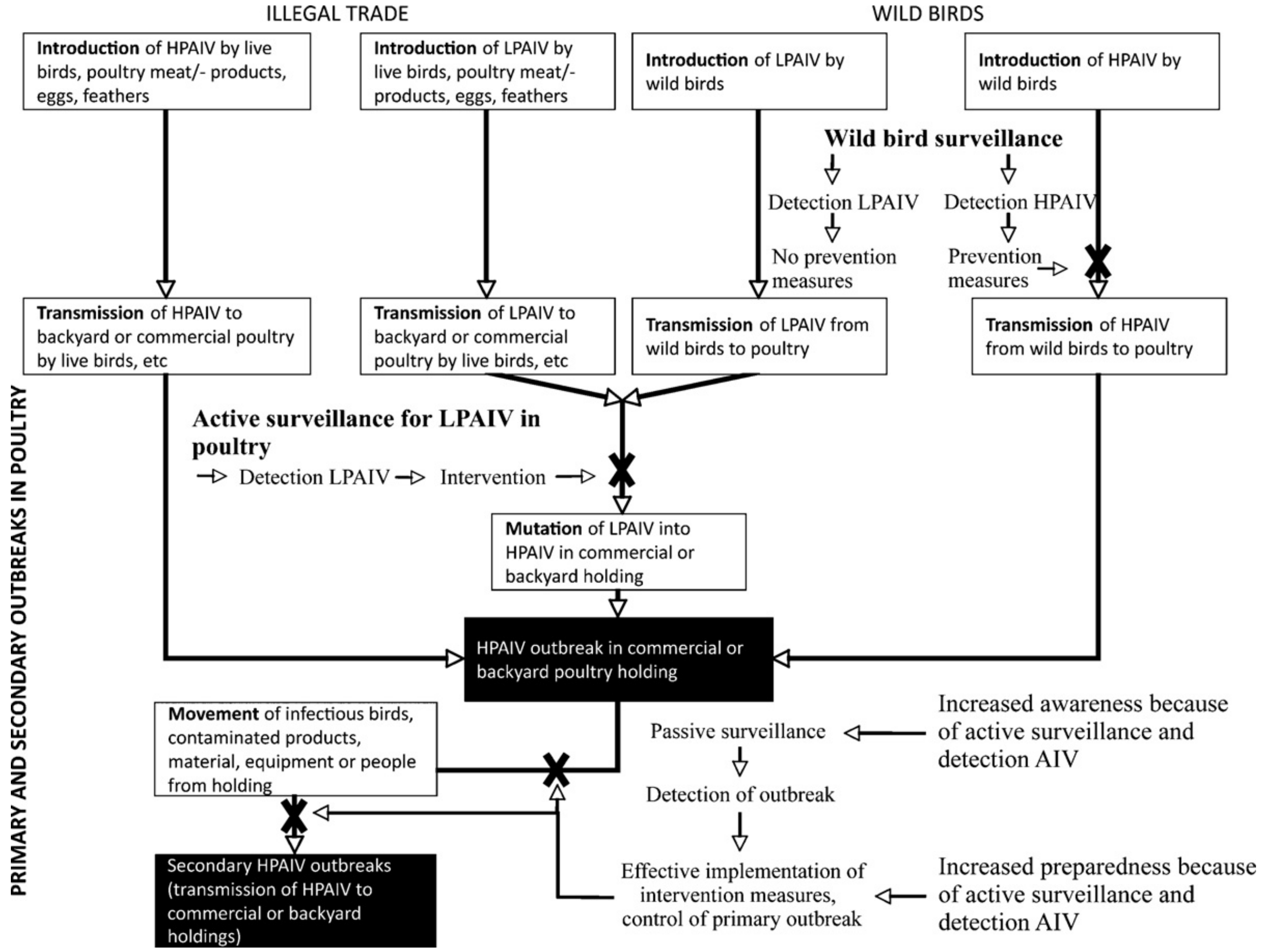

Fig. 1. Overview of avian influenza virus (AIV) surveillance and intervention activities in Switzerland in relation to pathways of AIV introduction by illegal trade and wild birds and subsequent transmission to poultry holdings. HPAIV: highly pathogenic AIV, LPAIV: low pathogenic AIV.

required to record any AIV outbreak in the central, publicly available "information system for cases of notifiable diseases" (https://www.infosm.bvet.admin.ch/public/).

Given the surveillance objectives, the technical outcome measure for surveillance must reflect two important characteristics of the mitigation system, namely early detection and early response. Because the detection of AIV in the poultry or wild bird population triggers intervention measures that are clearly defined in national response plans, surveillance and intervention are inextricably linked. In the current structure of the system, the response measure is a fixed activity depending on a variable surveillance outcome. Together they are expected to keep AIV out of the poultry production system in the long term, and both must be taken into account when assessing the technical outcome of surveillance.

The aim of this project was to explore the potential for guiding policy makers charged with taking resource allocation decisions for AIV surveillance. The main objectives were (i) to assess the technical effectiveness of AIV surveillance in giving early warning, thus to enhance early response and prevent spread within the poultry population, and (ii) to relate the expected improvement in effectiveness to the financial cost of surveillance that contributed to it.

2. Methodology

2.1. General overview

Because the quantification of the final technical outcome, i.e. the number of HPAIV outbreaks avoided, would be a time-consuming and complex simulation task, an intermediate outcome measure of effectiveness was chosen. The measure chosen was the probability of primary and secondary HPAIV outbreaks in poultry with active surveillance in place relative to the situation with no active surveillance. Even though an intermediate outcome is only a partial measure of effectiveness, it is an admissible indication of what the surveillance programme achieves. This measure is a proxy for a known reduction in expected, but potentially very high, economic costs over time.

Because of the lack of quantitative data, a qualitative risk assessment approach based on the framework outlined by the World Organisation for Animal Health (Anon., 2010b) was used. It included a release and exposure assessment as described below. The HPAIV outbreaks could either stem from an introduction of LPAIV and subsequent mutation into HPAIV or the transmission of HPAIV via wild birds or illegal trade to poultry (Fig. 1). The difference in probabilities of primary and secondary outbreaks between a scenario with surveillance and a scenario without surveillance was compared to the costs of surveillance for the year 2009.

Pathways of AIV release and exposure as well as the impact of both wild bird and poultry surveillance on the disease dynamics were identified (Fig. 1). Either detection of a case in wild birds or poultry would trigger intervention measures aimed at disrupting a transmission pathway directly, for example by housing poultry, or indirectly by increasing disease awareness and preparedness of poultry holders and the veterinary service, thereby facilitating an effective response in case of a primary outbreak.

2.2. Risk questions

2.2.1. Wild bird surveillance

Because both LPAIV and HPAIV had been found in the wild bird population in Switzerland (Baumer et al., 2010), a release assessment on country level was deemed redundant. Therefore, a modified release assessment describing the biological pathways necessary to release AIV into a particular environment was used. The questions were:

- *Release assessment:* What is the probability of transmission of HPAIV from wild birds to poultry on commercial or backyard farms in Switzerland with and without wild bird surveillance in place (primary outbreak)?
- *Exposure assessment:* What is the probability of transmission of HPAIV from commercial or backyard farms to other poultry farms with and without wild bird surveillance in place (secondary outbreak)?

2.2.2. Active poultry surveillance

- *Release assessment:* What is the probability that LPAIV which was introduced and transmitted via wild birds or illegal trade to poultry mutates into HPAIV on commercial or backyard farms with and without active surveillance in poultry in place (primary outbreak)?
- *Exposure assessment:* What is the probability of transmission of HPAIV from commercial or backyard farms to other poultry farms with and without active surveillance in poultry in place (secondary outbreak)?

2.3. Study population

In 2009, there were 13,800 poultry holdings registered in Switzerland with 8.7 million poultry. The majority of the birds was broilers (5.2 million) and laying hens (2.2 million) (Anon., 2011). There were 430 holdings that kept ≥1000 laying hens and 800 holdings with ≥1000 broilers. The majority (>85%) of poultry holdings in 2009 kept less than 50 birds (Federal Office for Statistics). Because the differentiation between commercial and backyard holdings in Switzerland is not clear cut and there is no officially recognised categorisation available, backyard holdings were defined for the purpose of this analysis as holdings with a population of less than 50 birds. In a survey conducted in 2007, 91% of poultry holdings indicated to have a free-range area (Saurina, 2009). Generally, the level of biosecurity is low in backyard holdings and increases with an augmentation in flock size and commercialisation.

2.4. Estimation of probabilities

To estimate the probabilities of primary and secondary outbreaks, detailed steps for transmission and mitigation measures were described. They were the same for both commercial and backyard holdings. Pathway 1 was to determine the probability of HPAIV transmission from wild birds to commercial and backyard poultry holdings with and without wild bird surveillance (Fig. 2). Pathway 2 described the chain of events to determine the probability that LPAIV introduced by wild birds or illegal trade and transmitted to poultry holdings mutates into HPAIV (Fig. 3). The starting point for LPAIV in poultry was a combination of the probabilities of a primary outbreak in commercial and backyard holdings found through illegal trade or wild birds. Because more than one factor contributes to the probability estimate of the starting point (additive effect), the highest probability was considered. Pathway 3 was to determine the probability of HPAIV transmission from an infected poultry holding to other commercial or backyard holdings with and without **wild bird** surveillance in place (Fig. 4). Pathway 4 was to determine the probability of HPAIV transmission from an infected poultry holding to other commercial or backyard holdings with and without **poultry** surveillance in place (identical to Fig. 4, but with the impact of poultry surveillance modelled).

A workshop was held with four Swiss AIV experts to discuss and agree all steps of the pathways and estimate probabilities and uncertainties using data from the scientific literature whenever possible.

Four probability categories were included in the risk assessment, namely negligible (N, event is so rare that it does not merit to be considered), low (L, event is rare but does occur), medium (M, event occurs regularly), and high (H, event occurs very often). For each probability, the uncertainty of the estimate was also given (high, h, medium, m, low, l). The expert group discussed the translation of available quantitative estimates into qualitative estimates and agreed on the following scheme: <0.1% = negligible; ≥0.1–20% = low; >20–50% = medium; and >50% = high.

For all situations where events were dependent on the previous step and therefore represented a hierarchical chain of events (Figs. 2–4), a combination matrix based on an approach suggested by Beckett (2007) was used. With this matrix an increase of probability along the pathway is not possible (Table 1).

The potential impact of active surveillance activities and/or detection of LPAIV or HPAIV on disease awareness and preparedness which, in turn, affects the probability of secondary outbreaks, was assessed as follows. It was hypothesised that probabilities related to disease detection by farmers would be increased by raising disease awareness. Similarly, probabilities related to the effectiveness of

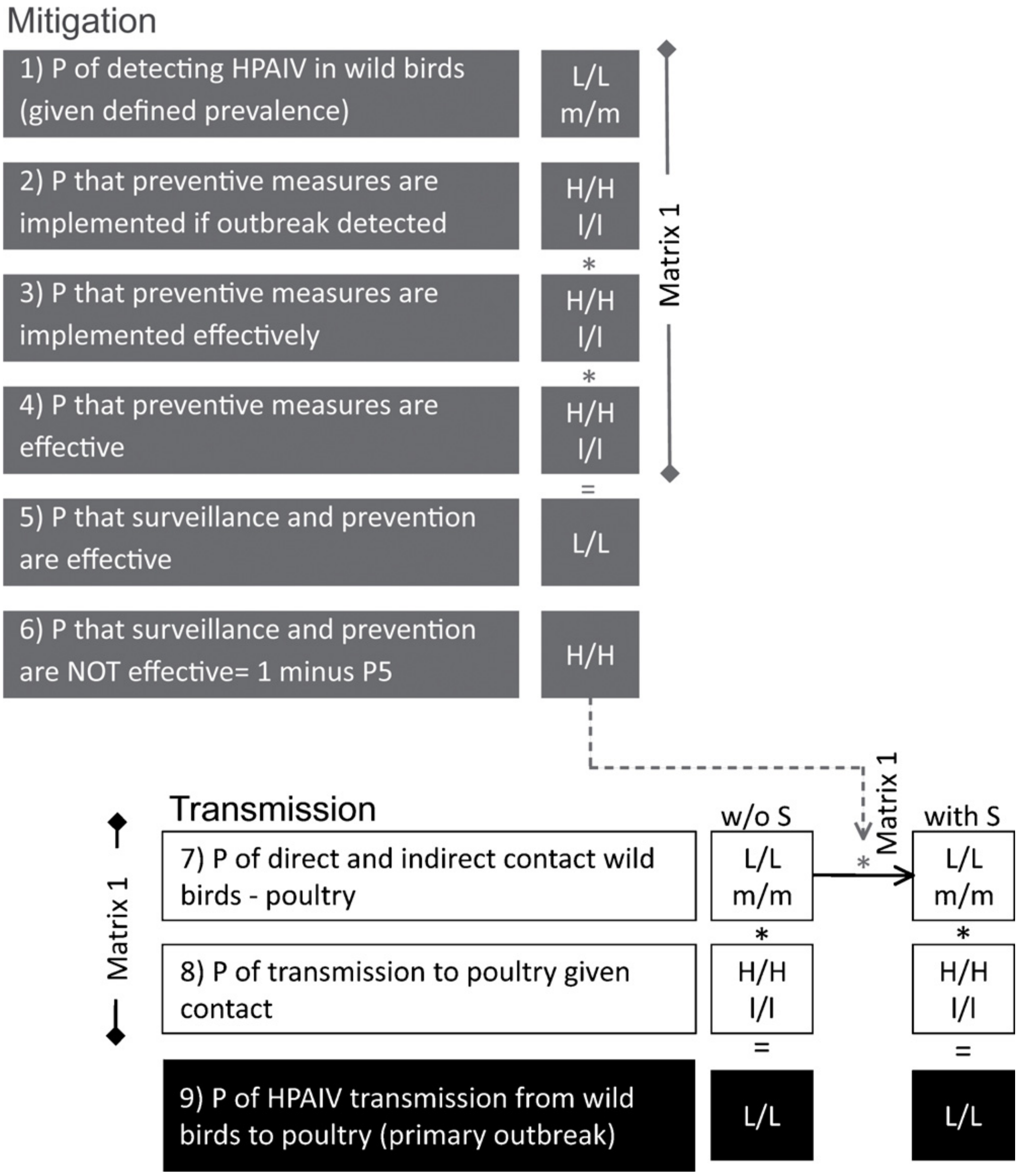

Fig. 2. Transmission (white boxes) and mitigation (grey boxes) sub-steps to determine the probability (*P*) of highly pathogenic avian influenza virus (HPAIV) transmission from wild birds to poultry (black box) with and without (w/o) surveillance (*S*). The probability estimate per box is shown in capital letters and the uncertainty level in lower-case for commercial (before slash) and backyard poultry holdings (after slash).

disease control by the veterinary service were expected to increase with raising disease preparedness. Hence, for each probability that potentially could be increased by raised disease awareness or preparedness, two strata were defined: Stratum 1, the probability of an event happening with that level of awareness or preparedness that exists in the absence of active surveillance; Stratum 2, the probability of an event happening with awareness or preparedness increased as a consequence of active surveillance and/or detection (Fig. 4). For example, the probability of a farmer noticing clinical signs in poultry could change from low (Stratum 1) to medium (Stratum 2) should active surveillance or outbreak detection have a medium or high impact on disease awareness. Table 2 shows the possible probabilities of a disease detection or control event happening without active surveillance, and the changed probability of that same event occurring with increased awareness or preparedness of farmers or the veterinary service because of active surveillance and/or detection.

Table 1
Matrix 1 is used for a hierarchical chain of events where the probability along the pathway cannot be increased.

Event 1	Event 2			
	Negligible	Low	Medium	High
Negligible	Negligible	Negligible	Negligible	Negligible
Low	Negligible	Low	Low	Low
Medium	Negligible	Low	Medium	Medium
High	Negligible	Low	Medium	High

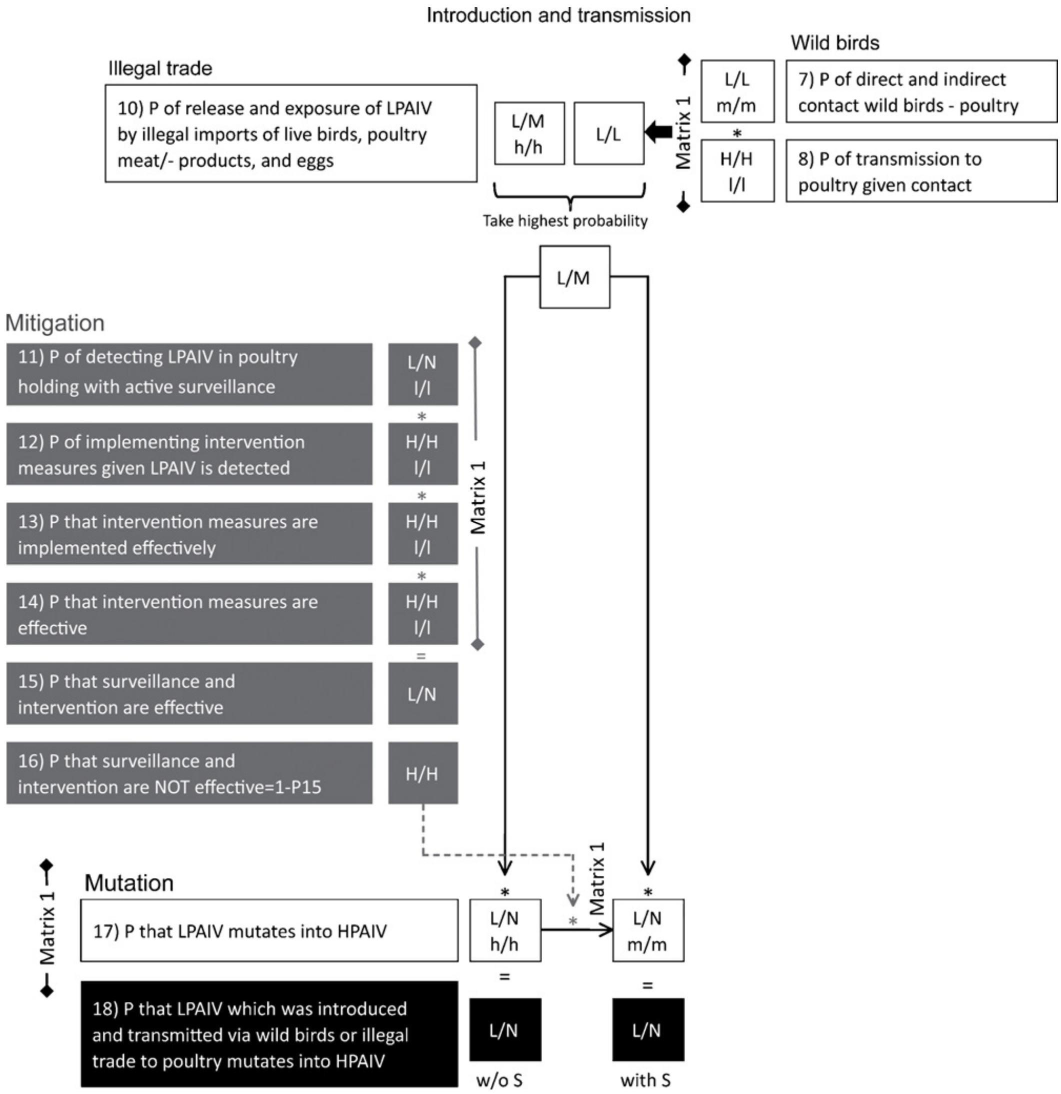

Fig. 3. Introduction, transmission and mutation (white boxes) as well as mitigation (grey boxes) sub-steps to determine the probability (*P*) of a mutation of low pathogenic avian influenza virus (LPAIV) introduced via wild birds or illegal trade to poultry into highly pathogenic avian influenza virus (HPAIV) (black box) with and without (w/o) surveillance (*S*). The probability estimate per box is shown in capital letters and the uncertainty level in lower-case for commercial (before slash) and backyard poultry holdings (after slash).

Disease awareness and preparedness are unlikely to decrease with surveillance and/or detection; therefore the Stratum 2 probabilities must be the same, or higher, than those in Stratum 1. In cases where both factors impact on disease awareness and preparedness (an additive effect), the higher estimate was used (Fig. 4). All probabilities associated with the impacts of active surveillance and/or detection on disease awareness and preparedness were derived during the expert group discussions.

Disease mitigation measures were expected to be effective in reducing the probability of disease transmission and spread. The impact of surveillance, prevention and intervention measures on transmission and spread of AIV was

Table 2
Matrix used where the probability of disease detection by farmers or the probability of intervention implementation and effectiveness by the veterinary service ("event") can be increased by the impact of avian influenza virus surveillance and/or detection on awareness and preparedness.

Initial probability of event happening	Impact of active surveillance and/or disease detection on awareness and preparedness			
	None	Low	Medium	High
Negligible	Negligible	Low	Low	Medium
Low	Low	Low	Medium	Medium
Medium	Medium	Medium	Medium	High
High	High	High	High	High

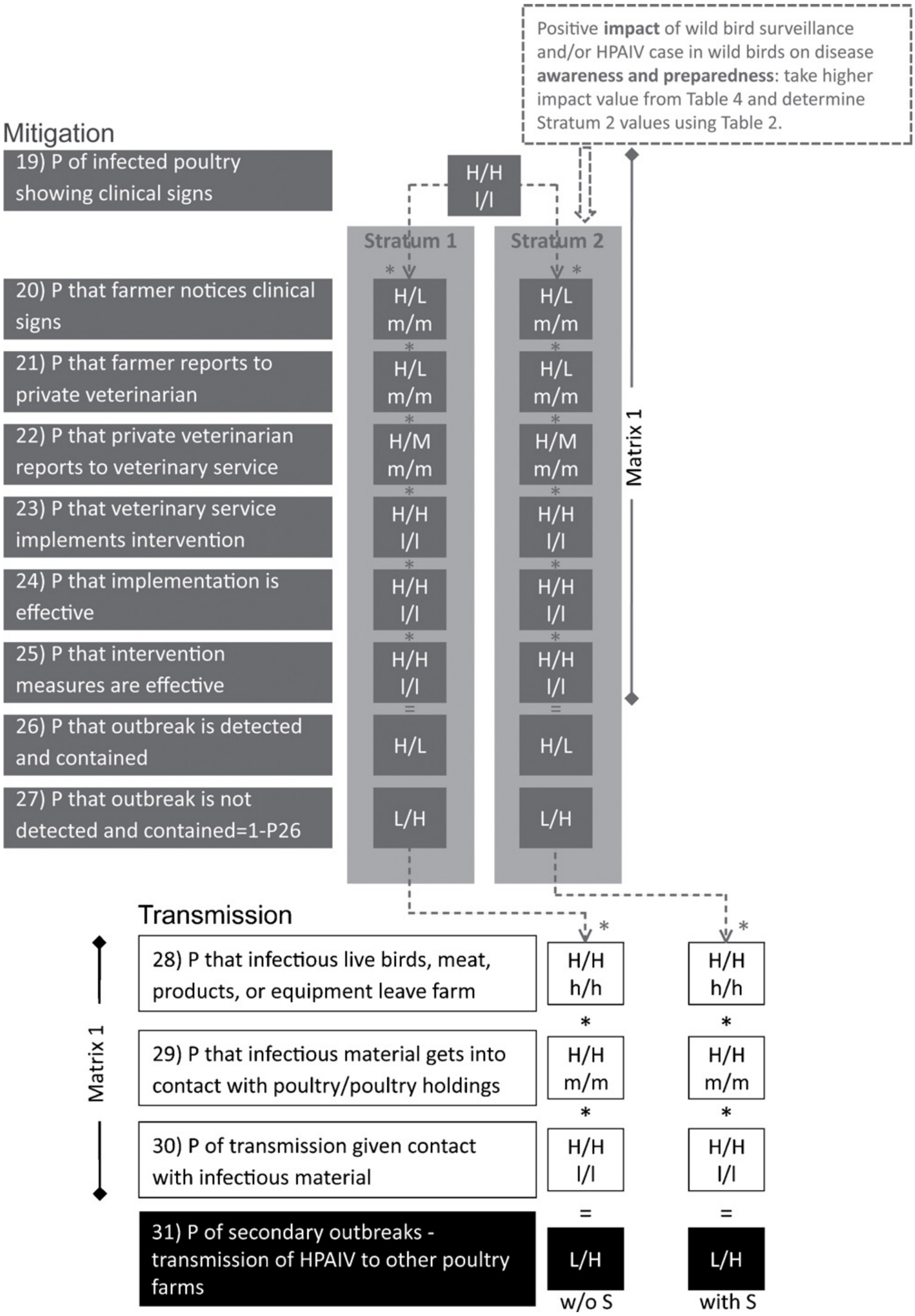

Fig. 4. Transmission (white boxes) and mitigation (dark grey boxes) sub-steps to determine the probability (*P*) of transmission of highly pathogenic avian influenza virus (HPAIV) to other poultry farms (black box) with and without (w/o) surveillance (*S*) given a primary outbreak. The probability estimate per box is shown in capital letters and the uncertainty level in lower-case for commercial (before slash) and backyard poultry holdings (after slash). Stratum 1 is the probability of a disease detection or control event happening with that level of awareness or preparedness that exists in the absence of active surveillance. Stratum 2 is the probability of an event happening with awareness or preparedness increased as a consequence of active surveillance and/or detection. The dotted box explains how to determine the estimates in Stratum 2.

integrated as the 'probability of non-effectiveness', which was calculated as 1 minus the probability of effectiveness of disease mitigation measures: 1 − H = L; 1 − M = M; 1 − L = H; 1 − N = H, as suggested by Wieland et al. (2011).

For example, in Fig. 2 the probability of HPAIV transmission from wild birds to poultry without surveillance is the vertical multiplication of probabilities 7 and 8 using matrix 1. With surveillance, probability 7 may change its value because of the mitigation measures implemented. First, probabilities 1, 2, 3 and 4 are multiplied vertically using matrix 1. Next, 1 minus the estimated probability gives the probability of non-effectiveness. By multiplying probability 7 by this figure using matrix 1, probability 7 with surveillance is determined.

2.5. Surveillance costs and cost-effectiveness ratio

The surveillance costs were derived from a previous study (Sauter, 2008) and included the costs in euros for organisation, material, sample taking, laboratory analysis and labour for active wild bird and poultry surveillance. The average cost-effectiveness ratio (ACER) was specified as the difference in costs without and with surveillance (ΔC) divided by the difference in HPAIV outbreak probability without and with surveillance (ΔP).

3. Results

Table 3 summarises the outcome of the AIV risk assessment to determine the effectiveness of surveillance in wild birds and poultry. Remarkably, the results show that surveillance does not reduce any of the probabilities addressed in the risk questions. Moreover, active surveillance did not affect any of the uncertainties around the probabilities addressed. Estimated probabilities and uncertainties for commercial and backyard holdings, respectively, are presented in Figs. 2–4. The impact of surveillance activities or detection on disease awareness and preparedness is shown in Table 4. The rationale for the estimates and combinations are described in Table A1.

Taking into account the international AIV disease situation at the time of analysis (October 2009–March 2010), the expert group concluded that the most likely prevalence for AIV circulation in the wild bird population would be <0.1% and that the probabilities of detection by the implemented wild bird surveillance would be low (Fig. 2). All probabilities of implementation and the effectiveness of intervention measures were classified as high with a low uncertainty (Figs. 2–4).

The probability of release and exposure of LPAIV by illegal imports was low for commercial and medium for backyard holdings with a high uncertainty. For backyard holdings, this probability was higher than the release and exposure of LPAIV by wild birds and was therefore taken as starting point for pathway 2 (Fig. 3).

The probabilities of backyard holders noticing clinical signs and reporting to a private veterinarian were estimated to be low, resulting in a high probability of secondary outbreaks in backyard holdings. On the other hand, the probabilities of commercial holders noticing clinical signs and reporting to a private veterinarian were estimated to be high. The probabilities of the veterinary service implementing intervention measures and the implementation as well as the intervention being effective were estimated to be high for the scenario without surveillance and could not further increase due to raised disease awareness and preparedness (Fig. 4). The probability estimates for pathway 4 with **poultry** surveillance were identical to the ones in pathway 3 which illustrates **wild bird** surveillance (Fig. 4).

The annual surveillance costs were estimated to be 20,000 € for wild bird and 11,000 € for poultry surveillance. But because the difference in estimated probabilities was zero, it follows that cost-effectiveness ratios in any conventional sense are formally undefined. The implications are considered below.

4. Discussion

This paper presents a practical way of assessing the technical outcome of active AIV surveillance in terms of changes in probabilities for virus transmission or mutation,

Table 3
Outcome of a qualitative risk assessment to estimate the probability of primary and secondary avian influenza virus (AIV) outbreaks in commercial and backyard holdings in Switzerland without (w/o) and with surveillance in place. HPAIV: highly pathogenic AIV, LPAIV: low pathogenic AIV, L: low, H: high, N: negligible, ΔP: difference in probability.

Outcome	Commercial holdings			Backyard holdings		
	w/o *S*	with *S*	ΔP	w/o S	with *S*	ΔP
Wild bird surveillance						
Probability of HPAIV transmission from wild birds to poultry (primary outbreak)	L	L	0	L	L	0
Probability of transmission of HPAIV to other poultry farms given primary outbreak (secondary outbreak)	L	L	0	H	H	0
Poultry surveillance						
Probability that LPAIV which was introduced and transmitted via wild birds or illegal trade to poultry mutates into HPAIV (primary outbreak)	L	L	0	N	N	0
Probability of transmission of HPAIV to other poultry farms given primary outbreak (secondary outbreak)	L	L	0	H	H	0

and taking into account both biological transmission pathways and mitigation measures. By explicitly addressing the impact of various mitigation activities on AIV transmission as well as the awareness and preparedness of both poultry holders and the veterinary service, it provides a transparent way for decision-makers to explore and identify which factors are most influential for AIV spread and its containment. Thereby it provides a qualitative alternative to measuring technical outcomes in other ways, for example using complex epidemiological models.

The approach is based on the assumption that there is a perceived risk of potential spread of HPAIV to humans with potentially fatal consequences, which was the most likely scenario at the time of analysis. At that time, the decision regarding the desirable level of disease had already been taken. Therefore, it was only possible to investigate if the programme implemented was considered subjectively to have been cost-effective, and not whether there exists some alternative combination of surveillance and intervention that might have been preferred. Importantly, the common presumption of all types of CEA is that the positive effect of a programme is known. This may be due to a perception or the fact that the total expected benefits from a project, whether monetary or notional, are considered high enough to outweigh the costs (Mishan and Quah, 2007). Thus, the approach lends itself to the *ex post* analysis of veterinary surveillance programmes with clearly defined technical targets.

The intermediate outcome measure chosen is an indicator of the potential benefit resulting from the mitigation programme. However, only the final outcome measure, namely the number of HPAIV outbreaks in poultry avoided would allow quantification of the economic benefits accruing from reduced production losses and human health costs. For such a comprehensive analysis, a complex epidemiological simulation model would be needed. Knowing the number of farms affected would enable a link to be established between the intermediate and final outcome measures, as recommended by Drummond (1997). If the risk of HPAIV outbreaks in poultry and transmission to humans is recognised as negligible, the economic value of surveillance is almost exclusively reflected by its ability to give early warning that triggers a rapid response and thereby avoids production losses.

The use of a modified risk assessment approach to determine the effectiveness of surveillance for CEA has two important advantages. It is based on the well-established risk assessment framework suggested by the World Organisation for Animal Health (Anon., 2010b), and it allows investigation of the relationship between transmission pathways and mitigation measures. Thus it provides information about the effectiveness of surveillance and, at the same time, highlights critical points in the transmission–mitigation interaction. In this study, however, the results showed that surveillance in both wild birds and poultry had no perceptible impact on the estimated probabilities of primary and secondary outbreaks of AIV. Possibly, four qualitative probability categories were not enough to detect small differences. However, the use of more categories is not recommended due to considerable uncertainty and lack of data. If data are abundant and accurate, the expansion of the number of probability categories or the use of a quantitative approach should be considered to increase the precision of the model.

The surveillance costs were less than one quarter of the approximately €134,000 spent annually on salmonella surveillance in poultry in Switzerland, and so is a relatively small sum. Nevertheless, for the existing policy to have any real economic value, the implicit value of non-monetary benefits that accrue from the surveillance programme still must be considered at least to cover its cost. Otherwise the resources expended, however modest in financial terms, are being used wastefully. Conceivably, surveillance is valued for the peace of mind it provides, a kind of insurance in the minds of the general public should expert opinion be shown in error about its negligible actual efficacy and contribution to protection against AIV.

The experts agreed that surveillance activities and detection of HPAIV in wild birds or LPAIV in poultry would increase disease awareness and preparedness of the veterinary service, but not of poultry holders. Because the quality of the veterinary service and the effectiveness of implementation and interventions were already at their maximum level (high) for the time interval considered, they could not be enhanced by active surveillance. The situation is likely to be different in countries without the technical and financial capacity to implement effective interventions. Also, after a prolonged time period of non-occurrence of AIV and consequential low awareness, the probability of effective implementation may decrease. In such a case, disease awareness and preparedness could be improved by detection of an HPAIV case in wild birds or a LPAIV case in poultry through active surveillance.

The present analysis did not include the value of passive AIV surveillance. Contrary to active surveillance that implies active deliberation about the nature and scale of investment necessary, passive surveillance activities can be considered as a fixed cost. In the Swiss system, the resources used for passive surveillance, namely having in place laboratories, testing and reporting of notifiable pathogens, are not attributable to specific surveillance activities. They are part of a package of overhead costs necessarily incurred by the veterinary service to be able to comply with Swiss legislation. If deemed necessary, passive surveillance may be enhanced by measures such as

Table 4
Impact of active surveillance for avian influenza virus (AIV) or detection of highly pathogenic AIV (HPAIV) or low pathogenic AIV (LPAIV) outbreak on disease awareness and preparedness of farmers and veterinary service staff.

	Surveillance in wild birds or poultry	HPAIV outbreak in wild birds	LPAIV outbreak in poultry
Farmers	None	None	None
Veterinary service	Low	Medium	High

disease awareness campaigns, a variable cost. Assessing the value of passive or enhanced passive AIV surveillance would require estimating its benefit, or effectiveness, and comparing it to the proportion of overhead and variable costs incurred. As in any economic analysis, the monetary or non-monetary benefit resulting from surveillance would have to be determined in accordance with the specific surveillance objective.

Even though passive surveillance was not the focus of this analysis, it was linked to the assessment by the impact active surveillance or detection may have on disease awareness and preparedness. The probabilities of backyard holders noticing clinical signs and reporting to a private veterinarian were estimated to be low, resulting in a high probability of secondary outbreaks. This finding suggests that measures aimed at increasing disease awareness among backyard poultry holders may reduce the probability of secondary outbreaks given a primary outbreak in backyard holdings.

5. Conclusion

The approach presented is a qualitative approach to measure the effectiveness of early warning surveillance given the target of early detection to enable early response and thus contain an AIV outbreak. Its transparent structure facilitates decision-makers' understanding of the current situation and the relationships between surveillance, intervention and mitigation outcomes. It helps to identify critical points in the system and highlights areas where more specific data are required. In principle, the effectiveness measure provided can be used in CEA to determine if a selected strategy is considered to be cost-effective. However, CEA only provides information about technical efficiency in relation to a pre-defined target, but not overall economic efficiency, which requires knowledge of least-cost combinations of surveillance and intervention and the level of loss avoidance that maximises net benefit overall. In this study, even a limited CEA approach is sufficient to show that resources can be wastefully invested in active surveillance, albeit at a small financial cost. However, the investment may be regarded as a very small price to pay to reassure people nervous about the potential consequences of a new and feared zoonosis that at least efforts are being made to prevent it from ever entering a susceptible human population.

Conflict of interest statement

The authors declare that there is no conflict of interests.

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Appendix A.

See Table A1.

Table A1
Comprehensive rationale for probability (*P*) estimates for the qualitative risk assessment used to estimate the probability of primary and secondary avian influenza virus (AIV) outbreaks in commercial and backyard holdings in Switzerland with and without surveillance. HPAIV: highly pathogenic AIV of the H5 or H7 type, LPAIV: low pathogenic AIV of the H5 or H7 type, N: negligible, L: low, M: medium, H: high.

Probability	Rationale
1) P of detecting HPAIV in wild birds (given defined prevalence)	Knight-Jones et al. (2010) conducted scenario tree analysis to assess which surveillance system component had the greatest probability of detecting HPAIV H5N1 in Switzerland from September 2006 to August 2007 given that infection was present in wild waterbirds. The probability of detection was reported for six surveillance components including 'sentinel surveillance' at 1%, 5% and 0.1% prevalence. The **expert group** concluded that 0.1% prevalence in wild birds was clearly overestimated. They expected the HPAIV prevalence in wild birds to be <<0.1%. Further, they stated that prevalence is expected to stay very low even during an outbreak in wild birds, even though there might be clusters of higher prevalence. Taking into account the international AIV disease situation at the time of analysis, it was agreed that the most likely prevalence was one of <0.1%. Therefore, the probabilities of detection for the 0.1% prevalence from Knight-Jones et al. (2010) were taken: Probability of detecting HPAIV H5N1 (mode and 5^{th} and 95^{th} percentiles in brackets) for sentinel surveillance: September–April 0.12 (0.05–0.20), May–August 0.08 (0.04–0.15)
2) P that preventive measures are implemented if outbreak detected	Hauser et al. (2006) developed a scenario tree to facilitate the decision about implementing a protection zone in the case of detection of HPAIV in wild birds. In the protection zone, special measures (e.g. housing of birds, movement restrictions) are to be implemented as stipulated in the technical guidelines regarding measures in the case of suspect and confirmed cases of HPAIV in wild birds (Reg. 2007/09-08/1). In four of seven possible scenarios, a protection zone would be implemented.
3) P that preventive measures are implemented effectively	The **expert group** agreed that preventive and intervention measures as well as their implementation would be highly effective (these considerations also apply to the probabilities 4, 12, 13, 14, 23, 24 and 25). All prevention and intervention measures are clearly documented in national legislation, guidelines and contingency plans. They are based on current scientific knowledge and respect Swiss specific practicalities, such as farming practices and the institutional setting. Federal and cantonal veterinary offices and related officials have unrestricted access to this information and all modern communication tools are available and in use. The quality of the veterinary service is considered to be high (Rüsch and Kihm, 2003; Anonymous, 2009).
4) P that preventive measures are effective	See 3)
5) P that surveillance and prevention are effective	Combination of probabilities 1), 2), 3) and 4) using matrix 1: Both commercial and backyard holdings: L x H x H x H= L
6) P that surveillance and prevention are NOT effective	1 minus probability 5) = 1 – L = H
7) P of direct and indirect contact wild birds – poultry	Saurina (2009) conducted a cross-sectional survey from August to December 2007 to quantify the contacts between wild birds and domestic poultry in Switzerland and to determine factors influencing these contacts. 13% of survey respondents owning a free-range area reported to have observed waterbirds. Personal interviews with poultry holders showed that birds had not necessarily been observed directly in the free-range area, but overall around the free-range area, e.g. flying over it. 61% of professional holdings and 92% of hobby holdings indicated to have a free-range area (significant difference). Other birds were observed more frequently: 75% of respondents indicated to have seen small birds and 53% birds of prey. Further it was found that the degree of professionalism did not impact on contacts between wild waterbirds and poultry. The **expert group** agreed that only wild water birds were of relevance for the transmission of either LPAIV or HPAIV to poultry (Artois et al., 2009). Indirect contacts would also include flying over the free-range area and contamination with droppings. Hence, it was concluded to use the observations of wild water birds as a conservative estimate for direct and indirect contacts. Because the transmission to intensively reared or indoor flocks was considered to be negligible (Anonymous, 2006), the proportion of holdings with a free-range area was taken into account according to the following equation: $PropC_{FR} * PropFR + PropC_{ID} * (1\text{-}PropFR)$ Where $PropC_{FR}$ is the proportion of free-range holdings that have contacts with wild waterbirds (survey answers extrapolated to the whole of Switzerland =12%, Saurina 2009), *PropFR* the proportion of poultry holdings with a free range area (61% of commercial and 92% of backyard holdings) and $PropC_{ID}$ the proportion of indoor holdings with contacts with wild waterbirds (0%).

Table A1 (*Continued*).

<table>
<tr><td></td><td>For commercial holdings: 0.12·0.61 + 0·(1-0.61) = 7.32%
For backyard holdings: 0.12·0.92 + 0·(1-0.92) = 11.04%</td></tr>
<tr><td>8) P of transmission to poultry given contact</td><td>In the European Food Safety Authority's risk assessment (Anonymous, 2006) the probability of transmission of Asian lineage H5N1 HPAIV to poultry given exposure was classified as high with a low uncertainty.</td></tr>
<tr><td>9) P of HPAIV transmission from wild birds to poultry (primary outbreak)</td><td>Combination of probabilities 7) and 8) for the scenario without surveillance and probabilities 6) to 8) for the scenario with surveillance using matrix 1:
Both commercial and backyard holdings:
Without surveillance: L x H = L
With surveillance: H x L x H = L</td></tr>
<tr><td>10) P of release and exposure of LPAIV by illegal imports of live birds, poultry meat/-products, and eggs</td><td>Läubli (2010) assessed the qualitative risk for the introduction of notifiable avian influenza viruses via illegal imports into Switzerland. The probability of release and exposure for different commodities were reported as follows (the uncertainty was high throughout):
<table>
<tr><th></th><th colspan="2">P release</th><th colspan="2">P exposure</th></tr>
<tr><th>Commodity</th><th>Commercial</th><th>Backyard</th><th>Commercial</th><th>Backyard</th></tr>
<tr><td>Live birds</td><td>L</td><td>L</td><td>L</td><td>M</td></tr>
<tr><td>Meat and meat products</td><td>L</td><td>M</td><td>L</td><td>M</td></tr>
<tr><td>Eggs</td><td>N</td><td>L</td><td>n/a</td><td>L</td></tr>
<tr><td>Feathers</td><td>N</td><td>N</td><td>n/a</td><td>n/a</td></tr>
</table>
Where the P of release was negligible, the P of exposure was not estimated (labelled n/a). The probabilities of release and exposure were combined using matrix 1 and the highest estimate was taken as a starting point for the commercial and backyard holdings.</td></tr>
<tr><td>11) P of detecting LPAIV in poultry holding with active surveillance</td><td>EU Decision 2007/268/EC stipulates that the number of poultry holdings to be sampled shall be defined to 'ensure the identification of at least one infected holding if the prevalence of infected holdings is at least 5%, with a 95% confidence interval'.
Because the prevalence is expected to be much lower if LPAIV is present in the poultry population, the expert group agreed that the P of detecting LPAIV in poultry holdings with the current sample size was low for commercial farms and negligible for backyard farms as they are not included in the sample.</td></tr>
<tr><td>12) P of implementing intervention measures given LPAIV is detected</td><td>See 3)</td></tr>
<tr><td>13) P that intervention measures are implemented effectively</td><td>See 3)</td></tr>
<tr><td>14) P that intervention measures are effective</td><td>See 3)</td></tr>
<tr><td>15) P that surveillance and intervention are effective</td><td>Combination of probabilities 11) to 14) using matrix 1:
Commercial holdings: L x H x H x H= L
Backyard holdings: N x H x H x H = N</td></tr>
<tr><td>16) P that surveillance and intervention are NOT effective</td><td>1 minus probability 15):
Commercial holdings: 1 – L = H
Backyard holdings: 1 – N = H</td></tr>
<tr><td>17) P that LPAIV mutates into HPAIV</td><td>Evidence of mutation of LPAIV to HPAIV was shown in Canada, Italy, the United States, the Netherlands, Mexico and Chile (Bowes et al., 2004). Poultry and farm densities have been suggested to be risk factors for mutation. Fiebig et al. (2009) reported that of the total 49,437 recorded poultry farms in Switzerland, 95% had less than 500 birds.
The expert group agreed that a mutation from LPAIV to HPAIV is extremely unlikely in backyard holdings because of the low poultry density (negligible probability). However, in commercial holdings with high poultry densities, the mutation was deemed more likely to occur. However, as most holdings in Switzerland have rather small numbers of poultry compared to other countries, the P of mutation was considered to be low for commercial farms.</td></tr>
<tr><td>18) P that LPAIV which was</td><td>Combination of probabilities 7), 8), 10) and 17) for the scenario without surveillance and probabilities 7), 8), 10), 16) and 17) for the scenario with surveillance</td></tr>
</table>

Table A1 (*Continued*).

introduced and transmitted via wild birds or illegal trade to poultry mutates into HPAIV	**Without surveillance:** Commercial holdings: L x L = L Backyard holdings: M x N = N **With surveillance:** Commercial holdings: L x H x L = L Backyard holdings: M x H x N = N
19) P of infected poultry showing clinical signs	Only AIV of the H5 and H7 subtypes are known to cause disease in susceptible bird species, but not all H5 and H7 viruses are highly virulent (Alexander, 2007). Chickens infected with HPAIV strains show a wide range of clinical symptoms from respiratory and digestive disorders to death within 24 hours (Elbers et al., 2005; Pantin-Jackwood and Swayne, 2009).
20) P that farmer notices clinical signs	A cross-sectional study conducted among Swiss poultry keepers from August to December 2007 showed that the mean knowledge of backyard holders was significantly lower than the knowledge of professional holders (Saurina, 2009). The **expert group** agreed that the AIV knowledge of backyard holders was very limited and that only very few would contact a veterinarian if their birds showed clinical symptoms. The most likely action of backyard holders would be to dispose of sick or dead birds without reporting it. On the other hand, commercial holdings are considered to operate at a high professional level, are generally knowledgeable about AIV and have regular visits by their veterinarian.
21) P that farmer reports to private veterinarian	See 20)
22) P that private veterinarian reports to veterinary service	The **expert group** agreed that veterinarians in charge of commercial herds have a higher understanding of poultry diseases and the importance of national disease mitigation measures and are therefore expected to report any suspect case of AIV they find in commercial flocks. Veterinarians who treat backyard flocks are expected to be less experienced with poultry diseases and the expert team agreed that they would only have a medium P to report disease.
23) P that veterinary service implements intervention	See 3)
24) P that implementation is effective	See 3)
25) P that intervention measures are effective	See 3)
26) P that outbreak is detected and contained	Combination of probabilities 19)-25) using matrix 1. **Stratum 1 (without surveillance):** Commercial holdings: H x H x H x H x H x H x H = H Backyard holdings: H x L x L x M x H x H x H = L With surveillance, probabilities 19-25) may be increased due to raised awareness and preparedness (Table 2). Because none of these probabilities changed (Table 4), the 'with surveillance' probabilities are as follows: **Stratum 2 (with surveillance):** Commercial: H x H x H x H x H x H x H = H Backyard: H x L x L x M x H x H x H = L
27) P that outbreak is NOT detected and contained	1 – probability 26) Commercial holdings: 1 – H = L Backyard holdings: 1 – L = H
28) P that infectious live birds, meat, products, equipment leave farm	Hauser et al. (2005) assessed the risk of introduction of AIV into Swiss poultry holdings. They stated that the virus is likely to be shed in faeces as well as respiratory secretions. Further, both hatching eggs and eggs for human consumption may contain the virus in an early stage of infection and a high concentration of virus is expected to be found in blood. The **expert group** agreed that it is highly probable that infectious live birds, poultry products, and/or equipment leave the farm.
29) P that infectious material gets into contact with poultry/poultry holdings	Fiebig et al. (2009) conducted a study to identify between-farm contacts of commercial and non-commercial poultry holdings in Switzerland. Poultry movements were identified for 65% of the participating farms, with 79% among commercial and 55% among non-commercial farms. Commercial and non-commercial farms were directly connected by between-farm poultry movements. The European Food Safety Authority concluded (Anon. 2008) that spread of AIV is facilitated by the

Table A1 (*Continued*).

	high integration of the poultry industry. The **expert group** agreed that it is highly probable that infectious material gets into contact with poultry/poultry holdings.
30) P of transmission given contact with infectious material	See 8)
31) P of secondary outbreaks - transmission of HPAIV to other farms	Combination of probabilities 27) to 30). **Without surveillance:** Commercial holdings: L x H x H x H = L Backyard holdings: and H x H x H x H = H **With surveillance:** Commercial holdings: L x H x H x H = L Backyard holdings: H x H x H x H = H

See (refs. Alexander, 2007; Anon., 2006, 2008, 2009; Artois et al., 2009; Bowes et al., 2004; Elbers et al., 2005; Fiebig et al., 2009; Hauser et al., 2005, 2006; Läubli, 2010; Pantin-Jackwood and Swayne, 2009; Rüsch and Kihm, 2003).

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