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Accepted Version

Bisdorff, B., Schauer, B., Taylor, N., Rodriguez-Prieto, V., Comin, A., Brouwer, A., Dorea, F., Drewe, J., Hoinville, L., Lindberg, A., Martinez-Aviles, M., Martinez-Lopez, B., Peyre, M., Pinto Ferreira, J., Rushton, J., Van Schaik, G., Stark, K. D. C., Staubach, C., Vicente-Rubiano, M., Witteveen, G., Pfeiffer, D. and Hasler, B. (2017) Active animal health surveillance in European Union Member States: gaps and opportunities. Epidemiology and Infection, 145 (4). pp. 802-817. ISSN 1469-4409 doi: https://doi.org/10.1017/S0950268816002697 Available at https://centaur.reading.ac.uk/69226/

Active animal health surveillance in European Union Member States: Gaps and opportunities

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SUMMARY

Animal health surveillance enables the detection and control of animal diseases including zoonoses. Under the EU-FP7 project RISKSUR, a survey was conducted in 11 EU Member States and Switzerland to describe active surveillance components in 2011 managed by the public or private sector and identify gaps and opportunities. Information was collected about the hazard, target population, geographical focus, legal obligation, management, surveillance design, risk-based sampling, and multi-hazard surveillance. Two countries were excluded due to incompleteness of data. Most of the 664 components targeted cattle (26.7%), pigs (17.5%) or poultry (16.0%). The most common surveillance objectives were demonstrating freedom from disease (43.8%) and case detection (26.8%). Over half of components applied risk-based sampling (57.1%), but mainly focused on a single population stratum (targeted risk-based) rather than differentiating between risk levels of different strata (stratified risk-based). About a third of components were multi-hazard (37.3%). Both risk-based sampling and multi-hazard surveillance were used more frequently in privately funded components. The study identified several gaps (e.g. lack of systematic documentation, inconsistent application of terminology) and opportunities (e.g. stratified risk-based sampling). The greater flexibility provided by the new EU Animal Health Law means that systematic evaluation of surveillance alternatives will be required to optimize cost-effectiveness.

INTRODUCTION

Animal health surveillance (AHS) forms a key element in the detection and control of animal and zoonotic diseases, in demonstrating disease freedom to ensure safe trade and providing valuable data for decision-support [1]. A key feature of surveillance is the need for the systematic (continuous or repeated) measurement, collection, collation, analysis, interpretation, and timely dissemination of data [2]. Hence, single surveys or analytical studies do not fall under this surveillance definition. The need for systematic analysis and interpretation arises from the close link between surveillance and intervention strategies in case undesired changes are observed [3], which distinguishes surveillance from monitoring systems. Monitoring, i.e. the collection of animal health data without a clear related action plan, usually only applies when the aim is to assess the initial health status of a population, whilst otherwise data collection without a clear related action plan should not be encouraged [4]. In contrast to passive surveillance, which relies on the detection and reporting of clinical signs, active surveillance is initiated by the investigator using a defined protocol to perform actions that are scheduled in advance [2]. Whilst public health surveillance commonly relies on notifiable disease reporting (passive surveillance) and the analysis of secondary data, AHS places stronger emphasis on collecting primary data via active surveillance for example to fulfill trade requirements and ensure food safety.

In the European Union (EU) AHS is regulated by the Community Animal Health Policy (CAHP), which aims to reduce the negative impact of animal diseases on animal and public health, animal welfare, and the economy by ensuring safe intra-community trade with live animals and animal products [5]. Historically, the CAHP included almost 50 basic directives and regulations and 400 pieces of secondary legislation, most of which were adopted between 1988 and 1995 [1]. An external evaluation launched by the Commission in 2004 to assess the performance of the CAHP concluded that it lacks an overall strategy, places insufficient focus on disease prevention and does not provide enough flexibility to adapt new scientific and technological developments. Audit reports also

indicated different interpretations of requirements e.g. regarding specifications of risk categories as part of the multi-annual national control plan, resulting in diverse surveillance approaches taken by Member States [6]. The new EU Animal Health Law published in March 2016 [7] is based on the EU Animal Health Strategy "Prevention is better than cure" [5] and streamlines the huge number of legal acts into a single law, which shall also prevent piecemeal and crisis-driven policy development in the future [1]. Besides EU regulations, national and regional requirements as well as private initiatives exist, which vary between countries. Hence, the surveillance landscape in the EU includes a mixture of regulated and non-regulated activities managed by the public sector, private sector or both.

Given budget limitations, it is crucial to carefully design and regularly evaluate surveillance systems to optimize cost-effectiveness. Traditionally, input-based standards were applied, which required specific activities to be carried out regardless of the characteristics of the population. In recent years, considerable progress has been made regarding surveillance design. Alternative approaches include the application of output-based standards [8, 9], where surveillance is designed to meet defined requirements (surveillance sensitivity, design prevalence), thus supporting flexible approaches targeted to the characteristics of the population under surveillance and the available capacities. Two probabilistic output-based measures are applied, i.e. the probability ("confidence") of detecting a case (surveillance sensitivity) and the probability that a population is free from disease (negative predictive value) [8]. Whilst surveillance sensitivity allows achieving the targeted probability at the set design prevalence for different testing regimes, sample sizes and risk strata, the negative predictive value provides opportunities to combine information from multiple surveillance components and to take the value of historical information into account [8, 10, 11]. Consequently, heterogeneity in populations can be more adequately accounted for including various risk levels [9], and surveillance effectiveness can be quantified in populations that are too small to achieve the desired probability of detection by applying input-based standards [10-12]. Hence, these probabilistic approaches offer opportunities to lower costs whilst achieving the same target or achieve greater effectiveness at the same cost. Various analyses have been published demonstrating the superiority

of output-based over input-based standards or risk-based over random sampling strategies. For instance, it was estimated that risk-based strategies reduced the cost to demonstrate freedom from infectious bovine rhinotraecheitis and enzootic bovine leucosis in the EU between 2002 and 2009 by six million Euros [13]. Output-based standards have been evaluated for example for *Trichinella* spp. [14], Bovine Herpes virus 1 [15], Avian Influenza virus [16], Transmissible Spongiform Encephalopathies [17, 18], *Mycobacterium bovis subsp. tuberculosis* [19-22], *Mycobacterium avium subsp. paratuberculosis* [11, 23, 24], Classical Swine Fever virus [25], Bluetongue Disease virus [26], and resistant pathogens [27]. However, output-based approaches need to be based on sound epidemiological knowledge including an evaluation of the epidemiological situation in the region, require close collaboration and exchange between scientists and policy makers [13] and need to be documented in a transparent manner to allow cross-country comparisons [28].

For early detection (or early-warning surveillance), alternative approaches include for example sentinel, participatory and syndromic surveillance strategies [29]. Syndromic surveillance can be defined as "surveillance of health indicators and diseases in defined populations in order to increase the likelihood of timely detection of undefined (new) or unexpected (exotic or re-emerging) threats" [2]. By detecting a disease early, potential devastating consequences of spread and thus economic impacts can be considerably minimised [28, 30]. Testing the same samples simultaneously for multiple hazards (multi-hazard surveillance) presents a general option to reduce surveillance costs and thus provides an important alternative to consider compared to targeting a single hazard only.

Although these approaches are increasingly promoted in scientific research, there is a lack of overview of AHS activities in EU countries and to what extent alternative strategies are already in place. Therefore, as part of the EU-FP7 RISKSUR project (2012-2015) (http://www.fp7-risksur.eu/), a survey was carried out to describe existing surveillance activities in EU countries, with the aim to identify gaps and opportunities. Furthermore, a better understanding of existing surveillance

activities and differences between countries also contributed to inform the development of decision support tools for the design and evaluation of surveillance systems (http://webtools.fp7-risksur.eu/).

METHODS

Survey design: The reference year was 2011 as this was the latest reporting period for which expenditures were accessible at the time of data collection (spring to autumn 2013). All seven "partner countries" (CH, DE, ES, FR, NL, SE, UK) of the RISKSUR consortium as well as five selected "non-partner countries" (BG, CZ, DK, IE, IT) were included in the data collection process (subsequently referred to as study countries). Non-partner countries had been selected based on dissimilarity to partner countries regarding geographical region (e.g. targeting countries from Eastern and Southern Europe) and animal populations, production systems and hazards present, as well as the availability of a responsive official contact person. Furthermore, an in-country contact person had to be available to support data collection, especially due to language barriers and insufficient publicly accessible information on surveillance components, which would not have allowed for data collection otherwise.

Sequential numbers were randomly assigned to countries to preserve confidentiality. All hazards (e.g. pathogens, syndromes, antimicrobial resistance, animal welfare) and species were covered, regardless of whether surveillance was managed by the public or private sector. Surveillance associated with import or export testing was not considered as requirements depend on the trading partners of the respective country. Even though data were collected on active and passive components, only active surveillance components were considered in this analysis as data on passive surveillance were considered to be too similar between countries.

Questionnaire design: A questionnaire, comprising two sections with a total of 26 variables, was designed to collect information on surveillance components (see Supplementary Section S1 for a copy of the questionnaire and Supplementary Table S1 for examples). A surveillance component was

147 defined as a single surveillance activity used to investigate the occurrence of one or more hazards or
148 health events in a specified population, and which has a self-contained (i.e. conclusive and
149 comprehensive in itself) surveillance protocol that focusses on a particular data source. The
150 following key variables were used for analysis: targeted threat, disease or health event, target
151 population, species and sector(s), geographical focus (local, national or regional), primary purpose,
152 legal obligation, management (private, public or both), description of the component, study design
153 (e.g. survey, continuous data collection), case definition (e.g. laboratory test for pathogen/toxins or
154 host response, clinical signs, pathology, indirect indicators), risk-based sampling, and multi-hazard
155 surveillance. Cost information is not presented in this paper as data gaps were too large to make
156 meaningful inferences. Risk-based sampling was defined as "preferentially sampling strata within the
157 target population that are more likely to be exposed, affected, detected, become affected, transmit
158 infection, or cause other consequences" [4]. For risk-based components, a post-hoc distinction was
159 further made between targeted risk-based (focusing only on one sub-stratum of the population) and
160 stratified risk-based (sampling intensity differs between population strata). Multi-hazard surveillance
161 was defined as "surveillance activities where samples collected for one disease agent are analysed
162 for more than one purpose or for other disease agents, either in parallel or at a later stage". For the
163 surveillance definitions and characteristics used in the questionnaire, data collectors were referred
164 to the final report from the International Conference on Animal Health Surveillance (ICAHS) in May
165 2011 [4].

166 *Data collection:* The questionnaire was circulated within the RISKSUR consortium to collate feedback.
167 Twenty-nine staff from RISKSUR partner countries collected the data in their own country and in
168 collaboration with the assigned contact person in non-partner countries. All but one data collector
169 were either trained veterinarians (n = 24) or animal scientists (n = 5). One external data collector who
170 was temporarily employed in one non-partner country to ensure that language did not present a
171 barrier was not working in the veterinary field. A training session was held with data collectors via
172 Skype to review the protocol and thus standardize data collection. After approval by the RVC ethics

committee (No. 2013 0071H: Ethical clearance for RISKSUR mapping), a database was developed in Microsoft ACCESS® (Microsoft Corporation, Redmond, Virginia) and distributed amongst data collectors. Information on surveillance components was predominantly collected through a grey literature search, including government or non-government reports, national legislations and other information, whilst scientific literature only sometimes provided indications of surveillance efforts. Representatives from public and private institutions were contacted to verify or complement information [31]. Finally, data were re-entered into a shared web-based SQL database.

Data management: Seven researchers from six institutes (APHA, CIRAD, FLI, RVC, SVA, UCM) spent two months on consistency checks of a sub-set of the database [31], which included discussions on standardized use of terminology and application to recorded components. A terminology working group was initiated to verify conclusions regarding means of data acquisition and surveillance purpose and objective [32]. Based on the results of this working group, the term 'surveillance objective' will be used instead of 'surveillance purpose' throughout the text. Prior to preparing this manuscript, a final consistency check was performed by a single investigator. This involved checking categorisations once again of those key variables, for which strong inconsistencies were identified during the initial consistency checks (i.e. surveillance objective, means of data acquisition, and risk-based sampling) and verification that components were consistently split according to the following criteria: 1) Individual hazard(s) unless for unspecific components (e.g. meat inspection); 2) specified population: Species and if applicable target sector; 3) data source: Sampling point, case definition; 4) risk-based sampling; and 5) data collection method (means of data acquisition, study design).

Data analysis: Data were analysed in Stata (StataCorp. 2015. *Stata Statistical Software: Release 14*. College Station, TX: StataCorp LP). A stacked bar chart of the number of components stratified by the sector managing the component (public, private, both, unknown) was created. Countries with obvious deficiencies in data completeness were excluded from subsequent analyses. Surveillance component was chosen as the level of analysis. The percentage and 95% confidence interval of

components (number of recorded components / total number of recorded components) were calculated for each variable using the *cii command*. Associations between each variable with the independent variables management, species and objective were explored using r x c contingency tables. Cells with low frequencies were collapsed or discarded if considered appropriate. The conditional probabilities (column percentages; *tabulate command*) and adjusted residuals (*tabchi command*) were reported. Any cell with adjusted residuals greater than ±1.96 was highlighted in bold, as they are more extreme than would be expected if the null hypothesis of independence was true [33].

Completeness of surveillance components per country was estimated by matching the components recorded by each country with all obligatory EU components identified in the dataset (see Supplementary Table S2) and dividing the achieved number by the total. An EU component was considered obligatory if it was compulsory for any EU Member State, not just relating to restriction zones or countries with eradication programmes in place.

RESULTS

Descriptive results

The dataset prior to the final consistency check included 738 active AHS components. Seventy-three components were excluded as they were combined with another component (n = 42), failed to meet the surveillance definition (n = 10), included insufficient information (n = 8), related to export/import (n = 8), or were duplicates or considered erroneous (n = 5). Twenty-two components were added as recorded variables justified splitting the original component to achieve consistency in component splitting with other countries. Hence, the final dataset included 687 components.

The number of active AHS components recorded per country (median: 57.5; range: 10 – 105) stratified by the sector responsible for management (public, private or both) is shown in Supplementary Figure S1. In most countries, components were predominantly managed publicly

(median across countries: 65.6%; IQR: 47.5 – 75.7%) with a smaller percentage being managed privately (median: 19.8%; IQR: 9.3 – 25.6%) or in a public-private partnership (median: 7.9%; IQR: 3.9 – 10.8%).

Countries 5 (n = 13) and 11 (n = 10) were excluded from subsequent analyses as their data were considered to be too incomplete, thus resulting in 664 components in the final data set. The remaining countries reported 34.1 to 90.2% of the 43 obligatory EU components identified in the data set (median: 59.8%; interquartile range: 48.2 – 84.1%) (see Supplementary Table S2).

Components targeted 55 specific hazards (592 components), 21 hazard groups (e.g. wildlife diseases, emerging diseases) (n = 62) and three indicators (genetic, health, welfare) (n = 10). Supplementary Table S3 shows the number of components per hazard, the number of countries reporting at least one component for this hazard, and the median, minimum and maximum number of components for those latter countries. The most frequent hazards targeted by the hazard-specific components were *Salmonella* spp. (16.1%), *Brucella* spp. (7.7%), *Mycobacterium tuberculosis* (4.4%), Classical Swine Fever virus (3.9%), bluetongue disease virus (3.8%), avian influenza virus, scrapie virus and *Trichinella* spp. (3.6% each), and Aujeszky's disease and Enzootic Bovine Leucosis (3.3% each).

Descriptive results for all study countries and stratified by partner and non-partner countries are presented in Table 1. Categories of three variables significantly differed between partner and non-partner countries, i.e. legal requirement, management and risk-based sampling.

Cattle were the most frequent species targeted by components (26.7%), followed by pigs (17.5%), poultry (16.0%), and small ruminants (11.9%). Country 9 did not record any wildlife components and countries 1 and 7 only one general wildlife component. The category 'other species' covered fish (13 components), insect vectors (n = 9), and bees (n = 3). Less than five components were recorded for molluscs, shellfish or crustaceans (n = 4), animal feed (n = 4), and pets (n = 1). Most components were implemented at the national level (89.4%) and were based on EU regulations (68.4%). Twelve percent of components were based on additional national requirements.

The most commonly assigned surveillance objective was demonstrating freedom from disease (43.8%), followed by case detection (26.8%), prevalence estimation (19.7%), and early detection (9.8%). The sampling point was recorded as farm, abattoir, and insemination centre for 48.6%, 21.4%, and 15.6% of components, respectively. Data were usually recorded to be collected continuously (56.8%) or via repeated (usually annual) surveys (39.2%). Case reports (n = 15), sentinel surveillance (n = 8), participatory surveillance (n = 2), and event-based surveillance (n = 1) were recorded under 'other study designs'. Laboratory diagnosis (direct, indirect or both) was the most common case definition. Active clinical surveillance (n = 12), i.e. routine inspection by the competent authority without prior notification of abnormal signs by farmers, targeted Bluetongue disease, Classical Swine Fever and emerging diseases in more than one country. Most 'other case definitions' contained multiple case definitions including others than laboratory detection (e.g. indirect indicators, risk factors). Risk-based sampling and multi-hazard surveillance were recorded for 57.1% and 37.3% of components, respectively.

Bivariate results: Management

Components managed in a public-private partnership were more likely recorded (than what would be expected if the variables were independent) by partner (85.3%) than non-partner countries (14.8%) (Table 2). Privately managed components more frequently targeted cattle (46.6%) and less frequently small ruminants (8.4%) than public components (34.0% and 21.5%, respectively). Sixty percent of private components compared to 39.9% of public components aimed to demonstrate freedom from disease. In contrast, prevalence estimation and early detection were more frequently recorded as surveillance objective for public (22.7% and 11.5%) than for private components (8.6% and 3.3%). Continuous data collection was more commonly managed publicly (61.2%) than privately (39.5%), whilst repeated surveys were more predominant for private (58.6%) than public components. Risk-based strategies and multi-hazard surveillance were more often recorded for privately (66.0% and 68.1%, respectively) than for publicly managed components (53.1% and 28.6%, respectively).

Bivariate results: Species

Components targeting pigs were more likely based on additional national regulations (23.0%) than those targeting poultry (6.1%) (Table 3). The objective of demonstrating freedom from disease was more likely recorded for cattle and pigs (59.1% and 58.6%) than for poultry (15.1%). Case detection was more frequently recorded for poultry (65.1%) compared to the other three species groups, whilst prevalence estimation was more likely recorded for small ruminants (35.4%) compared to poultry (8.5%). Farm was more frequently recorded as sampling point for poultry and small ruminants (61.3 – 89.1%) than for cattle (46.0%) and pigs (37.2%), whilst abattoir was more common for surveillance components targeting pigs (38.1%) compared to poultry (10.9%). Risk-based strategies were relatively seldom recorded for pigs (50.4%), whilst multi-hazard surveillance was relatively frequent for pigs (59.0%) and cattle (44.0%). In contrast, multi-hazard surveillance was relatively uncommon for poultry (8.1%).

Bivariate results: Surveillance objective

The objective prevalence estimation was more frequently recorded by partner (72.9%) than by non-partner countries (27.1%) (Table 4). Components were more commonly implemented at the national level for the objective of demonstrating disease freedom than for early detection and at the regional level vice versa. Seventy-six percent of components with the objective of demonstrating freedom from disease were regulated by the EU compared to 45.5% of components aimed at early detection. Components aimed at early detection were more frequently regulated by national regulations or voluntary programmes than components with other objectives. At the farm level, the most frequent objectives were case detection (79.4%) and early detection (71.7%). The objective of annual surveys at insemination centres was consistently categorized as demonstrating freedom from disease (100%). Components aimed at demonstrating freedom from disease most commonly applied risk-based sampling (63.3%) and multi-hazard surveillance (59.5%) compared to other objectives (44.2 – 57.9% and 12.8 – 35.1%, respectively).

Risk-based sampling

The most frequent risk factors were production type (breeder, grower), age, region, herd size, and time period (Table 5). Of these top five risk factors, production type, age, and herd size predominantly included targeted risk-based strategies, where only a single stratum is under surveillance (e.g. only breeders or only animals above a certain age). In contrast, for the risk factor region, the component description mostly indicated stratified risk-based sampling, e.g. targeting regions with different sampling intensity depending on differences in epidemiological situation or risk of introduction. For the risk factor period, both targeted (e.g. sampling at the end of high risk period to demonstrate freedom from disease) and stratified risk-based approaches (varying sampling intensities between seasons) were reported.

DISCUSSION

To the authors' knowledge, this is the first systematic analysis of publicly and privately funded AHS components in EU Member States and Switzerland. Generating an overview of all active AHS components covering the public and private sectors and the full range of hazards and species was challenging as existence and design of surveillance components are generally not systematically documented [31]. Hence, gaps and opportunities were identified not just related to AHS design, but also to the ease and quality of data collection. This survey showed that the public and private sectors applied a range of activities at the national and regional level in addition to obligatory EU requirements. Even though data quality did not allow any in-depth between-country comparisons, observed patterns across the whole dataset are considered to provide valuable insights into how AHS was performed in 2011 in the ten study countries included in the analysis.

Differences between partner and non-partner countries

Systematic differences may exist between partner and non-partner countries due to the following reasons: Partner countries were comprised only of EU-12 Member States predominantly situated in

Central and Western Europe, who have a strong interest in animal health surveillance, which led to their participation in the RISKSUR project. This selection bias was aimed to be reduced by also incorporating EU-15 (CZ) and EU-25 (BG) Member States in the group of non-partner countries, which however also included three EU-12 Member States (DK, IE, IT) thus comprising a more heterogeneous group of Central, Southern and South-Eastern European countries. Furthermore, potential differences in the efforts of collecting the data, data accessibility and availability of contacts may have occurred given that partner countries may have had better contacts to relevant institutions and a stronger interest in data collection given their participation in the project consortium. Acknowledging these potential differences between partner and non-partner countries, we stratified descriptive results and tested for the effect of partner country (yes/no) as part of the bivariate analyses.

Descriptive results indicated significant differences between partner and non-partner countries for the variables management (category “both”), legal obligation (EU, private and none) and risk-based sampling (yes/no). The differences in management and legal obligation may indicate stronger investment of partner countries in non-EU regulated privately managed surveillance activities compared to non-partner countries. Another explanation may be that private and voluntary components were better captured in partner than non-partner countries given that data collection was highly challenging, so that a variety of information sources had to be screened and over 20 contacts were approached in some countries as part of data collection [34]. The difference in the percentage of risk-based components was not as pronounced as for the variables legal obligation and management. Avian influenza virus and Aujeszky’s disease virus were the only hazards for which the number of total components justified a comparison at the hazard level between partner and non-partner countries. For avian influenza, the difference was driven by one non-partner country recording eight surveillance components, all of which were risk-based as opposed to one to four components recorded by other countries, some of which were risk-based, whilst others were not. For Aujeszky’s disease, wildlife components were only recorded in partner countries (n = 2), none of

348 which were risk-based, and abattoir surveillance was recorded as risk-based in both non-partner
349 countries but only in one out of four partner countries recording this component. Therefore, we
350 conclude that the difference can be considered as spurious given that the percentages are to some
351 degree affected by the number of recorded components.

352 Bivariate results indicated a significant effect of partner versus non-partner countries for the
353 variables management (category "both") and objective (category "prevalence estimation"), but not
354 for the four compared livestock species groups. For the variable management, the same arguments
355 apply as discussed above. The higher number of components aimed at prevalence estimation may
356 indicate that partner countries invest relatively more to assess changes in the hazard situation (e.g.
357 antimicrobial resistance).

358 *Surveillance objective and means of data collection*

359 For active surveillance components, demonstrating freedom from disease was the most common
360 objective, whilst early detection was least common. These objectives are in fact closely linked as
361 activities to demonstrate freedom from disease are generally based on annual surveys, after which
362 early detection is needed to maintain confidence in freedom until the next survey. Early detection
363 activities were underrepresented in the data as passive surveillance components were excluded a
364 priori given that they were considered too similar between countries. However, for many hazards
365 passive surveillance is the predominant early detection component as it is continuously performed
366 on a daily basis across the entire domestic (and wildlife) animal population. Furthermore, it can be
367 highly cost-effective as testing is only performed if disease is suspected. For example Welby *et al* [35]
368 estimated detection probability (component sensitivity; CSe) and cost-effectiveness (CSe/cost in
369 €1000) for three surveillance components targeting Bluetongue virus serotype 8 in Belgium and The
370 Netherlands. Based on a within-herd prevalence of 20% and the assumption that disease awareness
371 is high, passive surveillance resulted in the highest probability of detection (CSe = 0.99) as compared
372 to active cross-sectional surveys (CSe: 0.73 - 0.75) and sentinel surveillance (CSe: 0.29 – 0.33) and a

cost efficiency ratio of 1.38 as compared to 0.52 (survey) and 0.41 (sentinel). However, sensitivity of passive surveillance is influenced by the clinical effects of disease, rate of transmission, population structure (e.g. herd size, production system), disease awareness of animal owners and veterinarians, and their preparedness to report [35, 36]. Therefore, it is important to also evaluate the sensitivity of passive surveillance [36], compare strategies to enhance disease awareness (e.g. awareness campaigns, training, adequacy of compensation) and reporting, and assess the acceptability by key stakeholders [37-39]. Effective dissemination of surveillance results to farmers and the public can also enhance engagement of these stakeholders and improve participation.

Given these limitations, active surveillance and syndromic surveillance may effectively enhance early detection [29]. Syndromic surveillance is also a (near) real-time surveillance activity aimed at early detection. Compared to passive surveillance, syndromic surveillance is less observer-dependent (depending on data source) and may detect abnormalities (e.g. in animal performance) before clinical signs occur, thus potentially resulting in enhanced timeliness. As part of One Health, syndromic surveillance in animal populations also provides opportunities for the early detection of public health risks [40]. Welby *et al* [35] estimated the probability of syndromic surveillance to detect Bluetongue serotype 8 in NL as 0.98 and 0.99 for milk production data assuming a within-herd prevalence of 2% and 20%, respectively. Despite the high effectiveness that can be achieved via syndromic surveillance, its application requires access to data sources that are sensitive to changes in the level of disease in the population [40] and efficient algorithms that can detect potential outbreak signals [41]. The current study identified 19 syndromic surveillance components recorded by four of the ten study countries. Ten of these components targeted multiple diseases, e.g. emerging diseases (n = 9) or many diseases (n = 1), whereas the remaining components were hazard-specific (n = 5) or targeted disease syndromes, i.e. mastitis or metabolic disorders (n = 4). Diagnostic material and pathology examinations were mentioned as predominant data sources (n = 9). Furthermore, production data (n = 5), information from practitioners (n = 1) and information sources of government, public and charity organizations (n = 1) were recorded, whilst the remaining three

components included insufficient information on the data source. These data suggest that syndromic surveillance is not being fully utilised by all countries yet, which is also in line with Dorea *et al* [31].

Risk-based sampling and multi-hazard surveillance

For active components aimed at early detection, comprehensive coverage is generally not cost-effective as disease needs to be detected at very low prevalence to fulfil the aim of early detection [42]. Therefore, risk-based and alternative approaches (e.g. syndromic surveillance) are important to consider to enhance the likelihood of (early) detection. Efforts to demonstrate freedom from disease and detect cases also benefit from risk-based approaches, especially risk-based sampling and risk-based requirement (i.e. incorporation of historical data) [10, 43], as the aim is to detect disease rather than providing representative estimates such as for prevalence estimation. The current data indicate that 50%, 63%, and 57.9% of components with the objectives early detection, demonstrating freedom from disease, and case detection, respectively, included risk-based approaches. Risk-based strategies and multi-hazard surveillance were more commonly recorded for the private sector compared to the public sector. Since 2/3 of private components were based on EU-regulations, this may only be partly explained by less stringent legal requirements. Differences between countries in the extent components are managed publicly or privately may contribute to the higher likelihood of risk-based approaches in the private sector with some countries being more progressive than others. But the private sector may also be under higher pressure to demonstrate cost-effectiveness, which is supported by the fact that the private sector more commonly focussed on aspects with higher economic importance (e.g. cattle and pigs, demonstrating disease freedom to ensure trade). Based on these findings it is hypothesized that risk-based sampling and multi-hazard surveillance could be incorporated more strongly as part of public animal health surveillance.

Albeit risk-based sampling was recorded for more than half of components, most of these risk-based components were targeted, only focussing on one population stratum instead of adjusting

surveillance intensity according to the risk level of different strata. Whilst it may be justified in some cases to only focus on a single stratum (e.g. serological surveillance in older animals), no statement can be made on the population strata not included. Therefore targeted risk-based sampling as recorded for most of the risk-based components is in fact similar to conventional designs, just being focussed on a single population stratum. Stratified risk-based sampling in contrast distinguishes between high- and low-risk strata of the population. Since all animals have a nonzero probability of being selected, probabilistic statements can still be made for the entire population, but surveillance sensitivity can be increased given a constant sample size or sample size can be reduced at constant target sensitivity. Furthermore, stratified risk-based sampling allows maintaining low level surveillance in low-risk strata to help retain awareness and provide incentives to comply with regulations, e.g. the withdrawal period for antibiotics [27].

Movement data provide opportunities to distinguish between farms having a high risk of introduction or spread based on the frequency of in- and out-degree movements and the number and characteristics of trading partners. However, animal movements were only recorded as a risk criterion by two countries (four components), one of which only targeted high turnover premises (i.e. targeted risk-based). Hence, opportunities exist to enhance utilization of quantitative (e.g. movement data), but also qualitative data (e.g. biosecurity level) to distinguish between risk levels of different population strata. The data provided little evidence of the application of alternative approaches such as participatory [44] or event-based surveillance [45].

Legal requirements

Many EU and national legislations still prescribe what has to be done (input-based) rather than what has to be achieved (output-based) and generally focus on a single pathogen. Such input-based requirements do not provide much stimulus to evaluate alternative surveillance designs in order to identify the most cost-effective approach for the specific population to be targeted. Even though input-based standards are simple to compare between countries, they may result in low sensitivity in

449 some population strata and excessive sample numbers in others [9]. EU countries vary considerably
450 in their population structure, trading patterns, hazard situation, and risk factors. Output-based
451 standards allow tailoring surveillance to the population of interest. However, epidemiologically
452 sound application of output-based standards requires epidemiological expertise, knowledge
453 regarding the target population, good data quality, and transparency. Interestingly, more recent
454 regulations (e.g. 2006/88/EC for aquatic animals, 2007/268/EC for avian influenza virus, 1266/2007
455 for bluetongue disease virus – see Supplementary Table S2) encourage application of risk-based
456 approaches and multi-hazard surveillance, indicating that the propagation of these alternative
457 strategies in literature has informed legal requirements. Also, the new EU Animal Health Law
458 explicitly emphasizes the need to take into account the epidemiology of disease, risk factors and
459 characteristics of the target population (Article 27) and allows application of alternative strategies
460 such as accounting for historical data to maintain disease free status (Article 36(1d)). Hence, the new
461 EU Animal Health Law provides enhanced opportunities to apply alternative surveillance approaches
462 to increase effectiveness and cost-efficiency of surveillance.

463 *Importance of hazards*

464 Economic importance and zoonotic potential (7/10 of the most frequent hazards have zoonotic
465 potential) appear to be important drivers for surveillance. As a result, species with little economic
466 value such as pets and wildlife were less frequently covered, which presents another gap in
467 surveillance. For zoonotic diseases, many alternative approaches have been promoted under the
468 concept of One Health including systems thinking, participatory approaches and priority setting [46-
469 49], which can only be achieved via effective collaboration between sectors (public-private) and
470 disciplines (animal-public health). Transparent documentation of surveillance components and
471 formal assessments of the entire surveillance system for a given hazard may also provide
472 opportunities to inform or benefit from these approaches and thus possibly enhance convergence
473 between human and veterinary health agencies. Such One Health approaches are increasingly

promoted and present true opportunities to advance the effectiveness of zoonotic disease surveillance, early preparedness and protection of human and animal health in the EU.

Sources of bias

Selection bias might have occurred by including all partner countries and selecting five non-partner countries. However, a systematic and transparent selection process with clearly specified criteria was applied in an effort to minimize selection bias. Due to time and resource constraints, data collection could not be expanded to all EU Member States.

Furthermore, information bias may have occurred due to differences between countries in the availability of information and efforts made to seek additional information, centralisation of efforts, and willingness of contacts to share information. The efforts required collecting information on existing public and private surveillance activities covering all hazards and animal species exceeded expectations by far. Therefore, various grey literature sources had to be screened and contact persons approached to gather information on the full range of activities. Many countries have no centralised system capturing at least the existence and design of surveillance system activities. Furthermore, surveillance documentation was more difficult to obtain for the private than the public sector. In a post-hoc questionnaire, data collectors ranked statements that a) the existence and b) the design of surveillance was adequately documented in their country, resulting in a median rank of 4 and 3 out of 5 (range 2-5) for public and 2 for both out of 5 (range 1-4) for private components [34]. Data collection also indicated considerable differences between countries regarding evaluation and dissemination of surveillance efforts as well as collaborations between the public and private sector. Furthermore, whilst some countries have a strongly centralised system (e.g. NL, SE, UK), others are strongly decentralised (e.g. DE, ES, FR). Regional variability is more pronounced in decentralised countries, which is difficult to capture. Lastly, some countries were concerned about confidentiality, so that participation was only agreed on if data were presented in aggregated form and countries were anonymised. These challenges were reflected by a wide range in the number of

499 reported components and percentage of obligatory EU components covered in the countries'
500 datasets. This latter percentage is underestimated as it is sometimes affected by the way
501 components were split (i.e. a country merging components not merged by other countries).
502 However, completeness has affected data quality in some countries, so that results have to be
503 interpreted with care and no between-country comparisons were attempted.

504 Another major limitation related to differences in applying terminology to specific components,
505 which led to initial high variability in how variables were categorized between countries. As a result,
506 extensive consistency checks were carried out and a terminology working group established to
507 improve the comparability of data. These inconsistencies in applying terminology and general
508 inconsistencies between data collected, as shown in this study, could therefore be used as a basis to
509 argue for a standardised documentation of the design of surveillance activities within the EU.
510 Documentation guidelines or standard forms have for example been developed by EFSA for
511 surveillance of *Echinococcus multilocularis* [50] and by the EU reference laboratory for surveillance of
512 fish diseases (http://www.eurl-fish.eu/Activities/survey_and_diagnosis.aspx). But no standard
513 requirements have been agreed on, which provide sufficient information to create an informed
514 overview, but sufficient flexibility to accommodate different approaches and preserve the necessary
515 degree of confidentiality.

516 *Recommendations regarding surveillance design*

517 It is difficult to make general recommendations regarding surveillance design as it depends on many
518 factors such as the hazard and population under surveillance, the hazard situation and objective.
519 When judging surveillance design, it is important to consider the surveillance system as a whole
520 including its passive and active components as components may complement each other. This
521 systems approach allows a) identifying surveillance gaps (i.e. sectors or age groups not covered) and
522 components with sub-optimal effectiveness and b) assessing opportunities to increase effectiveness
523 and economic efficiency.

524 The effectiveness of surveillance approaches can only be optimised if various surveillance designs are
525 formally compared as demonstrated manifold in published literature over recent years. This may
526 include comparisons of different testing regimes, sampling points and risk factors, strategies to
527 enhance awareness or incorporation of historical data. Hence, systematic documentation of current
528 designs, evaluation and comparisons with alternative strategies provide opportunities to select more
529 effective and efficient surveillance approaches. However, improved transparency and documentation
530 of design details may be needed to allow applying more flexible approaches.

531 *Recommendations derived from the process of collecting the data*

532 If registration of surveillance activities at country level was centralised, this would provide an
533 overview and allow for better coordination of efforts to be made between the public and private
534 sector. Furthermore, a minimum set of design variables could be defined in advance in order to
535 achieve consistency in documentation. This could be achieved through the use of the surveillance
536 design framework developed by the RISKSUR project, which provides a tool that can be used for
537 standardised documentation of surveillance efforts (http://webtools.fp7-risksur.eu/). Also, despite a
538 common source of definitions, terminology may lead to differences in interpretations when applied
539 to specific components, as shown by this study. Therefore, illustrating the correct application of
540 terminology based on specific components may be useful to supplement definitions and thus achieve
541 better consistency (http://www.fp7-risksur.eu/terminology). Given that surveillance can be
542 perceived to be a sensitive topic, it is also important to clearly explain to contributing parties the
543 purpose and expected outcome of more transparent documentation. Confidentiality concerns may
544 limit the application of alternative strategies, as these require transparent documentation to assess
545 the adequacy of assumptions and design specifications. However, these limitations stand in contrast
546 to the claim that surveillance is a public good [51]. Hence, there is a joint responsibility to address
547 factors limiting transparent documentation of surveillance activities.

All these aspects do not just pertain to this study but may cause problems with any compilation of surveillance activities across EU Member States (e.g. EFSA reports, EU summary reports). Hence, these gaps hinder information sharing in general and limit the ability to integrate information from various sources (e.g. active/passive, public/private, different species) in a meaningful manner. It is hypothesised that increased transparency would benefit all parties by enhancing trust, facilitating meaningful comparisons, and allowing more targeted complementation of activities based on the evaluation of the entire surveillance system rather than its individual components in isolation.

Conclusions

The study identified several gaps (lack of systematic documentation, inconsistent application of terminology, little evidence of surveillance in species with low economic importance) and opportunities (e.g. better uptake of alternative methods, increased use of stratified risk-based sampling, application of novel approaches promoted as part of One Health). The greater flexibility provided by the new EU Animal Health Law means that systematic evaluation of surveillance alternatives will be required to ensure that surveillance is as efficient and effective as possible [52].

SUPPLEMENTARY MATERIAL

For supplementary material accompanying this paper visit XXX.

ACKNOWLEDGMENTS

This project has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement number 310806. The authors would also like to acknowledge all data collectors, namely Jenny Frössling (SVA), Sophie Molia (CIRAD), Iveta Karabozhilova (RVC), Jo Hardstaff (RVC), Detlef Höreth-Böntgen (FLI), Angel Ortiz-Pelaez (APHA), Mark Rigby (AHPA), Thomas Rosendal (SVA), Helene Wahlström (SVA). We would also like to acknowledge Till Itlermann for advice on statistical analysis and would like to thank the three referees for their valuable comments on the manuscript.

FINANCIAL SUPPORT

European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement number 310806.

CONFLICT OF INTEREST

None.

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TABLES

Table 1. Percentage of active surveillance components (number of recorded components / total number of recorded components) and 95% confidence intervals (95% CI) by surveillance design variables for all ten study countries and stratified by whether countries were partners of the EU-FP7 RISKSUR project or not. Components comprised active surveillance components implemented in 2011. Categories, for which confidence intervals between partner and non-partner countries did not overlap, are highlighted in grey.

Variable (n)[a]	Category	All (n = 664)	Partner (n = 421)	Non-partner (n = 243)
Species	Cattle	26.7 (23.3, 30.2)	26.8 (22.7, 31.3)	26.3 (20.9, 32.3)
(664 / 421 / 243)	Pigs	17.5 (14.7, 20.6)	17.8 (14.3, 21.8)	16.9 (12.4, 22.2)
	Poultry	16.0 (13.3, 19.0)	14.0 (10.8, 17.7)	19.3 (14.6, 24.9)
	Small ruminants	11.9 (9.5, 14.6)	11.9 (8.9, 15.4)	11.9 (8.1, 16.7)
	Wildlife	10.2 (8.0, 12.8)	11.4 (8.5, 14.8)	8.2 (5.1, 12.4)
	Equidae	6.9 (5.1, 9.1)	7.4 (5.1, 10.3)	6.2 (3.5, 10.0)
	Multi	5.4 (3.8, 7.4)	5.0 (3.1, 7.5)	6.2 (3.5, 10.0)
	Other	5.4 (3.8, 7.4)	5.7 (3.7, 8.4)	4.9 (2.6, 8.5)
Management	Public	65.4 (61.5, 69.1)	64.4 (59.6, 68.9)	67.5 (60.5, 74.0)
(615 / 418 / 197)	Private	24.7 (21.4, 28.3)	23.2 (19.2, 27.6)	27.9 (21.8, 34.7)
	Both	9.9 (7.7, 12.6)	12.4 (9.4, 16.0)	4.6 (2.1, 8.5)
Area	National	89.4 (86.8, 91.7)	87.4 (83.9, 90.4)	92.9 (88.9, 95.8)
(662 / 421 / 241)	Regional	8.6 (6.6, 11.0)	9.7 (7.1, 13.0)	6.6 (3.8, 10.6)
	Local	2.0 (1.0, 3.3)	2.9 (1.5, 4.9)	0.4 (0, 2.3)
Obligation	EU	68.4 (64.6, 71.9)	58.5 (53.6, 63.3)	86.4 (81.3, 90.6)
(645 / 417 / 228)	National	11.6 (9.3, 14.4)	12.7 (9.7, 16.3)	9.6 (6.1, 14.2)
	Regional	2.2 (1.2, 3.6)	2.6 (1.3, 4.7)	1.3 (0.3, 3.8)
	Private	7.9 (59, 13)	11.8 (8.8, 15.2)	0.9 (0.1, 3.1)

Variable (n)[a]	Category	All (n = 664)	Partner (n = 421)	Non-partner (n = 243)
	None	9.9 (77, 125)	14.4 (11.2, 18.1)	1.8 (0.5, 4.4)
Objective	Disease freedom	43.8 (399, 476)	41.7 (36.9, 46.6)	47.3 (40.8, 53.8)
(656 / 417 / 239)	Case detection	26.8 (23.5, 30.4)	26.9 (22.7, 31.4)	26.8 (21.3, 32.9)
	Prevalence estimation	19.7 (16.7, 22.9)	22.5 (18.6, 26.9)	14.6 (10.4, 19.8)
	Early detection	9.8 (7.6, 12.3)	8.9 (6.3, 12.0)	11.3 (7.6, 16.0)
Sampling point	Farm	48.6 (44.7, 52.5)	47.2 (42.2, 52.2)	51.0 (44.5, 57.5)
(646 / 405 / 241)	Abattoir	21.4 (18.3, 24.7)	23.0 (19.0, 27.4)	18.7 (14.0, 24.2)
	Insemination	15.6 (12.9, 18.7)	14.8 (11.5, 18.7)	17.0 (12.5, 22.4)
	Wild	8.5 (6.5, 10.9)	8.4 (5.9, 11.5)	8.7 (5.5, 13.0)
	Rendering	3.7 (2.4, 5.5)	4.0 (2.3, 6.3)	3.3 (1.4, 6.4)
	Other	2.2 (1.2, 3.6)	2.7 (1.4, 4.8)	1.2 (0.3, 3.6)
Study type	Continous	56.8 (52.9, 60.6)	59.0 (54.1, 63.8)	52.9 (46.4, 59.4)
(655 / 415 / 240)	Survey	39.2 (35.5, 43.1)	35.9 (31.3, 40.7)	45.0 (38.6, 51.5)
	Other	4.0 (2.6, 5.8)	5.1 (3.2, 7.6)	2.1 (0.7, 4.8)
Case definition	Lab: Pathogen / toxin	42.9 (39.1, 46.8)	45.3 (40.5, 50.2)	38.7 (32.4, 45.2)
(655 / 417 / 238)	Lab: Host response	37.9 (34.1, 41.7)	34.8 (30.2, 39.6)	43.3 (36.9, 49.8)
	Both	7.6 (5.7, 9.9)	5.5 (3.5, 8.2)	11.3 (7.6, 16.1)
	Clinical / pathological	2.9 (1.8, 4.5)	3.8 (2.2, 6.2)	1.3 (0.3, 3.6)
	Other	8.7 (6.7, 11.1)	10.6 (7.8, 13.9)	5.5 (2.9, 9.2)
Risk-based	Yes	57.1 (53.2, 61.0)	52.1 (47.1, 57.0)	66.2 (59.7, 72.3)
(641 / 413 / 228)	No	42.9 (39.0, 46.8)	47.9 (43.0, 52.9)	33.8 (27.7, 40.3)
Multi-hazard	Yes	37.3 (33.4, 41.4)	40.4 (35.5, 45.4)	30.6 (24.0, 37.8)
(579 / 396 / 183)	No	62.7 (58.6, 66.6)	59.6 (54.6, 64.5)	69.4 (62.2, 76.0)

[a] Number of observations for those categories listed for the respective variable. The difference in observations compared to the number provided below the heading of 3rd to 5th column comprises the number of missing observations per category.

Table 2. Column percentages and adjusted residuals (in brackets)[a] of *management* versus variables for active surveillance components in 2011 recorded by 10 study countries included in the study (n = 615).

Variable	Category	Public	Private	Both
Partner country	Yes	66.9 (-0.77)	63.8 (-1.26)	**85.3 (3.05)**
(n = 615)	No	33.1 (0.77)	36.2 (1.26)	**14.8 (-3.05)**
Species group	Cattle	**34.0 (-2.43)**	**46.6 (2.25)**	42.2 (0.53)
(n = 441)	Pigs	23.8 (0.39)	22.9 (-0.07)	20.0 (-0.53)
	Poultry	20.8 (-0.35)	22.1 (0.27)	22.2 (0.16)
	Small ruminants	**21.5 (3.09)**	**8.4 (-3.13)**	15.6 (-0.27)
Geographical focus	National	**89.3 (-3.27)**	**97.2 (2.70)**	96.5 (1.33)
(n = 595)	Regional	**10.7 (3.27)**	**2.8 (-2.70)**	3.5 (-1.33)
Obligation	EU	**72.3 (2.85)**	65.8 (-0.79)	**49.2 (-3.40)**
(n = 610)	National or regional	**16.4 (2.37)**	**5.9 (-3.29)**	18.0 (0.97)
	Private or voluntary	**11.3 (-5.63)**	**28.3 (3.95)**	**32.8 (3.25)**
Surveillance objective	Disease freedom	**39.9 (-3.00)**	**59.9 (4.48)**	32.7 (-1.80)
(n = 608)	Case detection	25.9 (-1.05)	28.3 (0.32)	34.6 (1.26)
	Prevalence estimation	**22.7 (3.00)**	**8.6 (-3.86)**	23.6 (0.87)
	Early detection	**11.5 (2.68)**	**3.3 (-2.92)**	9.1 (-0.03)
Sampling point	Farm	58.0 (1.48)	**43.8 (-3.32)**	**70.0 (2.40)**
(n = 535)	Abattoir	**30.5 (5.27)**	**8.3 (-4.89)**	16.7 (-1.24)
	Rendering plant	5.1 (1.52)	0.0 (-2.91)	8.3 (1.75)
	Insemination centre	**6.3 (-8.58)**	**47.9 (11.31)**	**5.0 (-2.69)**
Study design	Continuous	**61.2 (4.42)**	**39.5 (-4.35)**	50.0 (-0.75)
(n = 609)	Survey	**33.6 (-5.16)**	**58.6 (5.06)**	46.6 (0.90)
	Other	5.3 (1.67)	2.0 (-1.62)	3.5 (-0.33)
Case definition	Direct	**66.1 (2.77)**	**37.4 (-3.04)**	50.1 (1.01)
(n = 556)	Serological	**23.2 (-2.64)**	**54.7 (4.21)**	**36.3 (-2.15)**
	Both	7.1 (-0.42)	**3.6 (-2.44)**	**10.8 (2.48)**

	Clinical / pathological	3.6 (0.15)	4.3 (0.83)	2.8 (-0.85)
Risk-based	Yes	**53.1 (-2.42)**	**66.0 (2.66)**	56.7 (0.00)
(n = 600)	No	**46.9 (2.42)**	**34.0 (-2.66)**	43.3 (0.00)
Multi-hazard	Yes	**28.6 (-6.58)**	**68.1 (8.15)**	31.7 (-1.21)
(n = 548)	No	**71.4 (6.58)**	**31.9 (-8.15)**	68.3 (1.21)

[a] Adjusted residuals greater than ±1.96 were highlighted in bold as they are more extreme than what would be expected if the null hypothesis of independence was true.

761 Table 3. Column percentages and adjusted residuals (in brackets)[a] of livestock *species* versus variables

762 for active surveillance components in 2011 recorded by 10 study countries (n = 487).

Variable	Category	Cattle	Pigs	Poultry	Small ruminants
Partner country	Yes	64.5 (0.75)	64.7 (0.57)	55.7 (-1.63)	63.3 (0.17)
(n = 487)	No	35.5 (-0.75)	35.3 (-0.57)	44.3 (1.63)	36.7 (-0.17)
Geographical	National	92.9 (-0.12)	89.0 (-1.89)	**100.0 (3.20)**	89.6 (-1.29)
focus (n = 474)	Regional	7.1 (0.12)	11.0 (1.89)	**0.0 (-3.20)**	10.4 (1.29)
Obligation	EU	68.1 (-0.51)	**59.3 (-2.70)**	**86.7 (4.17)**	65.8 (-0.78)
(n = 472)	National or regional	11.5 (-0.92)	**23.0 (3.46)**	**6.1 (-2.36)**	12.7 (-0.20)
	Private or voluntary	20.3 (1.45)	17.7 (0.17)	**7.1 (-2.96)**	21.5 (1.13)
Surveillance	Disease freedom	**59.1 (4.36)**	**58.6 (2.97)**	**15.1 (-7.35)**	41.8 (-0.94)
objective	Case detection	**14.5 (-4.71)**	**17.2 (-2.59)**	**65.1 (10.18)**	**16.5 (-2.21)**
(n = 487)	Prevalence estimation	21.0 (0.83)	14.7 (-1.39)	**8.5 (-3.14)**	**35.4 (4.04)**
	Early detection	5.4 (-1.57)	9.5 (0.77)	11.3 (1.53)	6.3 (-0.53)
Sampling point	Farm	**46.0 (-3.07)**	**37.2 (-4.40)**	**89.1 (7.36)**	61.3 (1.20)
(n = 456)	Abattoir	20.5 (-0.60)	**38.1 (4.78)**	**10.9 (-2.87)**	14.7 (-1.66)
	Rendering plant	6.3 (1.33)	**0.9 (-2.18)**	**0.0 (-2.36)**	**12.0 (3.34)**
	Insemination centre	**27.3 (3.87)**	23.9 (1.73)	**0.0 (-5.10)**	12.0 (-1.57)
Study design	Continuous	51.6 (-0.55)	55.7 (0.60)	60.4 (1.67)	43.4 (-1.87)
(n = 481)	Survey	44.6 (0.24)	41.7 (-0.53)	37.7 (-1.44)	54.0 (1.93)
	Other	3.8 (0.92)	2.6 (-0.22)	1.9 (-0.71)	2.6 (-0.16)
Case definition	Direct	**36.0 (-2.20)**	**24.6 (-4.48)**	**71.8 (6.75)**	44.9 (0.38)
(n = 452)	Serological	**55.3 (2.30)**	**60.9 (3.11)**	**24.3 (-5.49)**	46.2 (-0.36)
	Both	7.5 (0.67)	10.0 (1.76)	**1.9 (-2.11)**	5.1 (-0.51)
	Clinical / pathological	1.2 (-1.39)	4.6 (1.42)	1.9 (-0.51)	3.9 (0.72)
Risk-based	Yes	65.6 (1.23)	**50.4 (-2.95)**	62.3 (0.05)	71.1 (1.76)

(n = 477)	No	34.4 (-1.23)	**49.6 (2.95)**	37.7 (-0.05)	29.0 (-1.76)
Multi-hazard	Yes	**44.0 (2.61)**	**59.0 (5.44)**	**8.1 (-6.64)**	**25.0 (-2.09)**
(n = 426)	No	**56.0 (-2.61)**	**41.0 (-5.44)**	**91.9 (6.64)**	**75.0 (2.09)**

763 [a] Adjusted residuals greater than ±1.96 were highlighted in bold as they are more extreme than what would be

764 expected if the null hypothesis of independence was true.

765

766 Table 4. Column percentages and adjusted residuals (in brackets)[a] of *surveillance objective* versus
767 variables for active surveillance components in 2011 recorded by 10 study countries (n = 656).

Variable	Category	Case detection	Early detection	Disease freedom	Prevalence estimation
Partner country	Yes	63.6 (0.02)	57.8 (-1.01)	60.6 (-1.38)	**72.9 (2.45)**
(n = 656)	No	36.4 (-0.02)	42.2 (1.01)	39.4 (1.38)	**27.1 (-2.45)**
Geographical focus	National	91.2 (-0.36)	**84.4 (-2.29)**	**95.7 (3.11)**	88.0 (-1.74)
(n = 636)	Regional	8.8 (0.36)	**15.6 (2.29)**	**4.3 (-3.11)**	12.0 (1.74)
Obligation	EU	65.5 (-0.96)	**45.5 (-3.83)**	**76.4 (3.86)**	64.6 (-1.04)
(n = 636)	National or regional	13.2 (-0.21)	**23.6 (2.25)**	11.4 (-1.47)	15.0 (0.47)
	Private or voluntary	21.3 (1.35)	**30.9 (2.63)**	**12.1 (-3.37)**	20.5 (0.84)
Sampling point	Farm	**79.4 (7.28)**	**71.7 (2.37)**	**40.4 (-6.31)**	46.9 (-1.94)
(n = 574)	Abattoir	19.4 (-1.40)	23.9 (0.10)	**19.2 (-2.09)**	**38.1 (4.12)**
	Rendering plant	**1.3 (-2.18)**	4.4 (0.06)	**1.2 (-3.22)**	**15.0 (6.44)**
	Insemination centre	**0.0 (-6.84)**	**0.0 (-3.25)**	**39.2 (12.31)**	**0.0 (-5.45)**
Study design	Continuous	**69.9 (4.01)**	**73.4 (2.80)**	**36.3 (-9.42)**	**77.3 (5.19)**
(n = 649)	Survey	**28.3 (-3.36)**	**0.0 (-6.74)**	**62.7 (10.92)**	**20.3 (-4.83)**
	Other	1.7 (-1.78)	**26.6 (9.69)**	**1.1 (-3.38)**	2.3 (-1.07)
Case definition	Direct	**68.6 (6.36)**	**24.0 (-3.38)**	**27.6 (-8.64)**	**72.8 (6.20)**
(n = 592)	Serological	**24.4 (-5.17)**	44.0 (0.32)	**60.7 (8.53)**	**20.2 (-5.23)**
	Both	4.5 (-1.93)	**20.0 (3.22)**	10.3 (1.80)	**2.6 (-2.38)**
	Clinical / pathological	2.6 (-0.53)	**12.0 (3.69)**	**1.5 (-2.21)**	4.4 (0.79)
Risk-based	Yes	57.9 (0.37)	50.0 (-1.14)	**63.3 (2.97)**	**44.2 (-3.21)**

(n = 635)	No	42.1 (-0.37)	50.0 (1.14)	**36.7 (-2.97)**	**55.8 (3.21)**
Multi-hazard	Yes	**18.7 (-5.37)**	35.1 (-0.22)	**59.5 (9.83)**	**12.8 (-5.95)**
(n = 571)	No	**81.3 (5.37)**	64.9 (0.22)	**40.5 (-9.83)**	**87.2 (5.95)**

768 [a] Adjusted residuals greater than ±1.96 were highlighted in bold as they are more extreme than what would be

769 expected if the null hypothesis of independence was true.

770

771 Table 5. Percentage of risk-based sampling components (n = 366) stratified by risk factor (95% CI: 95%
772 confidence interval). Multiple selections of risk factors per components were allowed. The risk-based
773 components were a subset of active surveillance components (n = 664) recorded for 10 study countries
774 for the year 2011.

Risk factor	Percentage of components (95% CI)	Main type	Comments (remaining components either other type or unknown)
Production type	45.1% (39.9%, 53%)	Targeted	142/165: Only breeding animals; 96/142: Surveillance in artificial insemination centres
Age	24.3% (2%, 29.0%)	Targeted	36/89: Serological components targeting only older animals; 37/89: BSE/scrapie components targeting older animals only
Region	13.1% (9.8%, 17.0%)	Stratified	27/48: Surveillance intensity depended on epidemiological situation in the region
Herd size	11.2% (8.2%, 14.9%)	Targeted	37/41: Only large sized farms were targeted
Time period	6.0% (3.8%, 9.0%)	Varies	Restricted to high-risk period (e.g. demonstrate freedom at end of high-risk period) or different sampling intensity between seasons
Production for human consumption	3.6% (1.9%, 6.0%)	Targeted	
Farm factors	3.8% (2.1%, 6.3%)	Varies	5/13: Targeting only outdoor farms
Species	2.5% (1.1%, 4.6%)	Varies	Since components were generally split by species, this risk factor was predominantly recorded for avian influenza (distinction between wild bird and waterfowl species)
Event	2.2% (9%, 4.3%)	Targeted	Testing prior to transport

Disease status of the herd	2.2% (9%, 4.3%)	Targeted	E.g. certified free herds versus non-free herds
Trade	1.1% (3%, 2.8%)	Varies	Trade volume (e.g. out-degree movements)
Previous	2.2% (9%, 4.3%)	Stratified	Previous irregularities or positive findings
Various	8% (2%, 2.4%)	NA[a]	
Unknown	1.9% (8%, 3.9%)	NA[a]	

775 [a] Not applicable.