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# Assessment of biosecurity and control measures to prevent incursion and to limit spread of emerging transboundary animal diseases in Europe: An expert survey

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ABSTRACT

Decision-makers and risk managers are often called upon to prioritise on and recommend suitable measures to prevent the risk of introduction and spread of pathogens. The main objective of this study was to assess the perceptions of experts in Italy, Switzerland and the United Kingdom concerning the importance, effectiveness, feasibility, costs and acceptability of selected biosecurity measures to prevent the introduction and limit the spread of rabies, blue tongue (BT) and classical swine fever (CSF).

After identifying the most relevant measures by the project team, an expert knowledge elicitation was implemented through a questionnaire. After preliminary descriptive analyses, a number of statistical calculations were performed such as weighted medians, Spearman rank correlation tests, Wilcoxon comparison tests and ranking of measures.

Three experts from each country completed the questionnaires, one expert for each disease. The mean answer rates for CSF, BT and rabies were 73%, 100% and 99% respectively. "Tracing system for live animal trade" was highlighted as very relevant in all diseases. The implementation of a "restriction zone after a suspicion or confirmation" was also rated as a relevant measure, especially for CSF. We identified generally a small correlation between costs and the other criteria. Among the rabies experts, measures related to "zoonotic risk" were rated highly, supporting the idea of a One Health approach. Disagreement among experts concerned 43 measures for the three pathogens: the debated measures were "control of the wildlife CSF status", "arthropod-vector control" and "rabies vaccination for domestic animals".

Facing budget restriction, decision-makers need to prioritise their actions and make efficient prevention choices. With this study, we aimed to provide elements for reflection and to inform priority setting. The results can be applied through the implementation of similar surveys or directly from the knowledge already gathered in this study.



## 1. Introduction

In the context of animal health and production, biosecurity is defined as the sum of activities implemented to prevent, control and/or manage risks associated with specific hazards (e.g. infectious agents) [1,2]. Biosecurity measures can be applied at different levels (e.g. national, regional and farm level) to prevent the risks of introduction and limit the spread of pathogens.

The implementation of some biosecurity measures is strongly linked to policy and regulatory frameworks from national, European, and/or international authorities (e.g. livestock trade control, mandatory within the European Union). Disease control measures, including immediate event-based biosecurity measures, are usually part of national contingency plan and defined in European and international laws. Other activities are only recommended by national authorities and, in this case, voluntarily applied by stake-

*Abbreviations:* CSF, classical swine fever; BT, Blue Tongue; UK, United Kingdom; IT, Italy; CH, Switzerland.

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holders (e.g. all-in-all-out procedures on farms). The attitude towards, and willingness to implement, specific non-compulsory biosecurity measures may be related to the perceived risk of different hazards influencing the acceptability of the measure but also to the financial burden of implementing the measure [3–5].

Decision-makers and risk managers are often called to decide upon and recommend suitable measures to prevent the risk of introduction and limit the spread of pathogens. Depending on the expected impact and consequences of the incursion of a hazard, preventive measures may be preferable to reactive measures [6]. This creates a dilemma for risk managers who have to allocate finite resources between the two activities [7]. The optimum choice depends on different factors: total costs of prevention, the chance of incursion and extent of an outbreak and the related losses [7,8]. The decision-making process must be tailored to each country according to the process in place and the husbandry particularities [9,10]. Farmers are in need of governmental intervention and decisions, a tool for common understanding and action [11].

The European research project, SPARE "Spatial risk assessment framework for assessing exotic disease incursion and spread through Europe" [12] aims to create a risk assessment framework for risk managers and readily adaptable to known, specific emerging disease or unknown hazards. This will help assure general preparedness in existing early warning systems for decision-makers.

The main objective of this study was to assess the perceptions of experts in Italy (IT), Switzerland (CH) and the United Kingdom (UK) concerning the importance, effectiveness, feasibility, costs and acceptability of selected biosecurity measures relevant to three case study pathogens selected for use throughout the SPARE project: classical rabies, bluetongue (BT) and classical swine fever (CSF) [13]. The elicitation process was implemented through an expert knowledge elicitation. The results of this study will be of value to decision-makers and other stakeholders involved in the design and implementation of biosecurity measures.

## 2. Materials and methods

### 2.1. Selection of biosecurity measures

For each case study, the selection of biosecurity measures followed a two-step approach. First, we generated an inventory of biosecurity measures to prevent the introduction and spread of pathogens at national, regional and farm level, including 343 measures. The inventory was based on authors' knowledge, a review of key scientific papers, and of national and international standards. From this inventory we selected 28 measures for CSF, 27 for rabies and 25 for BT (Tables 1–3) for further analysis, based on the authors' expertise and outputs from the literature search.

Details of the methodology are described in 'Supplementary materials'.

### 2.2. Selection of experts

Our selection targeted experts familiar with the epidemiological situation of the diseases and with procedures for risk management. All experts were contacted through the consortium network. This direct and personal contact aimed to ensure a stronger commitment from the experts as we did not provide incentives for participating. Considering recommendations from EFSA to optimize the sample size regarding the availability of experts, their interest and resources [14], we selected three experts for each disease, one expert/disease from each country.

Regarding the experts' competencies, we targeted experts employed in national veterinary services or National Reference Laboratories. Thus, we guaranteed a global overview of measures implemented in the whole country. Regional services might have a very specific implementation view that would not be reflective of the general national approach.

### 2.3. Experts' opinions

An expert knowledge elicitation was used in this study [14]. Experts' opinion was elicited via questionnaires in October-November 2016 using questionnaires sent via e-mail. No ethical approval was required for this study. However, due to the sensitivity of some data, authorities were required to adhere to country anonymity. After receiving the experts' questionnaires, telephone calls and ad-hoc meetings were organised to discuss unclear answers or doubts expressed by experts.

The questionnaires, built on a Microsoft Excel (2010) spreadsheet, contain two parts: (i) the biosecurity measures implemented in the interviewee's country and their legal framework, (ii) the assessment of these measures regarding five criteria: importance, effectiveness, feasibility, costs and acceptability (definitions in Table 6 "Supplementary materials"). The questionnaires distinguished between measures to prevent the introduction and limit the spread of the disease. The scale of assessment ranged from 0 to 3 (0 being "very poor" and 3 being "very good"). This 4-point scale was used to force experts to take a position [15]. Furthermore, each expert could rate the uncertainty of each answer on a 3-point scale (1 being "not confident" and 3 being "very confident"). Interviewees could add biosecurity measures considered important for their country but not included in this initial list. In this case the expert was also asked to rate the newly added biosecurity measure. The full questionnaires are available from the first author on request.

The questionnaires were pre-tested within the consortium (through 3 pilot interviews) to minimise question ambiguity and generally refine the opinion process.

### 2.4. Statistical analysis

The biosecurity measures implemented for each disease are different; hence the analyses were performed separately for each case study (i.e. disease). However, the methodology is consistent for all case studies.

For each biosecurity measure (of a specific disease) the expert assessment score was calculated as the median of respondent scores from all countries. If a score was missing, the expect assessment score was based only on the two other answers. To integrate uncertainty into the assessment score, a weighted median was calculated based on uncertainty scores. However, a respondent's view of uncertainty is subjective; given the same facts and opinions one respondent may still view their response to be more uncertain than another. Thus, to avoid this bias, we adopted an approach where the uncertainty about the respondent's answer was incorporated into the respondent's score (Table 4). To estimate the impact of the uncertainty, we compared the non-weighted and weighted medians with a Wilcoxon-Mann-Whitney test.

A non-parametric Spearman's rank correlation test was performed to assess the correlation among the weighted medians related to the five criteria (importance, effectiveness, feasibility, costs and acceptability). To assess inter-expert agreement, the absolute value of difference between scores was calculated for each pair of experts, each criterion and each disease.

To compare each biosecurity measure, an overall score was calculated based on the weighted medians of the five criteria. This score is based on the surface area when the weighted medians are represented in a radar diagram (detailed in "Supplementary materials"). The larger the median scores for each criterion are,

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**Table 1**
Weighted medians of the perceived importance, effectiveness, feasibility, costs and acceptability of biosecurity measures against the introduction and spread of Classical Swine Fever in Italy, Switzerland and the United Kingdom.

| | Biosecurity category and measures | Perceived Importance wMed (Min – Max) | Perceived Effectiveness wMed (Min – Max) | Perceived Feasibility wMed (Min – Max) | Perceived Costs wMed (Min – Max) | Perceived Acceptability wMed (Min – Max) | Surface |
|---|---|---|---|---|---|---|---|
| | PREVENT INTRODUCTION | | | | | | |
| 1- | *Animal movements - Live animals trade (farm and wildlife animals)* | | | | | | |
| N/R | Reinforce controls of animal imports at hunting parks | 1 (0-1) | NA | 2 (2-2) | 1 (1-1) | 3 (3-3) | 3.8 |
| N | Reinforce control and surveillance of trade movements of live-animals at borders | 2.5 (2-3) | 3 (3-3) | 2 (2-3) | 1 (1-1) | 3 (2-3) | 12.4 |
| mF | Keep updated records of exchanges and trades in the farm | 3 (3-3) | 2 (2-2) | 3 (3-3) | 2 (2-2) | 3 (2-3) | 15.7 |
| F | Assure that replacement animals are sourced from establishment with equal or superior health status | 3 (3-3) | 3 (2-3) | 3 (2-3) | 2 (1-2) | 2 (2-3) | 16.2 |
| F | Implement a systematic quarantine for new pigs arriving at the farm | 3 (2-3) | 2 (2-2) | 1 (1-2) | 1 (1-2) | 2 (1-2) | 8.1 |
| F | Closed herd or all-in-all-out replacement | 2 (2-3) | 2 (2-2) | 2 (1-2) | 1 (1-2) | 1.5 (1-2) | 6.9 |
| 2- | *Animal products - Animal products trade* | | | | | | |
| N | Reinforce control and surveillance of trade movements of animal products at borders | 2.5 (2-3) | 3 (3-3) | 2.5 (2-3) | 2 (1-2) | 2 (2-2) | 13.8 |
| F | Limit exchanges of milk, semen and embryos between farms | 2 (2-2) | 2 (2-2) | 2 (2-3) | 2.5 (2-3) | 2 (2-2) | 10.5 |
| 3- | *Animal products – animal nutrition* | | | | | | |
| F | Ban feeding animals with animal products | 3 (3-3) | 3 (3-3) | 3 (3-3) | 3 (2-3) | 2 (2-2) | 18.5 |
| 4- | *Vehicle movements - Facilities* | | | | | | |
| F | Limit direct and indirect contacts between vehicles and animals, feed and water | 3 (2-3) | 2 (2-2) | 2 (2-3) | 2 (2-2) | 2 (2-2) | 11.4 |
| F | Limit the use of shared vehicles between farms | 3 (2-3) | 2 (2-2) | 2 (2-2) | 2 (2-2) | 1.5 (1-2) | 10.2 |
| mF | Cleaning and disinfection of the vehicle | 3 (3-3) | 2 (2-2) | 3 (3-3) | 2 (2-2) | 3 (2-3) | 15.7 |
| 5- | *Biosafety* | | | | | | |
| m | Implement good biosafety measures when transporting samples and carcasses | 3 (2-3) | 2 (2-2) | 3 (3-3) | 1 (1-2) | 3 (2-3) | 12.8 |
| 6- | *People movements - Facilities and best practices* | | | | | | |
| F | In-house or clean boots and clothes for visitors | 3 (2-3) | 2.5 (2-3) | 3 (2-3) | 2 (2-2) | 2 (2-2) | 14.7 |
| F | Access restriction for visitors* | 3 (2-3) | 2.5 (2-3) | 2 (2-2) | 3 (1-3) | 2 (2-2) | 14.5 |
| 7- | *Wildlife and hunting procedures - Reduction of infection pressure* | | | | | | |
| N/R | Implement control of wildlife population density** | 2 (0-3) | 0 (0-0) | 2 (1-2) | 2 (2-2) | 2 (0-2) | 5.7 |
| F | Prevention of contacts with wild animals** | 3 (1-3) | 2 (0-2) | 1 (1-2) | 1.5 (1-2) | 2 (1-2) | 8.8 |
| 8- | *Wildlife and hunting procedures – animal health* | | | | | | |
| N/R | Implement vaccination of wild animals population * | 1 (0-2) | 0 (0-0) | 0.5 (0-1) | 1 (1-1) | 2.5 (2-3) | 2.6 |
| N/R | Implement health surveillance of wild animals* | 2.5 (1-3) | 1 (1-1) | 2 (1-2) | 2 (2-2) | 3 (3-3) | 10.5 |
| 9- | *Wildlife and hunting procedures - awareness* | | | | | | |
| N/R | Awareness campaign among hunting tourists | 3 (3-3) | NA | 3 (3-3) | 2 (2-2) | 3 (3-3) | 10 |
| N/R | Awareness of secured practices for hunting procedures | 3 (3-3) | NA | 3 (3-3) | 2 (2-2) | 2 (2-2) | 7.6 |
| | PREVENT SPREAD | | | | | | |
| 10- | *Animal movements - Live animals trade (farm and wildlife animals)* | | | | | | |
| mR | Restrict the movement of live animals in a dedicated area if CSF is confirmed in a farm* | 3 (3-3) | 3 (3-3) | 3 (3-3) | 2 (0-2) | 3 (3-3) | 18.5 |
| R | Restrict the movement of live animals in a dedicated area if CSF is suspected in a farm* | 3 (2-3) | 3 (3-3) | 3 (3-3) | 2 (0-2) | 3 (3-3) | 18.5 |
| F | Provide good condition of isolation for suspicious animals at the farm | 3 (2-3) | 3 (2-3) | 3 (2-3) | 2 (2-2) | 3 (3-3) | 18.5 |
| 11- | *Animal products trade* | | | | | | |
| mR | Restrict the movement of animal products and by-products in a dedicated area if CSF is confirmed in a farm | 3 (3-3) | 3 (3-3) | 3 (3-3) | NA | 3 (3-3) | 12.8 |
| R | Restrict the movement of animal products and by-products in a dedicated area if CSF is suspected in a farm | 3 (3-3) | 3 (3-3) | 3 (3-3) | 2 (1-2) | 3 (3-3) | 18.5 |
| 12- | *Biosafety* | | | | | | |
| mF | Implement a stamping out procedure at farm according to the epidemiological situation if CSF is confirmed in a farm | 3 (3-3) | 3 (3-3) | 3 (3-3) | 1 (0-1) | 3 (3-3) | 15.7 |
| 13- | *Windborne spread - Facilities and best practices* | | | | | | |
| F | Maintain good practices for spray of manure in fields | 2 (1-2) | 2 (2-2) | 3 (2-3) | 2 (2-2) | 3 (2-3) | 13.3 |

*,**: Measures with a strong disagreement among the experts, on 1 or 2 criteria
N: implementation at national level; R: implementation at regional level; F: implementation at farm level;
m: mandatory in all three countries
NA: no answer

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**Table 2**
Weighted medians of the perceived importance, effectiveness, feasibility, costs and acceptability of biosecurity measures against the introduction and spread of Bluetongue in Italy, Switzerland and the United Kingdom.

| | **Biosecurity category and measures** | Perceived Importance wMed (Min – Max) | Perceived Effectiveness wMed (Min – Max) | Perceived Feasibility wMed (Min – Max) | Perceived Costs wMed (Min – Max) | Perceived Acceptability wMed (Min – Max) | **Surface** |
|---|---|---|---|---|---|---|---|
| | PREVENT INTRODUCTION | | | | | | |
| 1- | *Arthropods vectors direct transmission and windborne spread – Vector control in environment* | | | | | | |
| N | Control of vectors presence in vehicles for animal transportation (planes, trucks)* | 2 (2-2) | 2 (1-2) | 3 (2-3) | 2 (1-2) | 1 (1-3) | 9.5 |
| N/R | Vector density control in at-risk areas (e.g. near water points, wet-lands etc.)**** | 2 (0-2) | 1 (0-1) | 1 (0-2) | 1 (1-1) | 1 (0-2) | 3.3 |
| 2- | *Arthropods vectors direct transmission and windborne spread – Facilities and best practices* | | | | | | |
| F | Elimination of all breeding grounds (e.g. stagnant water)*** | 1 (0-3) | 1 (0-1) | 1 (0-2) | 1 (1-2) | 1 (1-2) | 2.4 |
| F | Arthropod control on susceptible ruminants (e.g. use of insecticides or insect repellents) | 2 (1-2) | 1 (1-1) | 2 (2-2) | 1 (1-1) | 2 (1-2) | 5.7 |
| F | Closed ventilation system at farm | 1 (1-1) | 1 (1-1) | 1 (1-1) | 1 (1-1) | 1 (0-1) | 2.4 |
| F | Adoption of best husbandry practices to limit the contact of animals with vectors (e.g. smoke against vectors, restricted areas for pastures where ticks are presents…)**** | 2 (0-2) | 1 (0-1) | 1 (0-2) | 2 (2-2) | 0 (0-2) | 2.4 |
| F | Separate different species of susceptible ruminants*** | 1 (0-2) | 0 (0-0) | 1 (1-2) | 2 (2-2) | 2 (1-3) | 3.8 |
| 3- | *Arthropods vectors direct transmission and windborne spread – Animal health* | | | | | | |
| N/R | Implement a preventive vaccination campaign of all susceptible species** | 3 (3-3) | 3 (2-3) | 2 (1-3) | 2 (0-2) | 2 (2-2) | 13.8 |
| N/R | Implement a preventive vaccination campaign of sheep only*** | 3 (1-3) | 2 (1-3) | 2 (1-3) | 2 (1-2) | 2 (1-2) | 11.4 |
| 4- | *Arthropods vectors direct transmission and windborne spread – Pastures management* | | | | | | |
| F | Avoid low-lying wet pastures with high density of vectors (during summer)** | 2 (0-3) | 1 (0-1) | 1 (1-1) | 2 (1-2) | 1 (0-1) | 4.3 |
| F | Stabling animals from late afternoon till morning (during summer) | 2 (2-2) | 1.5 (1-2) | 2 (1-2) | 2 (2-2) | 2 (1-2) | 8.6 |
| 5- | *Livestock trade – Live animals trade (farm animals)* | | | | | | |
| mN | Establish/reinforce an origin tracing system for live-animal trade | 3 (3-3) | 3 (2-3) | 3 (3-3) | 2 (2-2) | 2 (2-3) | 16.2 |
| mN | Establish/reinforce monitoring of trade movements of animals at national borders inspection posts | 3 (3-3) | 3 (2-3) | 3 (3-3) | 2 (2-2) | 2 (2-3) | 16.2 |
| N | Implement a systematic quarantine for susceptible ruminants from at-risk areas** | 2 (2-3) | 2 (1-2) | 2 (1-3) | 2 (2-2) | 1 (1-2) | 7.6 |
| N/R | Reinforce surveillance of animals in important trade/exchange areas (markets, trade shows, sales)* | 2 (1-3) | 2 (2-2) | 2 (2-2) | 2 (2-2) | 2 (2-2) | 9.5 |
| F | Purchase animals from farm with known disease status or health certificate* | 2 (2-3) | 2 (2-2) | 2 (1-3) | 2 (2-2) | 2.5 (2-3) | 10.5 |
| F | Quarantine new arrival animals | 2 (1-3) | 2 (1-2) | 1 (1-2) | 2 (2-2) | 2 (2-2) | 7.6 |
| 6- | *Livestock trade – BT case suspicion* | | | | | | |
| mF | Establish a Temporary Control Zone (TCZ) of an appropriate size to contain the disease around the premises if BTV is suspected in a farm (i.e. no susceptible ruminants are permitted to move to or from any premises within this zone) | 3 (2-3) | 3 (2-3) | 3 (2-3) | 1 (1-2) | 2 (2-2) | 13.8 |
| 7- | *Animal products - Trade* | | | | | | |
| mN | Establish an origin tracing system for animal product trade** | 3 (1-3) | 2 (1-3) | 3 (2-3) | 2 (1-2) | 3 (2-3) | 15.7 |
| F | Enhance control on origin of semen imported for artificial insemination** | 3 (1-3) | 2 (1-3) | 3 (2-3) | 2 (2-2) | 3 (2-3) | 15.7 |
| | PREVENT SPREAD | | | | | | |
| 8- | *Arthropods vectors direct transmission and windborne spread – Affected farms* | | | | | | |
| F | Implement a stamping out procedure in affected farm* | 1 (0-2) | 1 (1-1) | 2 (1-2) | 1 (0-1) | 0.5 (0-1) | 2.9 |
| F | Implement good biosafety measures when transporting samples and carcasses** | 3 (1-3) | 2 (1-3) | 2 (2-3) | 2 (2-2) | 2 (2-3) | 11.4 |
| F | Clean and disinfect the farm after the implementation of stamping out procedures*** | 1 (0-2) | 1 (0-1) | 2 (2-3) | 2 (2-2) | 0 (0-2) | 3.3 |
| F | Quarantine suspicious animals* | 2 (1-3) | 2 (1-2) | 2 (2-3) | 2 (2-2) | 2 (2-2) | 9.5 |
| 9- | *Livestock trade – BT case confirmation* | | | | | | |
| mF | Establish a Restricted Zone, including a Protection Zone and a Surveillance Zone (with a depth beyond the protection zone) if BTV is confirmed in a farm (i.e. the movement of susceptible animals, semen, ovum or embryos out of a restricted zone will be banned, except under licence (or a health certificate if to another Member State) to limit the risk of further spread) | 3 (2-3) | 3 (3-3) | 3 (3-3) | 1 (1-2) | 2 (2-2) | 13.8 |

*, **, ***, ****: Measures with a strong disagreement among the experts, on 1 to 4 criteria
N: implementation at national level; R: implementation at regional level; F: implementation at farm level
m: mandatory in all three countries

**Table 3**
Weighted medians of the perceived importance, effectiveness, feasibility, costs and acceptability of biosecurity measures against the introduction and spread of Rabies in Italy, Switzerland and the United Kingdom.

| | Biosecurity category and measures | Perceived Importance wMed (Min – Max) | Perceived Effectiveness wMed (Min – Max) | Perceived Feasibility wMed (Min – Max) | Perceived Costs wMed (Min – Max) | Perceived Acceptability wMed (Min – Max) | Surface |
|---|---|---|---|---|---|---|---|
| | PREVENT INTRODUCTION | | | | | | |
| 1- | *Livestock and wild animals trade – live animals trade* | | | | | | |
| mN | Establish an origin tracing system for live-animal trade** | 3 (1-3) | 3 (3-3) | 3 (3-3) | 2 (0-2) | 3 (3-3) | 18.5 |
| mN | Establish/reinforce monitoring of trade movements of animals at national borders inspection posts* | 3 (3-3) | 3 (3-3) | 3 (3-3) | 2 (0-2) | 3 (2-3) | 18.5 |
| mN/R | Reinforce surveillance of animals in important trade/exchange areas (markets, trade shows, sales)** | 3 (1-3) | 3 (0-3) | 3 (3-3) | 1 (1-2) | 3 (2-3) | 15.7 |
| F | Purchase animals from farm with known disease status or health certificate*** | 3 (0-3) | 3 (0-3) | 3 (3-3) | 1 (1-2) | 3 (0-3) | 15.7 |
| F | Quarantine new arrival animals* | 3 (2-3) | 3 (3-3) | 2 (1-2) | 1 (1-1) | 1 (1-3) | 10 |
| 2- | *Animals contacts – animal health management* | | | | | | |
| N/R | Implement a preventive vaccination campaign of farm animals and pets in free area***** | 1 (0-2) | 2 (0-3) | 1 (0-3) | 0 (0-2) | 1 (0-3) | 2.4 |
| N/R | Implement a preventive vaccination campaign only of farm animals living in areas close to affected regions***** | 1 (0-2) | 1 (0-2) | 1 (1-3) | 1 (0-2) | 1.5 (0-2) | 2.9 |
| N/R | Implement a preventive vaccination campaign only of pets living in areas close to affected regions*** | 2 (2-3) | 3 (1-3) | 2 (2-3) | 2 (0-2) | 2 (1-3) | 11.4 |
| 3- | *Animals contacts - facilities* | | | | | | |
| F | Establish facilities to avoid contact between farm animals and wildlife | 2 (1-2) | 2 (1-2) | 1.5 (1-2) | 1 (1-2) | 1 (1-2) | 4.8 |
| F | Prevention of contact between farm animal and pets | 1 (1-2) | 1 (1-2) | 1 (1-2) | 1 (1-2) | 2 (2-3) | 3.3 |
| F | Establish facilities to quarantine new arrivals animals*** | 1 (0-1) | 1 (0-2) | 2 (1-3) | 1 (1-2) | 1 (1-3) | 3.3 |
| 4- | *Pets movement and management – pets movements* | | | | | | |
| mN | Establish/reinforce monitoring of movements of pets at border by checking pet documentation | 3 (3-3) | 3 (2-3) | 3 (3-3) | 2 (1-2) | 3 (3-3) | 18.5 |
| 5- | *Pets movement and management – pets management* | | | | | | |
| N | Implement a systematic quarantine for pets entering the country from not-free areas*** | 3 (2-3) | 3 (3-3) | 3 (1-3) | 1 (0-2) | 2 (0-3) | 13.8 |
| F | Prohibit freely roaming of pets in farm | 1 (0-1) | 1 (0-1) | 2 (1-2) | 2 (1-2) | 1 (1-1) | 4.8 |
| 6- | *Wildlife and hunting procedures – wildlife health and management* | | | | | | |
| mN | Control of stray dogs*** | 3 (1-3) | 2 (0-3) | 1 (1-2) | 2 (1-2) | 2 (1-3) | 9.5 |
| mN/R | Control wildlife population density through regulated hunting practices*** | 2 (1-3) | 1 (1-2) | 2 (1-3) | 2 (0-2) | 2 (1-2) | 7.6 |
| N/R | Implement preventive vaccination campaigns of wild carnivores (e.g. Oral foxes vaccination, OFV)** | 3 (3-3) | 3 (3-3) | 3 (1-3) | 0 (0-1) | 3 (0-3) | 12.8 |
| N/R | Reinforce controls of live-animal imports at hunting parks**** | 2 (0-3) | 2 (0-2) | 3 (0-3) | 2 (2-3) | 2 (0-3) | 11.4 |
| 7- | *Zoonotic risk - biosafety* | | | | | | |
| m | Adopting best practices when transporting samples from field to the laboratory | 3 (3-3) | 3 (3-3) | 3 (3-3) | 2 (2-2) | 3 (3-3) | 18.5 |
| 8- | *Zoonotic risk – One health* | | | | | | |
| mN/R | Establish a cooperation between public health and veterinary sectors | 3 (3-3) | 3 (3-3) | 3 (2-3) | 2 (2-2) | 3 (2-3) | 18.5 |
| 9- | *Zoonotic risk – Disease awareness* | | | | | | |
| N | Implementation of educational campaign for livestock owners** | 2 (1-3) | 3 (1-3) | 3 (2-3) | 2 (1-2) | 3 (2-3) | 15.7 |
| N | Implementation of educational campaign for pets owners | 3 (3-3) | 3 (2-3) | 3 (2-3) | 2 (1-2) | 3 (3-3) | 18.5 |
| | PREVENT SPREAD | | | | | | |
| 10- | *Animals contact – animal health management* | | | | | | |
| F | Implement stamping out procedure of infected animals** | 3 (1-3) | 2 (0-3) | 3 (3-3) | 2 (1-2) | 3 (3-3) | 15.7 |
| mF | Adequate disposal of carcasses** | 1 (1-3) | 1 (0-3) | 3 (3-3) | 2 (1-2) | 3 (3-3) | 9 |
| 11- | *Pets management* | | | | | | |
| RAA | Compulsorily keep dogs at leash in rabies affected area with high risk of contact with wildlife** | 3 (1-3) | 2 (1-3) | 3 (2-3) | 2 (2-3) | 2 (2-3) | 13.3 |
| 12- | *Wildlife and hunting practices* | | | | | | |
| RAA | Prohibition of hunting with dogs* | 1 (1-2) | 2 (1-2) | 3 (3-3) | 3 (2-3) | 2 (1-3) | 11.9 |
| 13- | *Zoonotic risk – One health* | | | | | | |
| mN/R | Strengthen cooperation between public health and veterinary sectors | 3 (2-3) | 3 (3-3) | 3 (3-3) | 2 (2-2) | 3 (3-3) | 18.5 |

*, **, ***, ****, *****: Measures with a strong disagreement among the experts, on 1 to 5 criteria
N: implementation at national level; R: implementation at regional level; F: implementation at farm level;
RAA: rabies affected area; m: mandatory in all three countries

**Table 4**
Calculation detail of the five associated values of each score according to the uncertainty. When the median is based on three scores (one by expert), the weighted median is based on the 15 new values (5 associated values by experts), determined as described in the table.

| Score given | Uncertainty | Associated five values (Values cannot exceed 3 or be negative) |
|---|---|---|
| 2 (good) | 3 (very confident) | 2, 2, 2, 2, 2 |
| 2 (good) | 2 (confident) | 1, 2, 2, 2, 3 |
| 2 (good) | 1 (not confident) | 1, 1, 2, 3, 3 |
| 0 (very poor) | 1 (not confident) | 0, 0, 0, 1, 1 |
| 2 (good) | NA[a] | 1, 1, 2, 3, 3 |
| NA[a] | 2 (confident) | Not included in the median calculation |

[a] NA: no answer.

the larger is the area of the diagram: the area can be interpreted as the experts' overall perception regarding the combined criteria.

The statistical analyses were performed in Microsoft Excel (2010).

## 3. Results

### 3.1. Survey

A total of nine experts (in each country one expert was selected for each disease) were included in the survey.

Experts were satisfied by the list of biosecurity measures selected. Four additional measures were suggested; one for rabies and three for BT. Since these measures were evaluated only by the expert who suggested them, they were not included in the general analysis but presented separately (Figs. 4 and 5 "Supplementary materials").

The answer rate per expert ranged from 36% to 100%. The mean answer rates for CSF, BT and rabies were 73%, 100% and 99% respectively. For CSF, four measures were not scored in any of the three countries (score NA in Table 1). For BT and rabies, all measures were scored by at least one expert.

The median scores weighted by the uncertainty for each assessed criterion are summarised in Table 1 for CSF, Table 2 for BT and Table 3 for rabies. The normal and weighted median showed no significant difference ($p > 0.3$). Tables differentiate between measures to prevent introduction and measures to control spread.

The radar diagrams of the measures are presented in Fig. 3 "Supplementary materials" for CSF, Fig. 4 for BT and Fig. 5 for rabies.

Ten measures were shared among at least two questionnaires (Fig. 1). In five measures, the difference of the surface area was larger than 7: this high score difference is mainly due to the small score attributed to measures to prevent BT.

Correlation results for each pathogen and between the weighted median of the criteria are presented in Fig. 2.

### 3.2. Results for CSF

The weighted medians greater than or equal to 2 ("good" score) represent 68% (87/140) of answers for all criteria. Effectiveness and costs present more variability with less than 80% of the weighted medians over a score of 2 (good).

Among all the comparisons of agreement between experts, a score difference up to 2 (strong disagreement) represents 18% (10/187) of the comparisons.

The median value of the uncertainty in each country was 2 ("confident") or 3 ("very confident"). There are no differences of uncertainty between the different criteria. Inter-expert variability was high: two experts used the whole range of scores whereas the third always chose 3 ("very confident").

### 3.3. Results for BT

The weighted medians greater than or equal to 2 represent more than 60% (15/25) of answers for each criterion. Effectiveness and acceptability present more variability with more than 36% (9/25) of the answers under a score of 2. Fifty percent (63/125) and 18% (23/125) of the weighted median among all criteria are scored respectively with a score of 2 or 3.

Among all the comparison of agreement between experts, a score difference up to 2 represents 15% (51/336) of the comparisons with a scope from 3% (assessment of costs) to 30% (assessment of importance).

The median value of the uncertainty in each country was 2 or 3. There are no differences of uncertainty between the different criteria. Inter-expert variability was high: two experts used the whole range of score whereas the third always chose 2.

### 3.4. Results for rabies

The weighted medians greater than or equal to 2 represent 75% (702/135) of answers for each criterion, with an average of 75.2% among all criteria, a maximum of 82% (22/27) for feasibility and a minimum of 63% (17/27) for the costs. Forty-four percent (60/135) and 30% (41/135) of the weighted median among all criteria are scored respectively with a score of 3 and 2.

Among all the comparisons of agreement between experts, a score difference up to 2 represents 21% (85/399) of the comparisons with a scope from 15% (12/81 for costs) to 26% (21/81 for acceptability).

The median value of the uncertainty in each country was 3. They are no differences of uncertainty between the different criteria. One expert always chose the value of 3, the others only 2 or 3.

## 4. Discussion

Studies exist on the application of biosecurity measures and farmers' perceptions [16–18], and on farmer's incentives to apply them [3,4,11,19–22]. Few studies have specifically assessed the measures [15,23]. While reviews of biosecurity measures have started to evaluate measures, the evaluations remain secondary objectives [9,24–27]. This manuscript addresses this gap, by presenting an objective method to compare biosecurity measures according to their importance, effectiveness, feasibility, costs and acceptability. This method is implemented based on an expert elicitation process, where the uncertainty of experts' responses are integrated into the final evaluation in a way that limits biasing of results due to differences in individual experts subjective assessment of uncertainty. To our knowledge the methodology applied is innovative and provided a reliable support to integrate experts' level of confidence in the process. The fact that this weighted median is not different from the normal median can be explained by the small number of participants. A total of nine experts participated in the survey, three per disease, one from each country. Because of the limited incentives for experts to participate (with no financial incentives available), we favoured direct and personal contact with the support of the consortium partners to increase their commitment and willingness to participate. However, in other financial conditions and to increase the sample size, we would have organised workshops in each of the countries for each disease, gathering all valuable experts, to complete the questionnaire. Despite the limited sample size, we still believe the number is sufficient to provide robust results. An EFSA document dis-

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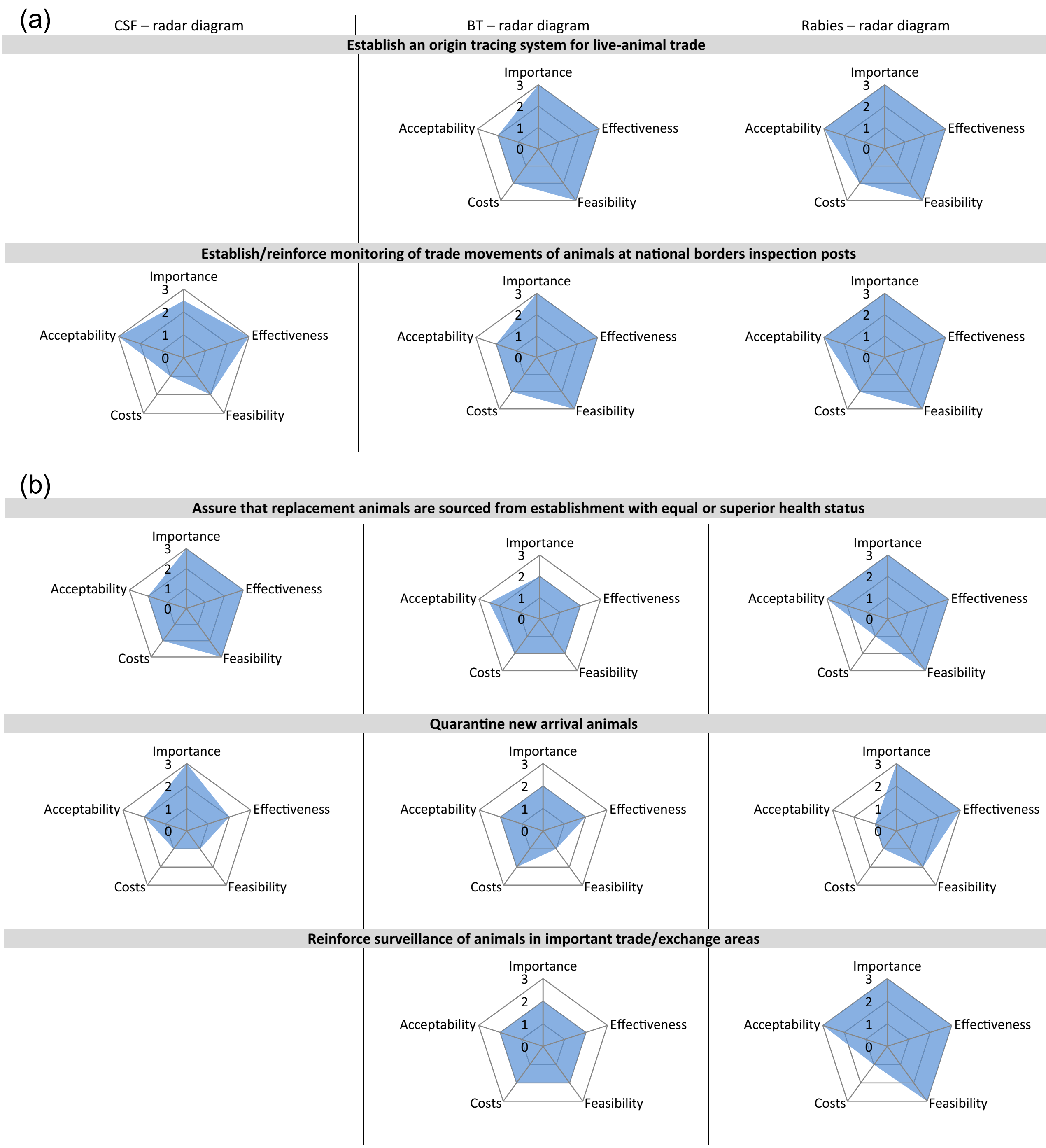


**Fig. 1.** Graphic representation of the comparable measures to prevent the introduction and limit the spread of CSF, BT and rabies in Italy, Switzerland and the United Kingdom. The graphs show the weighted median score of their perceived importance, effectiveness, feasibility, costs and acceptability.

cussing sample size for expert knowledge elicitation acknowledges the possible hurdles toward implementing an expert elicitation and provides suggestions for compromises [14]. We believe our approach is in line with the approach described in this EFSA document. Moreover, we are aware of the fact that the first expert contacted (with clear experience in biosecurity and the case study) might not be the one eventually answering the questionnaire or might have needed some help from colleagues to answer all the questions. Despite we did not encourage this compromise, we accepted it in order to increase the success rate. However the direct contact with experts aimed to address also this potential lack of expertise assuring quality in answers.

Kuster implemented a comparable study in CH [15]. They assessed importance and effectiveness of biosecurity measures. We decided to include more evaluation parameters, such as feasibility and costs. Decisions are based on several criteria, depending on the situation (e.g. during an outbreak or a "peace period"), the actors (e.g. trade or public health) or even the political situation (e.g. concern from consumers and farmers). Limiting the assessment of biosecurity to importance and effectiveness would oversimplify the problem, potentially misleading decision-makers in their choice.

All countries are free of CSF with no cases reported during the last 10 years [28,29]. Regarding BT, all three countries experienced

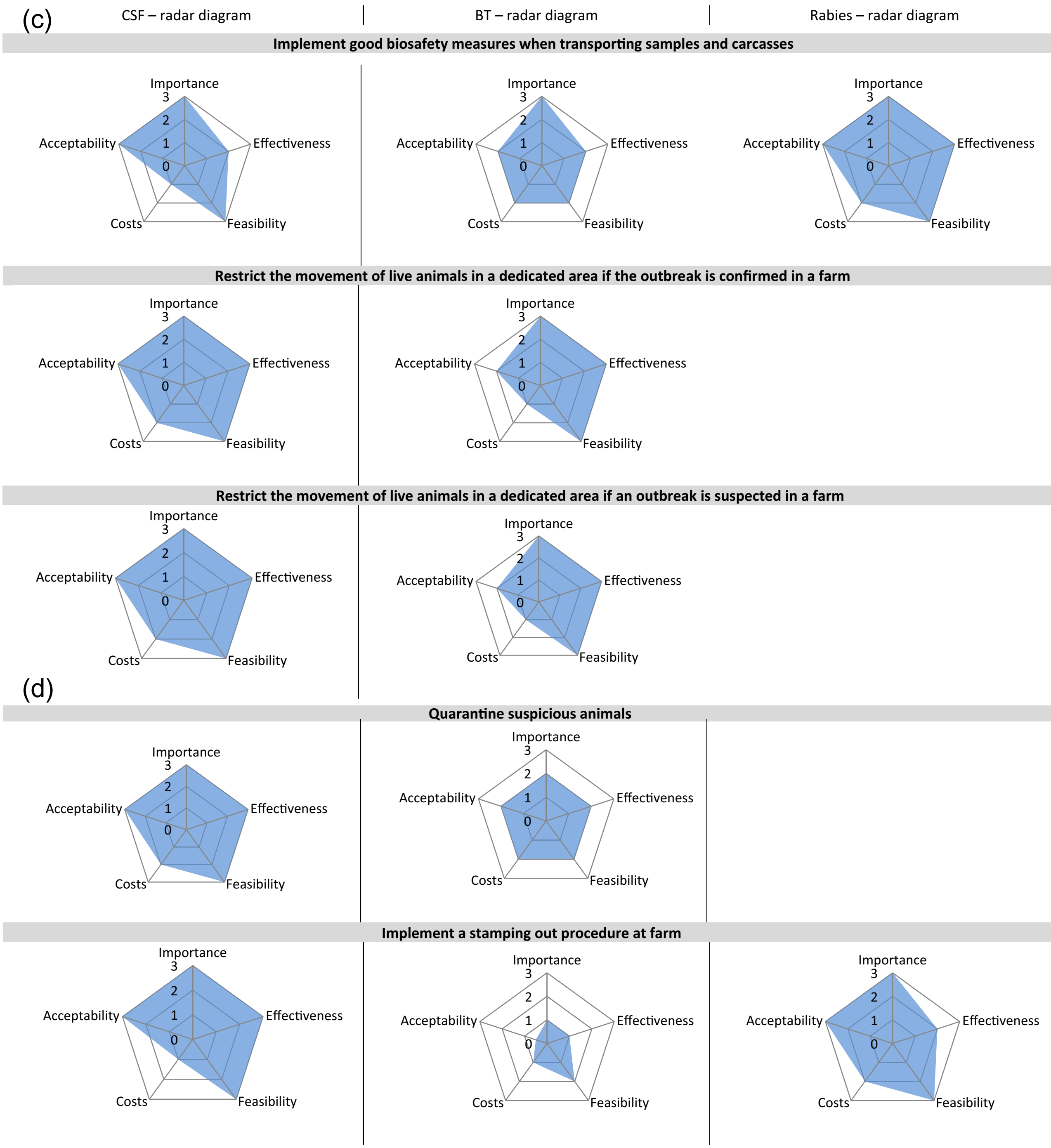


**Fig. 1** (*continued*)

outbreaks within the last 10 years: IT still faces outbreaks regularly, whereas CH had its last case in 2008 and the UK in 2007 [28,30]. Rabies was not reported in the UK or CH during the past 10 years, whereas IT reported cases in the period 2008–2011 [28,31,32]. It would be challenging (and beyond the scope of this survey) to prove a correlation between the animal health status and the results of the survey. However, some consideration can be attempted. Rabies experts were significantly more confident in their answers than other experts ($p < 0.05$). This could be explained by the fact that measures have been implemented for years now, well-studied by the scientific community. In general, the uncertainty also varies between experts for the same disease. This can be due to different reasons not directly investigated in the survey such as the knowledge accumulated after years of implementation and recommendation at national and international level. However apart from events influencing the confidence such as recent exposure to the disease, the level of confidence can be also determined by the intrinsic character and personality of the experts, a factor not easily controlled but can be alleviated thanks to different methods (e.g. DELPHI method, training pre-questionnaire, weighting experts according to their (relative) expertise). To alleviate this factor in our study, we provided experts with a clear definition of the uncertainty scale and explained it to the expert when technical assistance was requested.

The questionnaire length was substantial and might have had an impact on the answer rate. In order to improve the response

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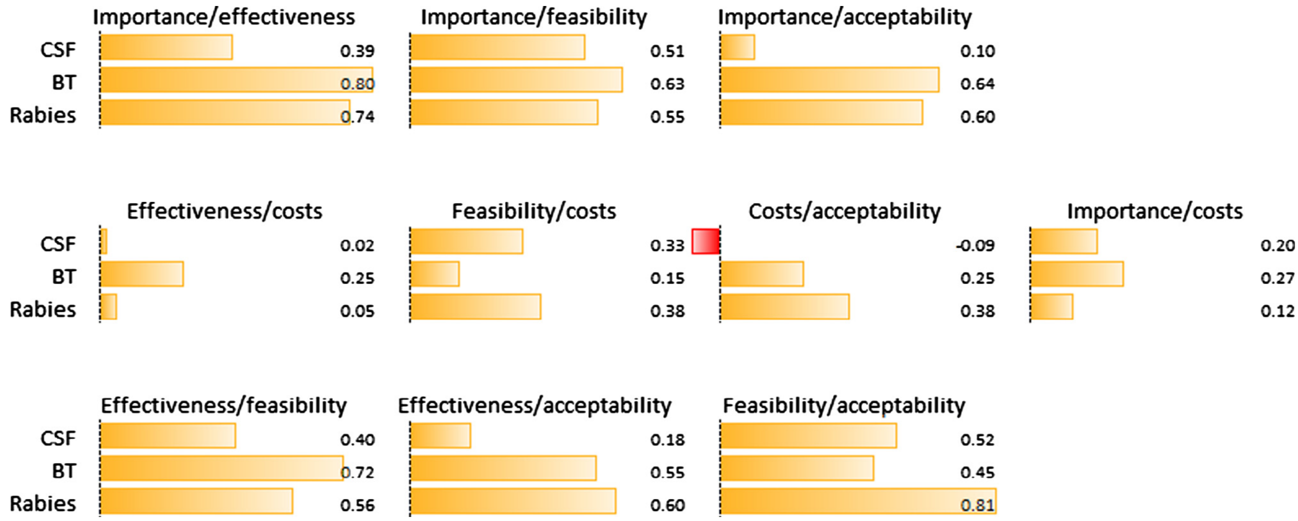


**Fig. 2.** Correlation coefficients from the Spearman rank correlation tests between the weighted medians of the criteria (importance, effectiveness, feasibility, costs and acceptability) within the three pathogens (CSF, BT and rabies).

rate, we had contacts with the experts during the survey; clarifications were provided very carefully and in a way such to avoid bias or orient answers from experts. Furthermore, in order to increase specificity in the answers and avoid misinterpretation of the terms used we provided clear definitions of each of the criteria (Table 6 "Supplementary materials"). Nonetheless, one expert had a low answer rate (36%) because they did not evaluate mandatory measures, which they assumed to be fully applied and not discussable. We received no feedback after contacting that expert a second time.

It is important to note that measures might obtain the same overall score from a different combination of the five criteria scores. For example "good biosafety measures when transporting samples" and "good practices for manure spray" for CSF had the same overall score, but where the second presents similar scores for each criterion, the first has very different scores. In our analysis, the five targeted criteria were weighted equally to calculate the overall score. However, in reality this may not be appropriate; decision-makers may consider some of the criteria to have higher priority than others. Each country has to decide on which criteria the decision must be based and the link between the relevance of a measure and its applicability remains complex and variable [3,11,20,21]. It is possible in the future to revise the methodology to assign different weightings to the targeted criteria. Alternatively, the results for the individual criteria can be taken into account, along with the overall score.

Regarding the rabies "zoonotic risk", experts highlighted the measure "strengthen the cooperation between public health and veterinary sector", supporting the idea of One Health in reducing its impact. However, the vaccination of farm animals was a source of strong disagreement among the experts. This might be because the disease has long been eradicated in farm animals in Western Europe and the cost of vaccinating exceeds the perceived benefits. Indeed vaccination of farm animals, dead-ends hosts, is perceived as a highly costly activity by experts. Current risks of introduction are mostly related to illegal importation of pets from infected areas and/or infected wild foxes crossing borders [33]. However, the risk of dissemination to farm populations in Western Europe is low. In IT, during the recent epidemic, very few farm animals were infected [32].

Well-known measures such as the implementation of a restricted zone were rated low for BT. This was due to divergence between experts regarding effectiveness and feasibility, likely because spread of vector-borne diseases are thought to be difficult to control completely this way. Several efficient measures have been detailed in the literature to prevent biting midges [34], even if most of them are only economically profitable for valuable animals [35], but vaccination seems the best way to prevent and control the disease [36]. This difficulty of disease control is also seen in measures concerning wildlife for CSF, which were poorly scored. This may have been affected by the differences in the density of wild boar populations in the targeted countries. For those countries with considerably less density (e.g. UK) those measures targeting wildlife are less relevant compared to others. This fact underlines that measures cannot be chosen solely based on best relevance. Combinations of measures are needed to ensure a sufficient biosecurity level within the country. Experts might also have lacked knowledge in entomology and disease dynamics in wildlife, or not had recent experience of an outbreak or endemic situation, causing them to be prudent in their answers.

There is no specific measure which reached high scores for the three pathogens. However, "tracing system for live animal trade" was highlighted as very relevant in all diseases. This mandatory measure is applied at European level [37]. This study had no purpose to identify essential measures and assess their impact on success. However, this measure was promoted by all experts and its inclusion in any biosecurity programme is perceived by experts as indispensable for success. The implementation of a "restriction zone after a suspicion or confirmation" was also rated as a relevant measure. Relevance of measures and commitment of governments enhance a measure's acceptability and implementation. Measures applied at voluntary basis might be more difficult to evaluate because of a smaller scale of application and a less obvious impact on field. We accessed different studies that identified relevant measures to be implemented at farm level to prevent the incursion of pathogens [39–41]. However, none of them evaluated the combination of measures.

We identified a lack of correlation between costs and the other criteria (Fig. 2). This is understandable for costs/effectiveness (a cheap measure can be effective and vice versa). It is more surprising to find that costs and acceptability seem not to be linked. Veterinarian services might have a global vision and bigger concerns justifying the investment, e.g. rabies is of public health significance, a CSF outbreak would threaten exportation. However, most of the biosecurity costs are upon farmers [42]: they accept to be in charge for most of the diseases [38] but consider that governments are responsible for biosecurity of emerging diseases [11,38,43], ensuring costs and/or policy. The sampling size is limited but the study suggests that in some occasions experts' perspectives on the same measure might be opposite. To ensure a better implementation of biosecurity measures, discussions and information sharing between all stakeholders (e.g. decision-makers, veterinarians, farmers) are recommended, e.g. risk communication or disease surveillance [38,44–47]. Enhanced sharing information between these stakeholders would support a better biosecurity level in the country [11,45]. Moreover, the acceptability of a measure from farmers implies a lot of different factors such as importance and effectiveness of the measure, availability of clear and reliable information, disease history, ease of implementation and costs [5,27,38,43,47–49]. Actions from governments should be tailored to situations, group of farmers and should not deny their experience [38,46].

Measures related to the change of practices such as "husbandry practices to limit the contact animal/vector" or "limit exchange of shared vehicles" received poor acceptability scores, impacting their general score. Indeed, changing work practices might be difficult; however, farmers have strong willingness to change when measures fit to their ethics and lifestyle motivation [48]. Other studies supported the fact that financial incentives, penalties and other financial considerations are not the dominant driver for farmers to change [5,48].

Facing budget restriction, decision-makers need to prioritise their actions and make efficient choices. With this study, we were able to bring elements for reflection. We believe that our survey's results are relevant and of immediate use in the targeted countries and that a similar approach could be applied in other countries to support their strategy to identify the best combination of biosecurity measures taking into consideration a set of several criteria.

## 5. Conclusion

This study provided valuable information about biosecurity measures to prevent the incursion and spread of rabies, BT and CSF in IT, CH and UK. The methodology developed can be used to gather information from experts and risk managers to update and revise practices to prevent the introduction and spread of the targeted diseases. At the same time, the methodology could be utilized in countries which are in the process of revising their surveillance and control strategies taking into consideration the risk of introduction of other pathogens of interest such as Lumpy Skin Disease.

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## Conflict of interest

None.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2017.07.034.

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