Characteristics of One Health surveillance systems: A systematic literature review

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ABSTRACT

The concept of One Health (OH) promotes the decompartmentalisation of human, animal, and ecosystem health for the more efficient and sustainable governance of complex health issues. This means that traditional boundaries between disciplines and sectors must be transgressed and that all relevant stakeholders must be involved in the definition and management of health problems. International efforts have been made to strengthen collaboration across sectors and disciplines and OH surveillance is strongly encouraged at global, national and local-level to efficiently manage hazards involving humans, animals and ecosystems.

This concept is intuitively appealing and would suggest the enhanced performance and cost-effectiveness of surveillance systems, as compared to more conventional approaches. Nevertheless, confusion and uncertainty regarding the practical application, outcomes and impacts prevail. We believe that this is due to the lack of a conceptual and methodological framework which would (i) define the characteristics of OH surveillance, and (ii) identify the appropriate mechanisms for inter-sectoral and multi-disciplinary collaboration, to ensure that the surveillance system performs well, with regard to the objective, the context and the health hazard under surveillance.

The objective of the study is to define the organisational and functional characteristics of OH surveillance systems, the context in which they are implemented, as well as the influential factors which may obstruct or support their implementation and performance. To achieve this, a systematic literature review of existing OH surveillance systems was conducted using the Prisma guidelines. The selected systems were assessed according to 38 predetermined variables. These allowed the characterisation of their objectives, organisation, functioning, performance and benefits. Data extraction was conducted using a spreadsheet and a database was built using an electronic multiple-choice questionnaire.

The literature search identified a total of 1,635 records. After the screening phase, 31 references were kept and 22 additional references retrieved from bibliographies were added. From these 53

selected documents, we retrieved 41 different surveillance systems in line with the definition proposed in this study. The analysis of this database enabled the identification of different dimensions and areas of collaboration. Barriers and levers for the implementation of OH surveillance systems were also identified and discussed.

Based on our results, we propose a framework to characterise the organisation of collaboration for the governance and operation of an effective OH surveillance system.

Keywords: surveillance, One Health, framework, collaboration

1. Introduction

Current international consensus highlights the need to develop integrated policies to efficiently manage health issues at the human-animal-environment interface (Jeggo and Mackenzie, 2012). The management of complex health issues should therefore shift from isolated, sectoral and linear, to systemic and transdisciplinary approaches to health. This requires the engagement of a wide range of stakeholders from different professional sectors and decision-making scales (including community) and of disciplines belonging to biosciences, social sciences and engineering (Queenan et al. 2016). Such an approach is in line with the One Health (OH) concept, which promotes collaborative efforts across sectors and disciplines as well as an ecosystemic approach to health, to attain optimal health for humans, animals and their environment (AVMA, 2008; Zinsstag et al., 2011). Close collaboration between health systems is therefore strongly encouraged, in particular in the surveillance of health hazards involving humans, animals and their environment (FAO, 2010). This means that we must also consider ecosystems within which conditions may trigger health risks for humans and animals (Queenan et al. 2016).

Health surveillance is the ongoing, systematic collection, analysis and interpretation of health-related data with the *a priori* purpose of preventing or controlling health hazards and identifying unusual events of health importance, followed by the dissemination and use of such information for health action (Lee and Thacker, 2011). There is no current consensual definition for a OH surveillance system. Stärk et al. (2015) and Berezowski et al. (2015) characterise OH surveillance as a system that collects data in multiple domains. For Hattendorf et al. (2017), using a OH approach to surveillance does not automatically imply that data must be collected both from animals and humans, as long as there is inter-sectoral collaboration that leads to improved health management. The definition provided by Karimuribo et al. (2012) also emphasises cross-sectoral collaborative efforts between the human and animal (wildlife and domestic) sectors.

Despite a lack of evidence to support this, the application of the OH concept to surveillance is expected to increase efficiency, cost-effectiveness and cost-benefits (Stärk et al., 2015; Babo Martins et al., 2017). Nevertheless, surveillance systems continue to be developed and operated in a highly sectoral approach (Baum et al., 2017). We argue that the OH approach is difficult to implement in the field of surveillance, partly due to the absence of a conceptual and methodological framework that characterises OH surveillance and supports the implementation of appropriate cross-sectoral and multi-disciplinary collaboration. Depending on the surveillance context and objective, the required collaborative efforts across sectors and disciplines might differ. They might be implemented for various activities throughout the surveillance process and engage different combinations of sectors, disciplines and decision-making scales (Dente et al., 2016; Babo Martins et al., 2017; Hattendorf et al., 2017).

We conducted a systematic literature review of the organisational and functional characteristics of existing OH surveillance systems, as well as the influential factors which may obstruct or support their implementation. Based on our results, we propose a framework that characterises the organisation of collaboration for the governance and operation of effective OH surveillance systems, and the factors that influence their performance and maintenance over time.

2. Materials and methods

In the absence of a consensual definition for a OH surveillance system and based on elements found in published literature (Karimuribo et al. 2012; Berezowski et al. 2015; Stark et al, 2015; Hattendorf et al., 2017), the following definition is proposed for this study. A OH surveillance system is a system in which collaborative efforts exist between at least two sectors (among human health, animal health, plant health, food safety, wildlife and environmental health) at any stage of the surveillance process, to produce and disseminate information with the purpose of improving an aspect of human, animal or environmental health.

2.1. Literature sources and search strategy

A systematic literature search was conducted according to the PRISMA requirements (Preferred Reporting Items for Systematic Reviews and Meta-analysis) (Moher et al., 2009). Searches were conducted using Google Scholar, PubMed and ScienceDirect. The literature search focused on scientific and grey literature, in French and English, published between 01/01/1985 and 31/12/2016. Keywords for four different domains were used, and applied only to the title, abstract and key words within literature (See Table 1).

2.2. Study selection

All documents retrieved from the bibliographic databases were screened by two reviewers following two distinct steps. For the first step, three inclusion criteria were applied to titles and abstracts: (i) the document describes a surveillance system (as defined previously), (ii) the surveillance system focuses on a health hazard, (iii) the surveillance system shows evidence of collaborative efforts between professionals working in at least two different sectors, among animal health, human health, food safety and the environment. In the second step, only references with the full text available were screened. An additional criterion was used: the document provides a detailed description of the surveillance organisation and operation. Articles and reports meeting all inclusion criteria were registered. Bibliographies of selected publications were reviewed to identify other relevant references.

2.3. Data extraction

To meet the objective of the review, the selected surveillance systems were assessed according to 38 predetermined variables, allowing the description of the organisation, the functioning, the surveillance context, the health hazards and domain under surveillance, the type of collaboration and underlying mechanisms, the barriers and favouring factors regarding on-going collaboration, and the performance and benefits of the systems (See Table 2). Variables related to collaboration were slightly refined during the information collection to capture the different dimensions and areas of collaboration arising from the literature review process. Data extraction was conducted using a spreadsheet; a database was then developed by entering this data into an electronic multiple-choice questionnaire, with pre-defined modalities. If data for certain organisational and functional variables was missing, additional searches were conducted on the webpages of the coordinating institutions to retrieve the missing information.

3. Results

The literature search identified a total of 1,635 records. After the screening phase, 31 references were kept and 22 additional references retrieved from bibliographies were added (Figure 1). From these 53 documents, we retrieved 41 different surveillance systems in line with the definition. Table 3 describes these systems regarding six main variables: hazard(s) under surveillance, domain(s) under surveillance, objective and purpose, coordination modalities (number of institutions involved and type of sector they belong to), sectors involved in the operation of the surveillance and type of inter-sectoral collaboration.

3.1. Dimensions and degrees of collaboration in One Health surveillance systems

The analysis of the existing systems led to the identification of four main dimensions where collaboration across sectors and disciplines may occur (variables 25 to 33 in Table 2): (i) institutional collaboration across sectors for the governance and operation of the surveillance system; (ii) collaboration at the different scales of the decision-making process; (iii) collaboration across disciplines; (iv) collaboration through public-private partnerships. These four dimensions are described in more detail below.

The first dimension refers to collaboration between sectoral institutions with different jurisdictions and mandates, mainly public health, animal health, plant health, environmental health and food safety. Collaboration can take place at the governance-level for the coordination and supervision of the surveillance system and/or at the operational-level for the implementation of surveillance activities, at the different steps of the surveillance process. Multi-institutional coordination is in place for 43.9% of the surveillance systems. If the coordination is led by a single sectoral institution (mainly the public health sector), in 87% of the cases, collaboration is established at the operational-level, with institutions in charge of other domains covered by the surveillance system. Where the mechanisms supporting institutional collaboration are described (36.6% of the surveillance systems), these most commonly (80% of the cases) include establishment of an inter-agency committee and/or the existence of official documents framing collaboration. Official documents are usually legal instruments, such as the inter-ministerial circular that describes the role and responsibilities of each party in the surveillance system for West Nile virus in France (Ministry of Health, 2012), or the legally binding agreement for data sharing between the animal health and the human health sectors within the RAIZO, in Canada (Roth D., 2011). At the operational-level, various degrees of collaboration were identified at all steps of the surveillance process: planning, data collection (including sampling and laboratory testing), data management, data sharing, data analysis/interpretation and results dissemination. These degrees of collaboration are presented in Figure 2.

The second collaborative dimension concerns the engagement of different disciplines, among biosciences, social sciences and engineering. The data retrieved was insufficient to allow a detailed description of the proportion of disciplines engaged in the surveillance process, but disciplines referring to biosciences (medicine, microbiology, epidemiology, entomology, ornithology, parasitology) showed a significantly higher representation. These disciplines can be used for different occupational purposes (risk assessment, risk management, research, etc.).

A third collaborative dimension can be described regarding collaboration between different decision-making scales. These scales include the different administrative jurisdictional scales within a same country (central, provincial and local authorities) but also the supra-national scales such as the international-scale (e.g. international organisations) or the regional-scale (e.g. regional economic communities). Within this dimension, the engagement of civil society must also be considered and is, for instance, clearly emphasised for two surveillance systems targeting rabies (Abbas et al, 2011; Lapiz et al., 2012).

Finally, a last collaborative dimension can be defined through the development of public-private partnerships within, but also across, sectors. For instance, in Canada, veterinary pharmaceutical companies as well as private veterinarians collaborate within the surveillance system for antimicrobial resistance, which is coordinated by the Ministry of Health (CIPARS, 2015; Grant et al., 2014). Reported private partners are mainly veterinarians, physicians, private laboratories, farmers, feed/food operators and pharmaceutical companies, on an individual basis or through professional organisations.

3.2. Factors influencing collaboration

3.2.1. Favouring factors

Factors that have positively influenced the implementation and the functioning of a collaborative surveillance system are mentioned for 21 systems (51.2%). Factors related to the existence of an appropriate framework to ease collaboration across sectors are the most numerous (71.4%). Some surveillance systems are embedded in an overarching OH programme and benefit from the existing inter-sectoral framework to develop collaborative surveillance activities. This is the case for the surveillance of rabies in Bohol, where collaborative surveillance activities are part of a programme for the elimination of rabies supervised by an inter-sectoral council (Lapiz et al., 2012). Other references emphasise the existence of an appropriate legal or institutional framework as a lever for collaboration (Abbas et al, 2011; Adamson et al., 2011; Lapiz et al., 2012; Ministry of Health, 2012). For two systems, however, collaboration is not supported by an official framework but by preferential relationships existing between individuals working in different sectors and disciplines (Epp et al., 2008; Adamson et al., 2011). For the surveillance of rabies in Tamil Nadu (Abbas et al, 2011), the clear definition of roles and duties of the different agencies involved is considered to have strongly supported the operationalisation of collaboration. The existence of inter-sectoral collaboration mechanisms already established at a supra-level will also usually provide a framework for infra-level collaboration. For instance, in Mongolia, the implementation of a multi-agency committee for zoonotic diseases at country-level was facilitated by the existence of inter-sectoral strategy at the regional-level - the Asia Pacific Strategy for Emerging Diseases (Batsukh et al., 2012). Finally, the last factor related to the existence of an appropriate framework to support collaboration refers to the supervision, by the same authority, of sectors in charge of surveillance components. In Italy, the veterinary services are under the authority of the Ministry of Health, and this administrative organisation is considered to strengthen the channels of communication across animal health and public health professionals within the integrated surveillance system for West

Nile Virus (Rizzo et al., 2012; Napoli et al., 2015). Other favouring factors are related to mechanisms ensuring the commitment of stakeholders, at the political and operational-levels (51.7% of the systems). For three systems (Talaska T., 1994; Sleigh et al., 1998a; Sleigh et al., 1998b; Wielinga et al., 2014), efficient and appropriate communication and consultation channels helped in achieving stakeholder commitment within the collaborative system. In two cases, the ability of the system to meet the objectives of the different stakeholders was specifically identified to be the key to success and sustainability of the surveillance system (Adamson et al., 2011; Donado-Godoy et al., 2015). For 51.7% of the systems, epidemiological factors are also mentioned as a motivation to establish collaboration for surveillance activities, such as the scientific evidence of the efficiency of using animal sentinels or vector surveillance components to protect human health (McNamara et al., 2013; Morgan D., 2006; Petrić et al., 2017), or the necessary recognition of the interconnectivity between domains in the conception of an efficient surveillance system (Talaska T.,1994; Morgan et al., 2009; Witt et al., 2004; Vrbova et al., 2016). For instance, some technical factors are also considered to favour collaboration and integration of data from different domains for 23.8% of the systems. The most common one refers to the availability of a joint database or the ease of data exchange, thanks to compatible sectoral information systems. In the surveillance of *Salmonella* in Brandenburg, a common data-bank is recognised to have stimulated the commitment of stakeholders to the collaborative system (Talaska T., 1994). The AFHSC-Division of GEIS operations predictive surveillance programme has developed, with partners from different sectors, a model merging data collected from several sources that supports pre-event advisories and alerts on the emergence of disease outbreaks (Witt et al., 2011). Another technical factor is related to the crucial role played by a fully functional national reference laboratory for harmonisation across data-sets and their further combination, as emphasised by Ammon et al. (2010) in their description of the surveillance of zoonotic diseases in the European Union.

3.2.2. Barriers

Barriers that hamper the operation of collaborative surveillance systems have been specified for 20 systems (48.8%). These are mostly technical barriers (78.6%): a lack of standardisation and harmonisation for data collection, incomplete data, insufficient data-sharing across sectors including unreliable cross-sectoral alert systems, incomplete multi-domain data analysis and interpretation. In four cases, the collaboration might not have reached a sufficient level because of the absence of engagement among the private sector (Sorensen et al., 2014) or an insufficient integration with certain sectoral components still conducted separately (Adamson et al., 2011; Roth D., 2011; Sorensen et al., 2014). As a result, the systems cannot meet their objective, such as the detection of health events in animals to prevent human cases or the attribution of sources for human cases of food-borne diseases. In addition, legal constraints are also mentioned for 42.9% of systems: the property and confidentiality of data, ethical issues, and an inadequate legal and operational framework to precisely define the roles and mandates of the different actors involved and to support collaboration at ground-level. Inappropriate amounts and allocation of resources are also impediments to collaborative approaches. On the one hand, budgets are vertically allocated and there are no resources available for cross-sectoral actions. On the other hand, resources are scarce, especially for surveillance activities, and stakeholders may have to compete for them, reinforcing the lack of collaboration (Batsukh et al., 2012; Johnson et al., 2018). Finally, competing priorities among actors may also obstruct the involvement of the different parties in a OH surveillance system. In the surveillance system for zoonotic diseases in New South Wales, the different interests of each sector in zoonoses is responsible for the inconsistency of notification between sectors (Adamson et al., 2011).

4. Discussion

The systematic literature review retrieved 41 existing surveillance systems, in which collaboration across sectors and disciplines may occur at different steps of the surveillance process and to various degrees. These systems are mainly characterised by the hazard under surveillance, the surveillance purpose, the type of sector leading the coordination and the type of sectors involved in the surveillance activities, as emphasised by the results of a multi-variate analysis conducted on the database (results not yet published).

However, these results should be interpreted with caution, due to certain biases in the retrieval methodology of the documents describing surveillance systems. Many surveillance systems, and especially those established for official purposes, do not necessarily lead to publications and so might not be included in our study. During the review, some documents referring to our definition of OH surveillance system were initially retrieved but were subsequently excluded from the analysis as they did not provide enough information. On the contrary, some surveillance systems may demonstrate collaboration across sectors, but as they were not mentioned in the references retrieved, they were not captured by our study. Moreover, the organisation of some systems may have evolved further since publication describing it, and data used for the analysis might be outdated. Additionally, the level of information relative to surveillance organisation may vary from one document to another, and some characteristics may not have been captured in our study because they were not mentioned by the authors. For instance, this systematic literature review does not allow the identification of certain barriers to collaboration which are commonly described as underpinning the operationalisation of OH surveillance, such as differing priorities between risk-bearers and risk managers, data sequestration, the undervaluation of certain sectors and disciplines or the fear of losing ownership and leadership (Häsler et al., 2012; Uchtmann and al, 2015). This can be explained by the fact that the objective of the review was to retrieve documents describing the organisation and functioning of OH surveillance systems and that barriers were poorly described in the selected documents. Finally, research on OH surveillance is gaining increasing attention and the study did not include some articles published after the search period.

The definition used for a OH surveillance system (collaboration among at least two of the following sectors: animal, human and environment) can be questioned regarding the most commonly agreed OH definition that promotes the inclusion of all three sectors (AVMA, 2008; Zinsstag et al., 2011). Moreover, the COHERE standards consider an OH epidemiological study only if it reports data collected in all three domains (Davis et al, 2017). However, some surveillance systems are set with a specific objective in a given socio-economic context that do not require or allow the inclusion of all the three domains. In our view, even if they do not include the three domains, surveillance systems demonstrating collaborative efforts among sectors and disciplines towards a more holistic approach should still benefit from consideration from a OH perspective. Moreover, challenges encountered for their operationalisation are similar and require the same needs in terms of governance and operational framework to favour their implementation. Nevertheless, to avoid confusion over terminology, these systems could be renamed, and "collaborative surveillance" is suggested.

In the last decade, the OH concept has been endorsed and largely promoted at the global and local-level (Vandermissen and Welburn, 2014). Despite the persistence of silo-thinking, many initiatives have emerged. In terms of surveillance, this study suggests that efforts mainly focus on the prevention of zoonotic diseases (including vector-borne and food-borne diseases), and more recently of antimicrobial resistance. The review has retrieved only two articles describing surveillance initiatives focusing on non-communicable hazards that bridged health and environmental sciences in an effort to address health risks related to environmental contaminants (Abelsohn et al., 2009; CDC, 2004; Malone and Culver 2008). Nevertheless, environmental contaminants (such as heavy metals, dioxins, PCB, myco- and phycotoxins, etc.) are a quintessential OH issue. Animals and humans share the same environment and the same sources of food and water; therefore, they are potentially exposed to the same chemicals. Additionally, humans can be contaminated through the ingestion of contaminated animal products, which are an essential part of the human diet (Buttke D.E., 2011). Moreover, it has been demonstrated that animals are sensitive indicators of environmental chemical hazards and could serve as sentinels for human environmental health risks (Reif J.S., 2011; Pearce and Douwes, 2013). Environmental contamination thus calls for a highly interdisciplinary approach to appropriately respond to the related health risk. Nevertheless, our study only retrieved a few examples of OH surveillance systems addressing chemical environmental hazards.

The definition of the OH concept is linked with the notion of attaining optimal health at once for humans, animals and the environment. In most of the documents retrieved, the primary purpose of the collaboration across sectors was to improve human health only. Nevertheless, OH offers the possibility to transcend the anthropocentric view of health and to shift the current focus to a more balanced strategy with benefits to all domains to improve health development in a sustainable way, as described by Queenan and al. (2017). If relevant, collaborative surveillance systems could be developed with a wider perspective and used to inform interventions in the animal and environmental sectors, to obtain gains for the health and welfare of animals, plants, and ecosystems (Rüegg et al., 2017; Rüegg et al., 2018). For instance, human diseases or behaviours could be monitored and act as risk indicators for animal and environmental health.

The study has highlighted that OH surveillance is often assimilated to integrated surveillance, insofar that data from different sources is jointly collected and/or *a posteriori* combined. The concept of collaboration, a fundamental principle of the OH concept (Zinsstag et al. 2011), is therefore not inherent to integrated surveillance when defined in this way. Indeed, a surveillance system can allow the acquisition and combination of data stemming from several domains, without demonstrating any beneficial collaboration for health management across sectors and disciplines. For instance, the surveillance of zoonotic diseases in the Russian Federation includes data collection in humans, wildlife and the environment and is coordinated by the public health sector alone, with limited collaboration with other sectors. This is considered to hamper the performance of the surveillance system (McNamara et al., 2013). As a result, this system may be considered more as an integrated system than a OH surveillance system. The term OH is also often used to characterise surveillance systems in food, because they integrate data collected at the different stages of the food chain. If data is collected and analysed by a single sector and does not support interventions to improve the health situation in another sector, this approach should not be considered as OH, as no added value emerges from inter-sectoral collaboration. On the contrary, regarding our definition, surveillance systems could be labelled OH even when collecting data in a single domain, if this data is used to inform another sector to improve health management. For instance, in the Gulf of Mexico, the national agency in charge of the environment monitors coastal waters (ecological and biological data) to predict blooms of harmful algae. Results are transmitted to the authorities in charge of public health and fisheries so that they can take appropriate action to manage the risk in their respective jurisdictions (Abelsohn et al., 2009). The risk mitigation measures would not have been implemented if collaboration was not operational across the three sectors. Hence, “integrated” and “OH” should not be considered as synonymous. Using one term for another interchangeably is confusing and does not support the effective operationalisation of the OH concept in the field of surveillance.

The same observation can be made regarding the terms “multi-disciplinary” and “multi-sectoral” which are regularly used, one for the other, to describe ongoing collaboration happening within surveillance systems. Discipline refers to a branch of knowledge (medicine, epidemiology, economics, sociology, etc.) while sector refers to a branch of activities (animal health, public health, food and water safety, environmental health, etc.). In our view, a surveillance system showing a multi-disciplinary approach without cross-sectoral collaboration should not be qualified as OH. Indeed, even if a sectoral institution establishes a multi-disciplinary team to integrate knowledge usually mobilized by other sectors, it will not be able to consider all the dimensions related to this sector (stakeholders, constraints, expectations, socio-economic factors, etc.). Multi-disciplinary and multi-sectoral are intrinsically linked but not interchangeable. Cross-sectoral collaboration will automatically lead to a multi-disciplinary approach, as each sector mobilizes at least one discipline (medicine, ecology, food hygiene, etc.). On the contrary, a multi-disciplinary approach can be developed within one sector without additional cross-sectoral collaboration.

Transdisciplinarity is, however, the quintessence of a OH initiative and refers to the integration across both sectors and disciplines (Rüegg et al., 2018). This approach links societal and scientific problems together, by combining scientific and extra-scientific insights. It creates new connections across distinct epistemic, social-organisational and communicative entities that are part of the problem context (Jahn and Keil, 2015). Surveillance systems designed according to a transdiciplinary approach will therefore entirely fulfil the requirements of a OH approach in its broader definition. Interests, expectations and knowledge of the different scientific, societal and political stakeholders and end-users of the system are considered, and the new knowledge produced is expected to contribute to the well-balanced improvement of animal, human, and environmental health.

Our findings reinforce the hypothesis that the lack of a conceptual framework to accurately define the notion of OH surveillance is undermining the operationalisation of collaborative efforts for efficient and sustainable surveillance systems. From our perspective, a OH surveillance system is, above all, characterised by the collaboration taking place among professional sectors (both public and private) and disciplines, at different decision-making scales, to coordinate and implement appropriate surveillance activities. Based on the analysis of existing OH surveillance systems, we propose a conceptual framework (Figure 3) to describe the different organisational levels of collaboration that need to be taken into consideration, and the factors influencing their effective governance and operation, in the long-term.

In our framework, we distinguished three different levels where collaboration must be organised and planned: (i) the policy-level, (ii) the institutional-level and (iii) the operational-level. At the policy-level, the collaborative strategy is clearly defined: collaborative efforts are elucidated in broad terms emphasising the rationale behind the necessary collaborative efforts as well as the OH surveillance objective. The different dimensions (sectors, disciplines, decision-making scales and public-private partnerships) in which collaboration will take place are clarified and the role of the surveillance actors acting and interacting in those dimensions are stated. Mechanisms for the steering and coordination of the collaborative surveillance system, as well as for scientific and technical support, are clarified. The way in which resources will be mobilized across sectors and then allocated to collaborative activities is established. For instance, Roth et al. (2003) propose that the budget allocated by each ministry for cross-sectoral activities could be proportional to the benefits that derive from the collaboration for each sector. In some countries, the government has been reorganised to reduce operational costs and silo-functioning. This is the case in Denmark, where a new Ministry in charge of food, agriculture and fisheries has been created, which is recognised to have improved inter-sectoral collaboration and thus the management of antimicrobial resistance (Wielinga et al., 2014). All these decisions need to be formalised and endorsed by stakeholders to ensure their further commitment. Depending on the country and context, the policy can be enunciated in policy or strategy documents, national action-plans or programmes, memorandums or directly released in legal instruments. This policy framework provides guidance to organise collaboration across professional institutions for the surveillance activities. At the institutional-level, appropriate collaboration modalities are then defined to achieve the desired goals of the policy. Collaboration is described in terms of: areas of implementation (planning, sampling, laboratory testing, data management and storage, data sharing, data analysis and interpretation, results dissemination), actors involved and their respective roles and responsibilities, technical mechanisms to support collaboration (establishment of a shared database, a working group, etc.), and mechanisms for the allocation and deployment of human, material and financial resources. The institutional framework defined at the national-level should be broken down at the sub-national-level to ensure coordination and harmonisation across the different jurisdictional levels, between and within each sector, if deemed necessary. This is of particular importance for official surveillance in countries experimenting with a decentralised system. Regulatory instruments, agreements or charters are issued to formalise and provide a frame for the implementation of the above decisions. Finally, institutional collaboration is translated into specific surveillance actions. This requires the establishment of procedures (or other similar mechanisms) in each institution involved to ensure the routine operation of the collaborative surveillance system, in compliance with the organisational structure decided at the policy and institutional-level. As for any surveillance system, the organisation and operation of a OH system are influenced by a set of contextual factors (epidemiological, ecological, economic, social and environmental) (RISKSUR, 2015) but also by the constraints and expectations of all the different actors and end-users, as well as international guidance. Nevertheless, in the case of OH surveillance, these factors are of particular importance as they may influence the inter-sectoral collaboration pattern, as well as the dimensions and areas of collaboration required to meet the surveillance objective. For instance, for the surveillance of antimicrobial resistance, the international community calls for countries to implement multi-domain surveillance involving the private sector and to provide guidance for the development of integrated surveillance in humans, food-producing animals and food of animal origin (WHO, 2017). Many countries have developed their surveillance strategy to comply with this guidance. The analysis of levers and barriers to collaboration in existing multi-sectoral surveillance systems resulted in the identification of a wide range of drivers that impact the performance and sustainability of OH surveillance. First, depending on the surveillance objective and context, the appropriate sectors (including both public and private institutions), decision-making scales and disciplines, must be identified and then involved in the governance and operation of the collaborative surveillance. In addition to the resources required to run the sectoral surveillance components, specific resources must be allocated for activities involving several sectors, both at the governance (provision of personnel to participate in steering committee, provision of appropriate training, evaluation of the system, etc.) and operational-level (organisation and participation in multi-sectoral working groups, development and maintenance of a joint database, etc.). Appropriate mechanisms must be defined and established to technically allow the collaboration to be implemented. For instance, efficient data-sharing on a routine basis would be hampered by the absence of a common database or incompatible sectoral information systems (Adamson et al., 2011). A crucial element is the identification of the area and degree of collaboration that will achieve the OH surveillance objective in the given context. Indeed, the concept of a OH surveillance system is not synonymous with an all-integrated system and collaboration can take place to various extents and at different steps during the surveillance process. Collaboration is resource-consuming; it is therefore important to find the minimum level of collaboration that will achieve the optimal performance and cost-effectiveness (Babo Martins et al., 2017). However, only proper and rigorous evaluations of surveillance, based on sound and appropriate methods, will allow the relevance and effectiveness of collaboration to be assessed. Collaboration that does not demonstrate any benefit would only result in decreasing stakeholder commitment and in hampering the sustainability of the system.

5. Conclusions

This review highlights that collaboration taking place in a OH surveillance system exists in different dimensions (across sectors, disciplines, decision making-scales and through public-private partnerships) and can be implemented at various steps of the surveillance process (from planning to dissemination of the surveillance results) with various degrees of integration. Several internal or external factors influence both the effective functioning of surveillance systems, as well as their sustainability overtime.

Even if a rigorous framework must be considered at the policy and institutional-level to ensure the effective operation of a OH surveillance system, there is not a single model for OH surveillance. Collaboration must be tailored to the surveillance objective and context, characterised by a wide range of factors (epidemiological, ecological, economic, social and environmental), and must consider the constraints and expectations of all surveillance actors and end-users. To assess if ongoing collaboration is appropriate and effective, evaluations should be conducted with a focus on the quality of inter-sectoral and inter-disciplinary collaboration. Specific evaluation attributes must be developed to allow the measurement of impacts and of the benefit resulting from collaborative surveillance as compared to a juxtaposition of isolated sectoral surveillance components.

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References

Abbas, S.S., Venkataramanan, V., Pathak, G., Kakkar, M., 2011. Rabies control initiative in Tamil Nadu, India: a test case for the "One Health" approach. Int. Health 3, 231–239.

Abelsohn, A., Frank, J., Eyles, J., 2009. Environmental Public Health Tracking/Surveillance in Canada: A Commentary. Healthc. Policy. 4, 37–52.

Adamson, S., Marich, A., Roth, I., 2011. One Health in NSW: coordination of human and animal health sector management of zoonoses of public health significance. N.S.W. Public Health Bull. 22, 105.

Ammon, A., Makela, P., 2010. Integrated data collection on zoonoses in the European Union, from animals to humans, and the analyses of the data. Int. J. Food Microbiol. 139, S43–S47.

Angelini, P., Tamba, M., Finarelli, A.C., Bellini, R., Albieri, A., Bonilauri, P., Cavrini, F., Dottori, M., Gaibani, P., Martini, E., 2010. West Nile virus circulation in Emilia-Romagna, Italy: the integrated surveillance system 2009. Euro. Surveill. 15, 19547.

AVMA, 2008. One health: a new professional imperative, American Veterinary Medical Association: One Health Initiative Task Force Final Report, pp. 1–76.

Babo Martins, S., Rushton, J., Stärk, K.D.C., 2017. Economics of zoonoses surveillance in a "One Health" context: an assessment of Campylobacter surveillance in Switzerland. Epidemiol. Infect. 145, 1148–1158.

Batsukh, Z., Tsolmon, B., Otgonbaatar, D., Undraa, B., Dolgorkhand, A., Ariuntuya, O., 2012. One Health in Mongolia, in: Mackenzie, J.S., Jeggo, M., Daszak, P., Richt, J.A. (Eds.), One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 123–137.

Baum, S.E., Machalaba, C., Daszak, P., Salerno, R.H., Karesh, W.B., 2017. Evaluating one health: Are we demonstrating effectiveness? One Health 3, 5–10.

Bellini, R., Calzolari, M., Mattivi, A., Tamba, M., Angelini, P., Bonilauri, P., Albieri, A., Cagarelli, R., Carrieri, M., Dottori, M., 2014. The experience of West Nile virus integrated surveillance system in the Emilia-Romagna region: five years of implementation, Italy, 2009 to 2013. Euro. Surveill. 19, 20953.

Berezowski J., Akkina J., 2, Vilas V.D., Del Rio V., DeVore K., Dórea F.C., 5, Dupuy C., Maxwell M.J, Singh V., Vial F., Streichert L., 2015. Do we need One Health surveillance? One Health Newsletter, 8(1). Available at: http://media.news.health.ufl.edu/misc/egh/One Health Newsletter/OHNL_Volume8_Issue1.pdf

Brown E.G. 2012. California Mosquito-Borne Virus Surveillance and Response Plan. http://westnile.ca.gov/downloads.php?download_id=3744&filename=2017%20CA%20Response%20Plan.pdf (accessed 18/12/2017).

Buttke, D.E., 2011. Toxicology, Environmental Health, and the “One Health” Concept. J. Med. Toxicol. 7, 329–332.

CDC, 2004. Tracking Program: Closing America's Environmental. Public Health Gap. https://www.cdc.gov/nceh/tracking/pdfs/aag04.pdf (accessed 19/12/2017).

CDC, 2013. West Nile Virus in the United States: Guidelines for Surveillance, Prevention, and Control. https://www.cdc.gov/westnile/resources/pdfs/wnvguidelines.pdf (accessed 18/12/2017).

CIPARS, 2015. The Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) annual report 2014. https://www.canada.ca/en/public-health/services/surveillance/canadian-integrated-program-antimicrobial-resistance-surveillance-cipars/cipars-2014-annual-report-summary.html (accessed 19/12/2017).

Coetzer, A., Kidane, A.H., Bekele, M., Hundera, A.D., Pieracci, E.G., Shiferaw, M.L., Wallace, R., Nel, L.H., 2016. The SARE tool for rabies control: Current experience in Ethiopia. Antiviral Res. 135, 74–80.

Danan, C., Baroukh, T., Moury, F., Jourdan-Da Silva, N., Brisabois, A., Le Strat, Y., 2011. Automated early warning system for the surveillance of Salmonella isolated in the agro-food chain in France. Epidemiol. Infect. 139, 736–741.

DANMAP, 2016. 2015 Report on Use of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from food animals, food and humans in Denmark. https://www.danmap.org/~/media/Projekt%20sites/Danmap/DANMAP%20reports/DANMAP%20%202015/DANMAP%202015.ashx (accessed 19/12/2017).

David, J.M., Danan, C., Chauvin, C., Chazel, M., Souillard, R., Brisabois, A., Weill, F.X., Jourdan-Da Silva, N., Picherot, M., Guillemot, D., 2011. Structure of the French farm-to-table surveillance system for Salmonella. Revue Méd. Vét. 162, 489–500.

Davis, M.F., Rankin, S.C., Schurer, J.M., Cole, S., Conti, L., Rabinowitz, P., Gray, G., Kahn, L., Machalaba, C., Mazet, J., Pappaioanou, M., Sargeant, J., Thompson, A., Weese, S., Zinnstag, J., 2017. Checklist for One Health Epidemiological Reporting of Evidence (COHERE). One Health 4, 14–21.

Dente, M.G., Riccardo, F., Nacca, G., Ranghiasci, A., Manuguerra, J.C., Escadafal, C., Jimenez-Clavero, M.A., Ramirez, E.P., Robert, V., Picard, M., 2016. Strengthening integrated surveillance for arboviruses in the Mediterranean and Black Sea regions in the framework of the One Health approach. Quaderni Della Società Italiana Di Medicina Tropicale E Salute Globale.

Donado-Godoy, P., Castellanos, R., León, M., Arevalo, A., Clavijo, V., Bernal, J., León, D., Tafur, M.A., Byrne, B.A., Smith, W.A., Perez-Gutierrez, E., 2015. The Establishment of the Colombian Integrated Program for Antimicrobial Resistance Surveillance (COIPARS): A Pilot Project on Poultry Farms, Slaughterhouses and Retail Market. Zoonoses and Public Health 62, 58–69.

EMPRES, 2000. RVF surveillance in West Africa. Bulletin 2000 15/3-4, 9. RVF. www.fao.org/3/a-x9550e.pdf (accessed 19/12/2017).

Epp, T., Waldner, C., Corrigan, R., Curry, P., 2008. Public Health Use of Surveillance for West Nile Virus in Horses: Saskatchewan, 2003-2005. Transbound. Emerg. Dis. 55, 411–416.

FAO, 2010. The FAO-OIE-WHO collaboration. Sharing responsibilities and coordinating global activities to address health risks at the animal-human-ecosystems interfaces. www.fao.org/3/a-i3579e.pdf (accessed 18/12/2017).

Founou, L.L., Founou, R.C., Essack, S.Y., 2016. Antibiotic Resistance in the Food Chain: A Developing Country-Perspective. Front. Microbiol. 7.

Galanis, E., Parmley, J., De With, N., 2012. Integrated surveillance of Salmonella along the food chain using existing data and resources in British Columbia, Canada. Food Res. Int. 45, 795–801.

Grant, J., Saxinger, L., Patrick, D., National Collaborating Centre for Infectious Diseases (Canada), 2014. Surveillance of antimicrobial resistance and antimicrobial utilization in Canada. http://www.deslibris.ca/ID/244350 (accessed 19/12/2017).

HAIRS, 2013. The processes of risk assessment undertaken by the Human Animal Infections Risks and Surveillance Group. http://www.hse.gov.uk/aboutus/meetings/committees/acdp/140213/acdp_100_p4c.pdf (accessed 19/12/2017).

Häsler, B., Gilbert, W., Jones, B.A., Pfeiffer, D.U., Rushton, J., Otte, M.J., 2012. The Economic Value of One Health in Relation to the Mitigation of Zoonotic Disease Risks, in: Mackenzie, J.S., Jeggo, M., Daszak, P., Richt, J.A. (Eds.), One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 127–151.

Häsler, B., Cornelsen, L., Bennani, H., Rushton, J., 2014. A review of the metrics for One Health benefits. Rev Sci Tech. 33, 453–64.

Hattendorf, J., Bardosh, K.L., Zinsstag, J., 2017. One Health and its practical implications for surveillance of endemic zoonotic diseases in resource limited settings. Acta Trop. 165, 268–273.

Jahn, T., Keil, F., 2015. An actor-specific guideline for quality assurance in transdisciplinary research. Futures 65, 195–208.

Jeggo M., Mackenzie J.S., 2014. Defining the future of One Health. Microbiol Spectrum 2(1):OH-0007-2012.

JIACRA, 2015. ECDC/EFSA/EMA first joint report on the integrated analysis of the consumption of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from humans and food-producing animals. http://www.ema.europa.eu/docs/en_GB/document_library/Report/2015/01/WC500181485.pdf (accessed 19/12/2017).

Johnson, I., Hansen, A., Bi, P., 2018. The challenges of implementing an integrated One Health surveillance system in Australia. Zoonoses Public Health 65, e229–e236.

Karimuribo, E.D., Beda, E., Wambura, P., Rweyemamu, M.M., Sayalel, K., Kusiluka, L.J., Short, N., Mboera, L.G., 2012. Towards One Health disease surveillance: the Southern African Centre for Infectious Disease Surveillance approach: proceeding. Onderstepoort J. Vet. Res.79, 1-7.

King, C.-C., Kao, C.-L., Liu, D.-P., Cheng, M.-C., Yen, H.-L., Lee, M.-S., Tsai, C.-P., Shih, S.-R., Shieh, H.K., Hsiu, J.-P., 2001. Seven integrated influenza surveillance systems in Taiwan, in: ICS. Elsevier, pp. 107–118.

Lapiz, S.M.D., Miranda, M.E.G., Garcia, R.G., Daguro, L.I., Paman, M.D., Madrinan, F.P., Rances, P.A., Briggs, D.J., 2012. Implementation of an Intersectoral Program to Eliminate Human and Canine Rabies: The Bohol Rabies Prevention and Elimination Project. PLoS Negl. Trop. Dis. 6, 1891.

Lee L.M., Thacker S.B., 2011. Public health surveillance and knowing about health in the context of growing sources of health data. Am J Prev Med. 41, 636–40.

Malone T., Culver M., 2008. Managing public health risks: role of integrated ocean observing systems (IOOS), in: Walsh P. J., Smith S., Fleming L., Solo-Gabriele H., Gerwick W.H. (EDS.), 2011. Oceans and Human Health: Risks and Remedies from the Seas. Academic Press, pp. 21-33.

Marka, A., Diamantidis, A., Papa, A., Valiakos, G., Chaintoutis, S., Doukas, D., Tserkezou, P., Giannakopoulos, A., Papaspyropoulos, K., Patsoula, E., Badieritakis, E., Baka, A., Tseroni, M., Pervanidou, D., Papadopoulos, N., Koliopoulos, G., Tontis, D., Dovas, C., Billinis, C., Tsakris, A., Kremastinou, J., Hadjichristodoulou, C., 2013. West Nile Virus State of the Art Report of MALWEST Project. Int. J. Environ. Res. Public Health 10, 6534–6610.

McNamara, T., Platonov, A., Elleman, T., Gresham, L., 2013. The Human-Animal Interface and Zoonotic Threats: The Russian Federation Approach. Biosecur Bioterror. 11, 185-195.

Ministry of Health, France, 2012. [Circulaire interministérielle DGS/RI1/DGALN/DGAL no 2012-360 du 1er octobre 2012 relative aux mesures visant à limiter la circulation du virus West Nile en France métropolitaine]. circulaires.legifrance.gouv.fr/pdf/2017/04/cir_42120.pdf (accessed 18/12/2017).

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Intern Med. 151, 264-9.

Morgan, D., 2006. Control of arbovirus infections by a coordinated response: West Nile Virus in England and Wales. Immunol. Med. Microbiol. 48, 305–312.

Morgan, D., Kirkbride, H., Hewitt, K., Said, B., Walsh, A.L., 2009. Assessing the risk from emerging infections. Epidemiol. Infect. 137, 1521.

Napoli, C., Iannetti, S., Rizzo, C., Bella, A., Di Sabatino, D., Bruno, R., Sauro, F., Martini, V., Santucci, V.U., Declich, S., Calistri, P., 2015. Vector Borne Infections in Italy: Results of the Integrated Surveillance System for West Nile Disease in 2013. BioMed Res. Int. 1–8.

NARMS, 2016. 2015 integrated report of the national antimicrobial monitoring system. https://www.fda.gov/downloads/AnimalVeterinary/SafetyHealth/AntimicrobialResistance/National AntimicrobialResistanceMonitoringSystem/UCM581468.pdf (accessed 19/12/2017).

NORM-NORMVET, 2016. Report on Usage of Antimicrobial Agents and Occurrence of Antimicrobial Resistance in Norway in 2015. https://unn.no/Documents/Kompetansetjenester,%20-sentre%20og%20fagr%C3%A5d/NORM%20-%20Norsk%20overv%C3%A5kingssystem%20for%20antibiotikaresistens%20hos%20mikrober/Rapporter/NORM_NORM-VET-2015.pdf (accessed 19/12/2017).

OIE, 2006. Global Early Warning and Response System for Major Animal Diseases, including Zoonoses (GLEWS). https://www.oie.int/doc/ged/D11304.PDF (accessed 18/12/2017).

ONERBA, 2016. 2015 Annual report (Edition November 2016). Scientific board of Onerba. http://onerba.org/onerba-2015/ (accessed 18/12/2017).

Pearce, N., Douwes, J., 2013. Research at the interface between human and veterinary health. Prev. Vet. Med. 111, 187–193.

Petrić, D., Petrović, T., Hrnjaković Cvjetković, I., Zgomba, M., Milošević, V., Lazić, G., Ignjatović Ćupina, A., Lupulović, D., Lazić, S., Dondur, D., Vaselek, S., Živulj, A., Kisin, B., Molnar, T., Janku, D., Pudar, D., Radovanov, J., Kavran, M., Kovačević, G., Plavšić, B., Jovanović Galović, A., Vidić, M., Ilić, S., Petrić, M., 2017. West Nile virus "circulation" in Vojvodina, Serbia: Mosquito, bird, horse and human surveillance. Molecular and Cellular Probes 31, 28–36.

Polley, L., Gaschler, C., Gajadhar, A., 2000. National occurrence reporting of Trichinella and trichinellosis using a computerized database. Vet. Parasitol. 93, 351–363.

Queenan, K., Häsler, B., Rushton, J., 2016. A One Health approach to antimicrobial resistance surveillance: is there a business case for it? Int. J. Antimicrob. Agents 48, 422–427.

Queenan, K., 2017. Roadmap to a One Health agenda 2030. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 12.

Reif, J.S., 2011. Animal sentinels for environmental and public health. Public Health Rep. 126, 50–57.

RISKSUR consortium. Best practices for risk-based and cost effective animal health surveillance in the European Union. https://www.fp7-risksur.eu//progress/best-practice-document (accessed 18/12/2017).

Rizzo, C., Salcuni, P., Nicoletti, L., Ciufolini, M.G., Russo, F., Masala, R., Frongia, O., Finarelli, A.C., Gramegna, M., Gallo, L., 2012. Epidemiological surveillance of West Nile neuroinvasive diseases in Italy, 2008 to 2011. Euro Surveill. 17, 20172.

Rizzo, C., Napoli, C., Venturi, G., Pupella, S., Lombardini, L., Calistri, P., Monaco, F., Cagarelli, R., Angelini, P., Bellini, R., Tamba, M., Piatti, A., Russo, F., Palù, G., Chiari, M., Lavazza, A., Bella, A., the Italian WNV surveillance working group, 2016. West Nile virus transmission: results from the integrated surveillance system in Italy, 2008 to 2015. Euro Surveill. 21, 30340.

Roth, F., Zinsstag, J., Orkhon, D., Chimed-Ochir, G., Hutton, G., Cosivi, O., Carrin, G., Otte, J., 2003. Human health benefits from livestock vaccination for brucellosis: case study. Bull. World Health Organ. 81, 867–876.

Roth, D., 2011. Surveillance for emerging infectious diseases: a Canadian perspective. National Collaborating Centre for Environmental Health. http://www.ncceh.ca/sites/default/files/Surveillance_Emerging_Infectious_Diseases_Dec_2011_0.pdf (accessed 19/12/2018).

Rüegg, S.R., McMahon, B.J., Häsler, B., Esposito, R., Nielsen, L.R., Ifejika Speranza, C., Ehlinger, T., Peyre, M., Aragrande, M., Zinsstag, J., Davies, P., Mihalca, A.D., Buttigieg, S.C., Rushton, J., Carmo, L.P., De Meneghi, D., Canali, M., Filippitzi, M.E., Goutard, F.L., Ilieski, V., Milićević, D., O'Shea, H., Radeski, M., Kock, R., Staines, A., Lindberg, A., 2017. A Blueprint to Evaluate One Health. Front. Public Health 5, 20.

Rüegg, S.R., Nielsen, L.R., Buttigieg, S.C., Santa, M., Aragrande, M., Canali, M., Ehlinger, T., Chantziaras, I., Boriani, E., Radeski, M., Bruce, M., Queenan, K., Häsler, B., 2018. A Systems Approach to Evaluate One Health Initiatives. Front. Vet. Sci. 5, 23.

Shuai, J., Buck, P., Sockett, P., Aramini, J., Pollari, F., 2006. A GIS-driven integrated real-time surveillance pilot system for national West Nile virus dead bird surveillance in Canada. Int. J. Health Geogr. 5, 17.

Sleigh, A., Li, X., Jackson, S., Huang, K., 1998. Eradication of schistosomiasis in Guangxi, China. Part 1: Setting, strategies, operations, and outcomes, 1953-92. Bull. World Health Organ. 76(4), 361-372.

Sleigh, A., Jackson, S., Li, X., Huang, K., 1998. Eradication of schistosomiasis in Guangxi, China. Part 2: Political economy, management strategy and costs, 1953-92. Bull. World Health Organ. 76(5), 497-508.

Sorensen, A.C., Lawrence, R.S., Davis, M.F., 2014. Interplay between policy and science regarding low-dose antimicrobial use in livestock. Front. Microbiol. 5,86.

Stärk, K.D.C., Arroyo Kuribreña, M., Dauphin, G., Vokaty, S., Ward, M.P., Wieland, B., Lindberg, A., 2015. One Health surveillance – More than a buzz word? Prev. Vet. Med. 120(1), 124–130.

SWAB, 2016. Consumption of antimicrobial agents and antimicrobial resistance among medically important bacteria in the Netherlands and Monitoring of Antimicrobial Resistance and Antibiotic Usage in Animals in the Netherlands in 2015. https://www.wur.nl/upload_mm/0/b/c/433ca2d5-c97f-4aa1-ad34-a45ad522df95_92416_008804_NethmapMaran2016+TG2.pdf (accessed 19/12/2017).

SWEDES, 2015. Consumption of antibiotics and occurrence of antibiotic resistance in Sweden. http://www.sva.se/globalassets/redesign2011/pdf/om_sva/publikationer/swedres_svarm2015.pdf (accessed 19/12/2017).

Talaska, T., 1994. A salmonella data bank for routine surveillance and research. Bull World Health Organ 72(1): 69-72.

Uchtmann, N., Herrmann, J.A., Hahn, E.C., Beasley, V.R., 2015. Barriers to, Efforts in, and Optimization of Integrated One Health Surveillance: A Review and Synthesis. EcoHealth 12(2), 368–384.

Vandermissen A., Welburn S.C., 2014. Current initiatives in One Health: consolidating the One Health Global Network. Rev. sci. tech. Off. int. Epiz., 33 (2), 421-432.

Vrbova, L., Patrick, D.M., Stephen, C., Robertson, C., Koehoorn, M., Parmley, E.J., De With, N.I., Galanis, E., 2016. Utility of algorithms for the analysis of integrated *Salmonella* surveillance data. Epidemiol. Infect. 144(10), 2165–2175.

Wahl, T.G., Burdakov, A.V., Oukharov, A.O., Zhilokov, A.K., 2012. Electronic Integrated Disease Surveillance System and Pathogen Asset Control System. Onderstepoort J Vet Res. Jun 20;79(2), 455.

WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR), 2017. Integrated surveillance of antimicrobial resistance in foodborne bacteria. Application of a One Health approach. http://apps.who.int/iris/bitstream/10665/255747/1/9789241512411-eng.pdf?ua=1 (accessed 20/12/2017).

Wielinga, P.R., Jensen, V.F., Aarestrup, F.M., Schlundt, J., 2014. Evidence-based policy for controlling antimicrobial resistance in the food chain in Denmark. Food Control 40, 185–192.

Witt, C.J., Brundage, M., Cannon, C., Cox, K., 2004. Department of Defense West Nile virus surveillance in 2002. Mil. Med. 169, 6, 421-428.

Witt, C.J., Richards A.L., Masuoka P.M., Foley D.H., Buczak A.L., Musila L.A., Richardson J.H., Colacicco-Mayhugh M.G., Rueda L.M., Klein T.A., Anyamba A., Small J., Pavlin J.A., Fukuda M.M., Gaydos J., Russell K.L., 2011. The AFHSC-Division of GEIS Operations Predictive Surveillance Program: a multidisciplinary approach for the early detection and response to disease outbreaks. BMC Public Health 2011, 11(Suppl 2):S1.

Zinsstag, J., Schelling, E., Waltner-Toews, D., Tanner, M., 2011. From “one medicine” to “one health” and systemic approaches to health and well-being. Prev. Vet. Med. 101(3-4), 148-56.

Figure captions

Figure 1. PRISMA flow chart describing the study selection process within the systematic review.

Figure 2. Possible degrees of operational collaboration at the different steps of the surveillance process.

Figure 3. Organisation of collaboration in a One Health surveillance system: a conceptual framework.

Table 1. Terms for search in bibliographic databases

Domains	Key words
Surveillance	Surveillance OR monitor*
One Health approach	“one health”, “one medicine”, ecohealth, holistic, “global health”, “integrated surveillance”, “integrated approach”, “integrated system”, “integrated data”, “integrating data”, inter-sector*, intersector*, cross-sector*, multi-sector*, multisector*, interdisciplinar*, inter-disciplinar*, multidisciplinar*, multi-disciplinar*, trans-disciplinar*, transdisciplinar*
Health hazard	disease* OR infection OR zoono* OR syndrom* OR outbreak* OR hazard* OR environment* OR residue* OR pesticid* OR pathogen OR bacteria OR antimicrobial* OR “antibiotic resistance”* OR virus OR parasit* OR contaminant* OR toxin*
Population	animal*, livestock, veterinar*, fish*, aquaculture, wildlife, food, herd*, farm*, cattle, cow*, bovine, ruminant*, pig, pigs, swine, poultry, bird*, avian , horse*, equine, dog*, cat, cats, sheep, goat*, plant*

*truncation operator

Table 2. Variables used for the characterisation of the surveillance systems

Level		Variable
Coordination of the surveillance system	1	Mono or multi-institutional coordination
	2	Number of institutions in charge of the coordination
	3	Type of institutions involved in the coordination (government, academia, independent agency, etc.)
	4	Administrative-level in charge of the coordination
	5	Number of sectors involved in the coordination
	6	Type of sectors in charge of the coordination
Geographical area	7	Level of coverage of the surveillance (supra-national, national, subnational)
	8	Territory under surveillance
Date	9	Year of establishment of first collaborative efforts
General organisation	10	Status of the surveillance system (stand-alone or part of a programme)
	11	Origin of funds (state, private, external, etc.)
	12	Sustainability of funding
	13	*A priori* or *a posteriori* integration of sectoral surveillance components
Objectives and purposes	14	Objectives of the surveillance system
	15	Purposes of the surveillance systems
Hazards under surveillance	16	Number of hazards (mono or multi-hazards)
	17	Type of hazards
	18	Communicability of hazards under surveillance
Domains under surveillance	19	Type of domains under surveillance (domestic animal, human, food, wildlife, etc.)
	20	Number of domains under surveillance
	21	Data sources in each domain
	22	Type of data in each domain
	23	Epidemiological status in each domain
Terminology	24	Terms which are used to describe inter-sectoral and inter-disciplinary collaboration
Type of collaboration	25	Type of sectors collaborating within the surveillance process
	26	Mechanisms in place to support institutional collaboration

	27	Decision-making scales involved in surveillance activities (supra-national authorities/organisations, national authorities, sub-national authorities, etc.)
	28	Private actors involved in surveillance activities (veterinarians, food/feed operators, pharmaceutical companies, etc.)
	29	Type of collaborative efforts for surveillance activities (conception of the surveillance protocol, joint sampling campaigns, laboratory facilities sharing, data exchange, inter-sectoral data analysis and interpretation, etc.)
	30	Mechanisms in place to support collaboration for surveillance activities
	31	Type of collaborative efforts for dissemination of surveillance results
	32	Mechanisms in place to support collaboration for dissemination of surveillance results
	33	Type of disciplines involved in the surveillance process
Factors influencing collaboration	34	Favouring factors for collaboration
	35	Barriers to collaboration
Performance of the surveillance system	36	Elements supporting evidence of a good performance of the system
	37	Elements supporting evidence of a bad performance of the system
Benefits	38	Elements supporting evidence of benefits of collaboration

Table 3. Principal characteristics of the existing surveillance systems.

System	Hazard(s)	Domain(s)	Primary objective and purpose	Coordination	Sectors collaborating	Inter-sectoral collaboration for data collection, exchange and analysis	References
The Surveillance of West Nile Virus in France	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid response	Multiple institutions (Animal health, Public health)	Animal health Environment Public health	Cross-sectoral notifications of unusual health events	Ministry of Health, 2012
The Surveillance of West Nile Virus in Vojvodina (Serbia)	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid response	Multiple institutions (Animal health, Public health)	Animal health Public health	Multi-domain data analysis by 1 institution	Petrić et al., 2017
The Surveillance of West Nile Virus in Saskatchewan (Canada)	West Nile virus	Domestic animal Environment Human Wildlife	Trends monitoring to support intervention design/evaluation	Multiple institutions (Animal health, Public health)	Animal health Public health	Continuous inter-sectoral data exchange Multi-domain data analysis by 1 institution	Shuai et al., 2006; Epp et al., 2008
The West Nile Virus Integrated Surveillance System in Greece	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid response	Single institution (Public Health)	Animal health Public health	Cross-sectoral notification of unusual health events Multi-domain data analysis by 1 institution	Marka et al., 2013
The West Nile Virus Integrated Surveillance System in the Emilia-Romagna Region	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid response	Single institution (Public Health)	Animal health Public health	Continuous inter-sectoral data exchange	Angelini et al., 2010; Bellini et al. 2014
West Nile Virus Surveillance in Italy	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid response	Single institution (Public Health)	Animal health Public health	Continuous inter-sectoral data exchange Joint inter-sectoral data analysis	Rizzo et al., 2012; Napoli et al., 2015; Rizzo et al., 2016
The Surveillance of West Nile Virus in the United States (ArboNET)	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid risk prediction	Single institution (Public Health)	Animal health Environment Public health	Continuous inter-sectoral data exchange	CDC, 2013
The Surveillance of West Nile Virus in England and Wales	West Nile virus	Domestic animal Environment Human Wildlife	Early detection for rapid response	Single institution (Public Health)	Animal health Environment Public health	Continuous inter-sectoral data exchange Joint inter-sectoral data	Morgan D., 2006

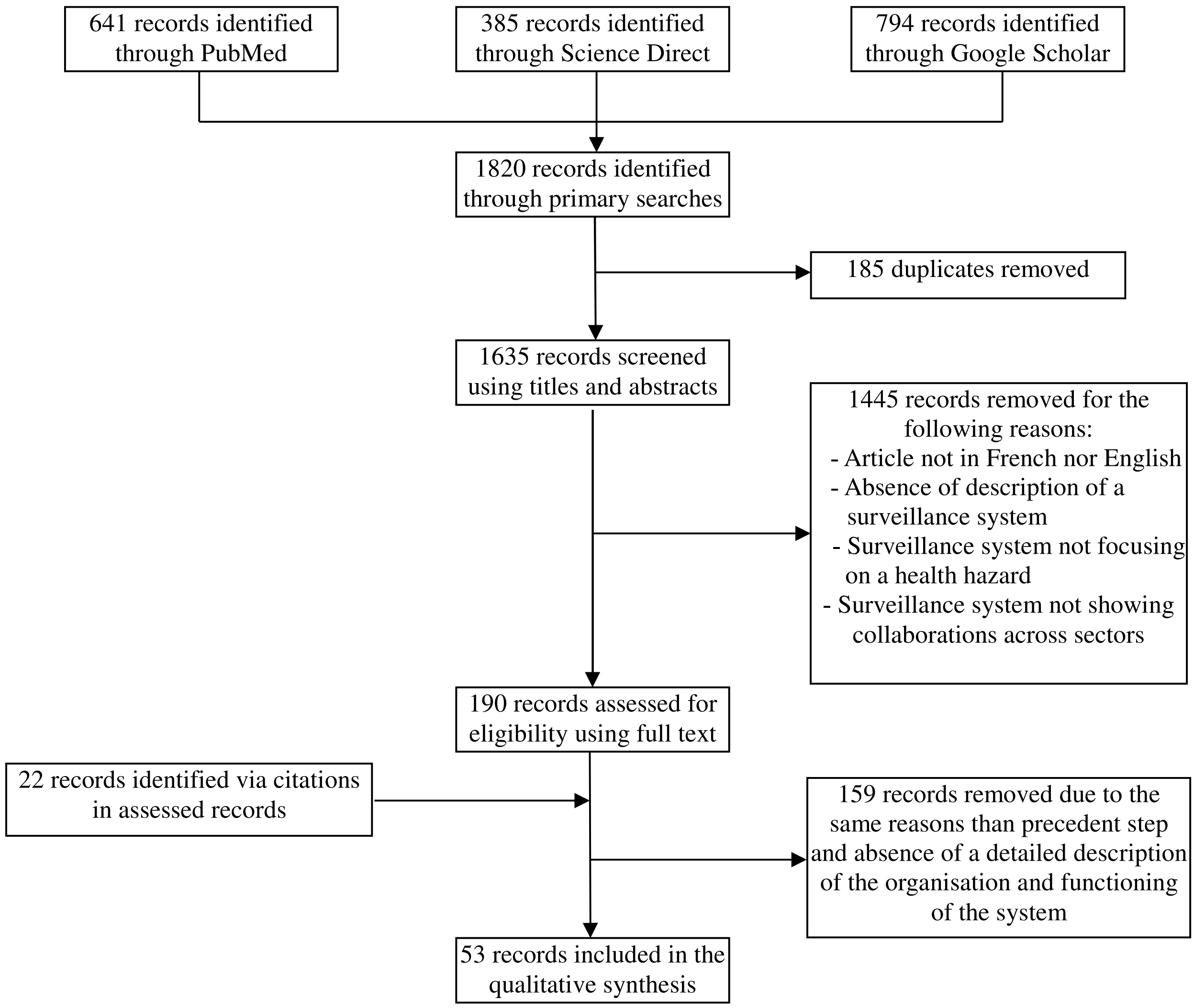
						analysis	
Surveillance of West Nile Virus in the United States in the Military Population	West Nile Virus	Domestic animal Environment Human Wildlife	Early detection for timely response	Multiple institutions (Animal health, Environment, Public health)	Animal health Environment Public health	Inter-sectoral collaboration for laboratory testing Continuous inter-sectoral data exchange Joint inter-sectoral data analysis	Witt et al., 2004
Surveillance of Rift Valley Fever in West Africa	Rift Valley virus	Domestic animal Environment	Early detection for rapid response	Single institution (Animal Health)	Animal health Public Health	Cross-sectoral notification of unusual health events	EMPRES, 2000
Influenza surveillance systems in Taiwan	Influenza virus	Domestic animal Human Wildlife	Early detection for rapid response	Multiple institutions (Animal health, Human health)	Animal health Public health	Cross-sectoral notification of unusual health events Joint inter-sectoral data analysis	King et al., 2001
California Mosquito-Borne Virus Surveillance and Response Plan	Vector-borne diseases	Domestic animal Environment Human Wildlife	Early detection for rapid response	Single institution (Public Health)	Animal health Public health	Continuous inter-sectoral data exchange	Brown E.G., 2012.
The surveillance of Rabies in Ethiopia	Rabies	Domestic animal Human Wildlife	Early detection for eradication or control	Single institution (Public health)	Animal health Environment Public health	Cross-sectoral notification of unusual health events	Coetzer et al., 2016
The surveillance of rabies in Bohol (Philippines)	Rabies	Animal health Human health	Early detection for rapid response	Multiple institutions (Animal health, Human health)	Animal health Human health	Cross-sectoral notification of unusual health events	Lapiz et al., 2012
The surveillance of rabies in Tamil Nadu (India)	Rabies	Domestic animal Human	Early detection for rapid response	Single institution (Animal health, Public health)	Animal health Public health	Cross-sectoral notification of unusual health events	Abbas et al., 2011
The surveillance of schistosomiasis in Guangxi (China)	Schistosomiasis	Domestic animal Environment Human	Trends monitoring for eradication or control	Single institution (Public health, Animal Health)	Animal health Environment Public health	Multi-domain surveillance implemented by 1 institution	Sleigh et al., 1998a; Sleigh et al., 1998b
The surveillance of zoonotic diseases in the Russian Federation	Zoonotic diseases	Human Wildlife Environment	Early detection for timely response	Public health	Animal Health Public Health	Multi-domain surveillance implemented by 1 institution	McNamara et al., 2013
The Electronic Integrated Disease Surveillance System (EIDSS)	Zoonotic diseases	Human Domestic animal	Early detection for timely response	Multiple institutions (Animal health,	Animal health Public health	Continuous inter-sectoral data exchange	Wahl et al., 2012

		Environment		Public health)		Joint inter-sectoral data analysis	
The inter-sectoral surveillance of zoonotic diseases in Mongolia	Zoonotic diseases	Domestic animal Human Wildlife	Early detection for timely response	Single institution (Animal health, Public health)	Animal health Environment Public health	Joint sampling campaigns Inter-sectoral collaboration for laboratory testing Inter-sectoral data exchange	Batsukh et al., 2012
Global Early Warning and Response System	Zoonotic diseases	Domestic animal Human Wildlife	Early detection for rapid risk assessment	Multiple institutions (Animal health, Food safety, Public health)	Animal health, Food safety, Public health	Cross-sectoral notification of unusual health events Joint inter-sectoral data analysis	OIE, 2006
Th Human Animal Infections and Risk Surveillance (HAIRS)	Zoonotic diseases	Domestic animal Human	Early detection for rapid risk assessment	Single institution (Public health)	Animal health Environment Food safety Plant health Public health	Planning Joint inter-sectoral data analysis	Morgan et al., 2009; HAIRS, 2013
The AFHSC - Division of GEIS operations predictive surveillance programme	Zoonotic diseases	Depends on the surveillance context	Early detection for rapid risk assessment	Single institution (Public health)	Depends on surveillance context	Continuous inter-sectoral data exchange Joint inter-sectoral data analysis	Witt et al., 2011
The surveillance of zoonotic diseases in New South Wales	Zoonotic diseases	Domestic animal Human Wildlife	Early detection for rapid response	Multiple institutions (Animal health, Environment, Public health)	Animal health Environment Public health	Cross-sectoral notification of unusual health events	Adamson et al., 2011
The surveillance of zoonotic diseases in European Union	Zoonotic diseases	Domestic animal Food Human	Trends monitoring to support interventions design/evaluation	Single institution (Animal health, Food safety)	Animal health Food safety Public health	Multi-domain data analysis by 1 institution	Ammon et al., 2010
The Animal Health Information Network in Canada (RAIZO)	Zoonotic diseases Antibiotic resistance	Domestic animal	Trends monitoring to support interventions design/evaluation	Single institution (Animal Health)	Animal health Public Health	Continuous inter-sectoral data exchange	Roth D., 2011
National Observatory of the Epidemiology of Bacterial Resistance to Antibiotics (ONERBA)	Antibiotic resistance	Domestic animal Human	Trends monitoring to improve knowledge	Multiple institutions (Animal health, Public health)	Animal health Public health	Inter-sectoral data sharing	ONERBA, 2016

The Swedish Antimicrobial Resistance Monitoring programme (STRAMA/SVARM)	Antibiotic resistance	Domestic animal Food Human Wildlife	Trends monitoring to support intervention design/evaluation	Multiple institutions (Animal health, Public health)	Animal health Food safety Public health	Cross-sectoral notification of unusual health events Joint inter-sectoral data analysis	SWEDES, 2015
The Dutch Integrated Antimicrobial Resistance Monitoring Programme (NethMap/MARAN)	Antibiotic resistance	Domestic animal Food Human Wildlife	Trends monitoring to improve knowledge	Multiple institutions (Animal health, Food safety, Public health, Plant health),	Animal health Environment Food safety Plant health Public health	Continuous inter-sectoral data exchange	SWAB, 2016
Canadian Integrated Programme for Antimicrobial Resistance Surveillance (CIPARS)	Antibiotic resistance	Domestic animal Food Human	Trends monitoring to support interventions design/evaluation	Single institution (Public health)	Food safety Public health	Multi-domain surveillance implemented by 1 institution	Grant et al., 2014; CIPARS, 2015
Antibiotic resistance programme in the European Union	Antibiotic resistance	Domestic animal Food Human	Trends monitoring to support interventions design/evaluation	Multiple institutions (Animal health, Food safety, Public health)	Animal health Food safety Public health	Joint inter-sectoral data analysis	JIACRA, 2015.
National antimicrobial resistance monitoring system in the United States (NARMS)	Antibiotic resistance	Domestic animal Food Human	Trends monitoring to improve knowledge	Multiple institutions (Animal health, Food safety, Public health)	Animal health Food safety Public health	Joint inter-sectoral data analysis	NARMS, 2016, Sorensen et al., 2014
The Danish integrated antimicrobial resistance monitoring programme (DANMAP)	Antibiotic resistance	Domestic animal Food Human	Trends monitoring to improve knowledge	Multiple institutions (Animal health Fisheries Food safety Public health)	Animal health Environment Fisheries Food safety Public health	Continuous inter-sectoral data exchange Joint inter-sectoral data analysis	Wielinga et al., 2014; Danmap, 2016
The Colombian integrated programme for antimicrobial resistance surveillance (COIPARS)	Antibiotic resistance	Domestic animal Food Human	Trends monitoring to improve knowledge	Single institution (Animal health, Food safety)	Animal health Food safety	Joint inter-sectoral data analysis	Donado-Godoy et al., 2015
Norwegian Surveillance System for Antimicrobial Drug Resistance in Norway (NORM) and NORM-Vet	Antibiotic resistance	Domestic animal Food Human Wildlife	Trends monitoring to support interventions design/evaluation	Multiple institutions (Animal health, Food safety, Public health)	Animal health Food safety Public health	*	NORM-NORMVet, 2016
The *Salmonella* Data Bank for Routine Surveillance in	*Salmonella*	Domestic animal Food Human	Early detection for eradication or control	Single institution (Public Health)	Animal health Food safety	Continuous inter-sectoral data exchange	Talaska T., 1994

Brandenburg (Germany)					Public health	Multi-domain data analysis by 1 institution	
The integrated *Salmonella* surveillance programme in Canada	*Salmonella*	Domestic animal Food Human	Trends monitoring to improve knowledge	Multiple institutions (Animal health, Food safety, Public health)	Animal health Food safety Public health	Joint inter-sectoral data analysis	Galanis et al., 2012; Vrbova et al., 2016
The surveillance of *Salmonella* in France	*Salmonella*	Domestic animal Food Human	Early detection for eradication or control	Multiple institutions (Animal health, Food safety, Public health)	Animal health Food safety Public health	Continuous inter-sectoral data exchange Multi-domain data analysis by 1 institution	Danan et al., 2011; David et al., 2011
The surveillance of *Campylobacter* in Switzerland	*Campylobacter*	Domestic animal Human	Trends monitoring to support intervention design/evaluation	Multiple institutions (Animal health, Public health)	Animal health Public health	Joint inter-sectoral data analysis	Babo Martins et al., 2017
The Surveillance of Harmful Algae Bloom in the Gulf of Mexico (USA)	Harmful algae bloom	Environment	Early detection for rapid response	Single institution (Environment)	Environment Fisheries Public health	Cross-sectoral notification of health events	Abelsohn et al., 2009
The environmental public health tracking program in the United States	Environmental hazards	Environment Human	Trends monitoring to support interventions design/evaluation	Single institution (Public Health)	Public Health Environment	Multi-domain data analysis by 1 institution	CDC, 2004; Malone and Culver 2008

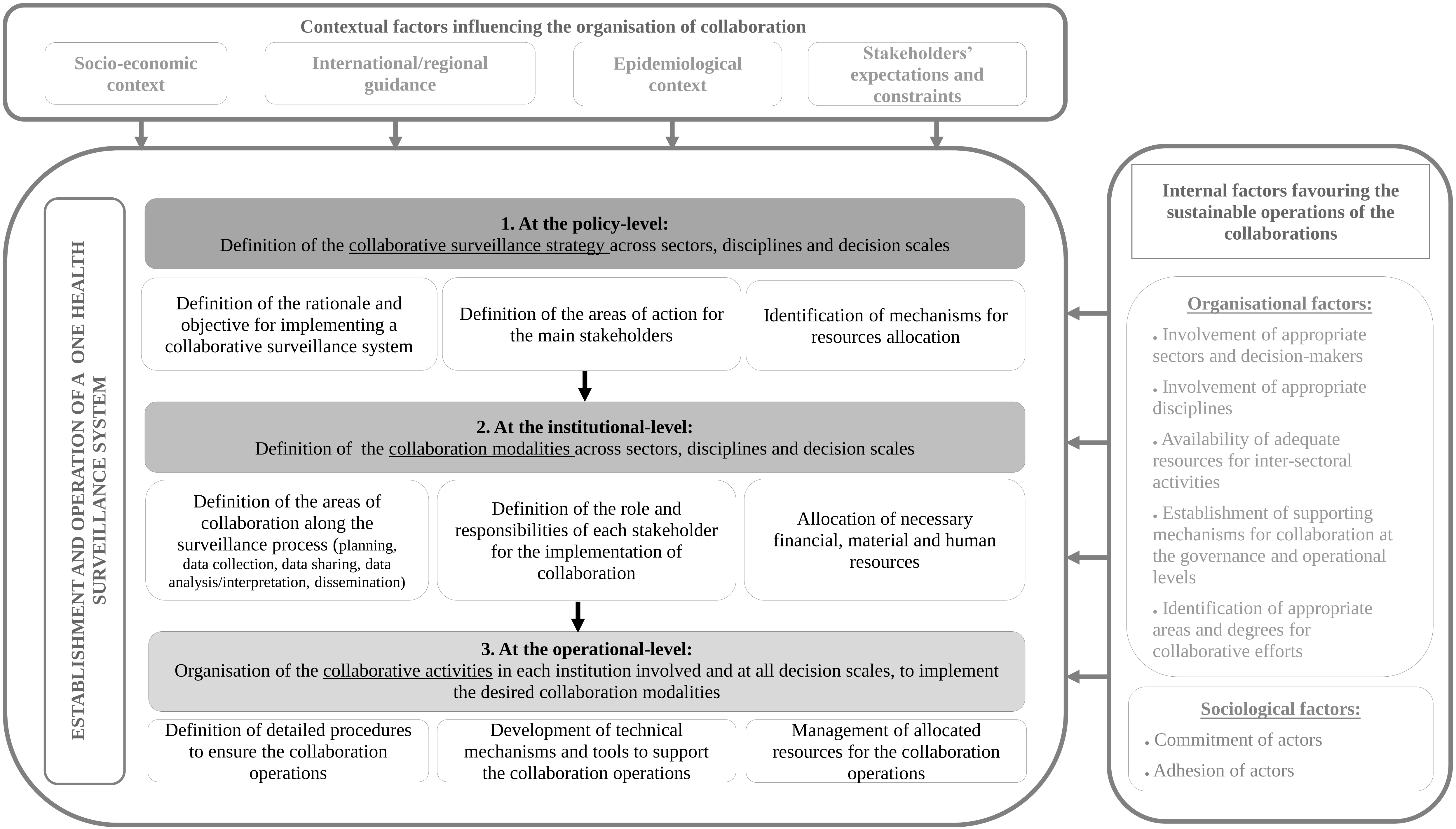
* inter-sectoral collaboration occurs only for the dissemination of surveillance results



641 records identified through PubMed
385 records identified through Science Direct
794 records identified through Google Scholar
1820 records identified through primary searches
185 duplicates removed
1635 records screened using titles and abstracts
1445 records removed for the following reasons:
- Article not in French nor English
- Absence of description of a surveillance system
- Surveillance system not focusing on a health hazard
- Surveillance system not showing collaborations across sectors
190 records assessed for eligibility using full text
22 records identified via citations in assessed records
159 records removed due to the same reasons than precedent step and absence of a detailed description of the organisation and functioning of the system
53 records included in the qualitative synthesis

Step of the surveillance process	Possible degrees of collaboration				
Planning	Undertaken separately in each sector	Undertaken by a single sector for all surveillance components	Cross-sectoral consultation but undertaken separately in each sector	Undertaken by a multi-sectoral working group	Undertaken by a multi-sectoral body
Data collection (sampling – laboratory testing)	Undertaken separately in each sector	Undertaken by a single sector for all components	Harmonisation across sectors	Joint activities across sectors	Undertaken by a multi-sectoral body
Data sharing	No data exchange	Notification of unusual events only	Ongoing data exchange		
Data analysis/ interpretation	Undertaken separately in each sector	Undertaken separately and then compared by a single sector	Jointly undertaken by a single sector for all components	Undertaken separately and then compared by a multi-sectoral working group	Jointly undertaken by a multi-sectoral working group or body
Results dissemination	Undertaken separately for each sector	Joint dissemination in separate sectoral activities	Joint dissemination by a single sector	Joint dissemination by a multi-sectoral working group	Joint dissemination by a multi-sectoral body

Figure 2. Possible degrees of operational collaboration at the different steps of the surveillance pr


Contextual factors influencing the organisation of collaboration
Socio-economic context
International/regional guidance
Epidemiological context
Stakeholders' expectations and constraints
ESTABLISHMENT AND OPERATION OF A ONE HEALTH SURVEILLANCE SYSTEM
1. At the policy-level:
Definition of the collaborative surveillance strategy across sectors, disciplines and decision scales
Definition of the rationale and objective for implementing a collaborative surveillance system
Definition of the areas of action for the main stakeholders
Identification of mechanisms for resources allocation
2. At the institutional-level:
Definition of the collaboration modalities across sectors, disciplines and decision scales
Definition of the areas of collaboration along the surveillance process (planning, data collection, data sharing, data analysis/interpretation, dissemination)
Definition of the role and responsibilities of each stakeholder for the implementation of collaboration
Allocation of necessary financial, material and human resources
3. At the operational-level:
Organisation of the collaborative activities in each institution involved and at all decision scales, to implement the desired collaboration modalities
Definition of detailed procedures to ensure the collaboration operations
Development of technical mechanisms and tools to support the collaboration operations
Management of allocated resources for the collaboration operations
Internal factors favouring the sustainable operations of the collaborations
Organisational factors:
• Involvement of appropriate sectors and decision-makers
• Involvement of appropriate disciplines
• Availability of adequate resources for inter-sectoral activities
• Establishment of supporting mechanisms for collaboration at the governance and operational levels
• Identification of appropriate areas and degrees for collaborative efforts
Sociological factors:
• Commitment of actors
• Adhesion of actors