Review and analysis of national monitoring systems for antimicrobial resistance in animal bacterial pathogens in Europe: a basis for the development of the European Antimicrobial Resistance Surveillance network in Veterinary medicine (EARS-Vet)

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Abstract

The monitoring of antimicrobial resistance (AMR) in bacterial pathogens of animals is not currently coordinated at European level. To fill this gap, experts of the European Union Joint Action on Antimicrobial Resistance and Healthcare Associated Infections (EU-JAMRAI) recommended building the European Antimicrobial Resistance Surveillance network in Veterinary medicine (EARS-Vet). In this study, we (i) identified national monitoring systems for AMR in bacterial pathogens of animals (both companion and food-producing) among 27 countries affiliated to EU-JAMRAI, (ii) described their structures and operations, and (iii) analyzed their respective strengths, weaknesses, opportunities and threats. Twelve countries reported having at least one national monitoring system in place, representing an opportunity to launch EARS-Vet, but highlighting important gaps in AMR data generation in Europe. In total, 15 national monitoring systems from 11 countries were described and analyzed. They displayed diverse structures and operations, but most of them shared common weaknesses (e.g. data management and representativeness) and common threats (e.g. economic vulnerability and data access), which could be addressed collectively under EARS-Vet. This work generated useful information to countries planning to build or improve their system, by learning from others’ experience. It also enabled to advance on a pragmatic harmonization strategy: EARS-Vet would follow the European Committee on Antimicrobial Susceptibility Testing (EUCAST) standards, collect quantitative data and interpret AMR data using epidemiological cut-off values.

Introduction

The monitoring of antimicrobial resistance (AMR) in bacterial pathogens of animals (i.e. in clinical isolates from diseased animals) is not currently coordinated at European level. To fill this surveillance gap, experts of the European Union Joint Action on AMR and Healthcare Associated Infections (EU-JAMRAI) (<https://eu-jamrai.eu/>), which aims to strengthen the European One Health strategy to tackle AMR (European Commission, 2017), recommended building the European Antimicrobial Resistance Surveillance network in Veterinary medicine (EARS-Vet) (Mader et al., 2021a). The objectives of EARS-Vet would be to report on the current AMR situation, follow AMR trends and detect emerging AMR in bacterial pathogens of animals in Europe. The information generated would contribute to: (i) advise policy makers on interventions to mitigate AMR, taking the One Health approach, (ii) monitor the impact of European efforts to tackle AMR in the animal sector, (iii) support antimicrobial stewardship initiatives, especially the development of antimicrobial treatment guidelines in veterinary medicine, (iv) evaluate or revise marketing authorizations of antimicrobials, (v) generate epidemiological cut-off values (ECOFFs) and clinical breakpoints for the interpretation of antimicrobial susceptibility testing (AST) results, (vi) assess the risk of AMR transmission between animals and humans via non-food related routes, e.g. by direct contact between humans and companion or food animals, and (vii) estimate the burden of AMR in animal health, e.g. attributable deaths and morbidity caused by infections with antimicrobial-resistant bacteria in animals.

In the One Health approach, EARS-Vet should be designed to complement and integrate with existing European monitoring systems for AMR, i.e. the European Antimicrobial Resistance Surveillance Network (EARS-Net) (European Centre for Disease Prevention and Control, 2020) and the European Food- and Waterborne Diseases and Zoonoses Network (FWD-Net) in the human sector (European Centre for Disease Prevention and Control, 2016; European Food Safety Authority and European Centre for Disease Prevention and Control, 2020), as well as the AMR monitoring in zoonotic and indicator bacteria, coordinated by the European Food Safety Authority (EFSA), which covers healthy food-producing animals, (European Food Safety Authority and European Centre for Disease Prevention and Control, 2020).

It was also agreed by EU-JAMRAI experts that EARS-Vet should work as a European network of national monitoring systems (Mader et al., 2021a). Thus, in a bottom-up approach, an important step consisted of reviewing and analyzing existing national systems in Europe to allow for the development of an EARS-Vet surveillance framework that considers what is relevant and feasible to monitor in countries, and to advance on a harmonization strategy. A definition of the EARS-Vet surveillance scope, i.e. the combinations of animal species, production types, bacterial species, clinical specimens and antimicrobials to be monitored in EARS-Vet was made by Mader et al. (Mader et al., 2021b). In brief, it covers cattle, swine, chicken, turkey, cats and dogs, with major bacterial diseases in each animal species, and antimicrobials of relevance to animal and / or public health. Although previous reviews of AMR monitoring systems in the animal sector have already been published (Schrijver et al., 2018; Mesa Varona et al., 2020), they did not focus on clinical animal isolates, did not consider companion animals and provided limited information on the structures and operations of systems.

To continue the development of the EARS-Vet surveillance framework, and support the establishment, improvement and harmonization of national monitoring systems for AMR in animal bacterial pathogens, the present study aimed to (i) identify existing national monitoring systems for AMR in bacteria from diseased animals among 27 countries affiliated to EU-JAMRAI (as potential future EARS-Vet participating countries), (ii) describe their structures and operations, and (iii) analyze their respective strengths, weaknesses, opportunities and threats (SWOT).

Materials and Methods

*Identification of national AMR* monitoring *systems in bacterial pathogens of animals*

EU-JAMRAI stakeholders from 27 countries of the EU/European Economic Area (EEA) were contacted in 2018-2020 and asked if a national monitoring system for AMR in bacterial pathogens of animals was in place in their country: Austria, Belgium, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Ireland, Latvia, Lithuania, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom. A national monitoring system for AMR in bacterial pathogens of animals was defined as any system collecting and regularly analyzing AST results produced on bacterial isolates from clinical samples of animals that can be considered as having a national coverage. However, no criteria were established on geographic data representativeness or scope of bacterial and animal species.

*Description and performance analysis of national AMR monitoring systems in diseased animals*

Stakeholders in individual countries who reported having a national monitoring system for AMR in diseased animals were invited to have their system described and performance analyzed, using a common methodology across participating countries.

The description of existing national AMR monitoring systems was done through a questionnaire covering the following key areas: (i) political and financial support, (ii) objectives, (iii) central institutional organization, (iv) laboratory network, (v) monitoring procedures, (vi) laboratory techniques, (vii) data management and analysis, (viii) communication and (ix) evaluation.

The performance analysis of national monitoring systems was done using SWOT (strengths, weaknesses, threats and opportunities) analyses (Renault). In countries where several national systems were identified, only one SWOT analysis was carried out, to assess the overall picture at national level.

Both questionnaires and SWOT analyses were completed in 2019 - 2020 during one-day physical meetings, except for one country (Estonia), where two virtual meetings were organized due to travel restrictions linked to the COVID-19 pandemic. Each physical or virtual meeting was jointly organized by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) and the EU-JAMRAI partner institution(s) of the visited country. Participants were relevant national stakeholders, including the coordinator(s) and key experts of the national AMR monitoring system, as well as an expert from ANSES, who conducted the questionnaire and facilitated the completion of the SWOT analyses. Frequently reported topics in SWOT analyses were identified *a posteriori* and used to describe the main strengths, weaknesses, threats and opportunities of national monitoring systems.

Results

**Identification of national monitoring systems for AMR in bacterial pathogens of animals**

The following 12 countries reported having a national monitoring system for AMR in diseased animals: the Czech Republic, Denmark, Estonia, Finland, France, Ireland, Germany, the Netherlands, Norway, Spain, Sweden and the United Kingdom. Stakeholders from Denmark, the Netherlands and Sweden reported more than one monitoring system in their countries (Table 1). Ten countries reported not to have such a system (Austria, Belgium, Croatia, Cyprus, Greece, Hungary, Italy, Poland, Portugal and Romania). However, contacted experts in Italy reported that AMR monitoring in diseased animals was organized in some regions (e.g. Friuli Venezia Giulia). In Belgium, two veterinary diagnostic laboratories performed independent regional AMR monitoring (ARSIA, 2017; Dierengezondheidszorg Vlaanderen). No information was retrieved from Latvia, Lithuania, Malta, Slovakia and Slovenia. Figure 1 shows on a map of Europe which countries have a monitoring system (at least one), no system, or where information is missing among countries affiliated to the EU-JAMRAI.

The questionnaire and SWOT analysis were completed for all countries identified with a national monitoring system for AMR in diseased animals, except the United Kingdom due to competing priorities. In total, 15 monitoring systems from 11 countries were described and analyzed (Table 1).

**Description of national monitoring systems for AMR in bacterial pathogens of animals**

Results are presented per each key area, as defined in Materials & Methods.

*Political and financial support (Table 1)*

All countries under investigation had a National Action Plan (NAP) to tackle AMR. All NAPs, except in the Netherlands and Estonia, specify the need to perform AMR monitoring in diseased animals and often request specific organizations to perform this monitoring. However, only two countries have set up a regulated system, i.e. AMR monitoring is enforced by law: Germany (Bundes Ministerium der Justiz und für Verbraucherschutz) and the Czech Republic (Government of the Czech Republic).

Even if not regulated or not integrated in NAPs, national monitoring systems can still benefit from governmental support such as in the Netherlands, where AMR monitoring is funded by the Dutch government (for companion animals) or by both the government and producer/interbranch organizations (for livestock). Still, some national monitoring systems remain independent initiatives such as the monitoring of the University of Copenhagen in companion animals, without dedicated governmental or specific financial support (AST cost is supported by animal owners).

When dedicated national funding is allocated, it can consist of a subsidy (i) to decrease the AST costs for farmers (in the Czech Republic and Spain) or (ii) to do more pathological examinations on farm animals, which are, ultimately, an important source of AST data (GD Animal Health Surveillance System). In this way, subsidies support two goals: collecting more monitoring data and supporting veterinary antimicrobial stewardship. In some countries (Norway and Germany), a budget has been allocated to re-test isolates at a central laboratory. This ensures AST harmonization, irrespective of isolate origin, in terms of method, antimicrobials tested, and interpretive criteria applied. It also enables to test antimicrobials which are not tested by field veterinary diagnostic laboratories, but which may be of interest in a public health perspective (e.g. carbapenems). Alternatively, funding can also be intended to complementary monitoring programs to fill gaps in the regular monitoring in diseased animals (e.g. the Swedish Veterinary Antibiotic Resistance Monitoring (Svarm) is complemented by a farm animal pathogen monitoring program (SvarmPat)). Other costs of AMR monitoring, such as human resources of the coordination team, may either be supported by the regular budget of the coordinating institution (e.g. French surveillance network for antimicrobial resistance in diseased animals (RESAPATH)) or by dedicated funding (e.g. hours for collecting, processing and reporting data in the GD Animal Health Surveillance System are subsidized via the Dutch animal Health monitoring).

*Monitoring objectives*

All national systems aim to regularly produce accurate estimates of resistance proportions in clinically relevant animal pathogens. However, they can have different objectives regarding the use of these estimates. Some monitoring systems, such as the Czech National Monitoring of Target Pathogens´ Antimicrobial Resistance (CZ NMTP) and the Spanish Antimicrobial Resistance Surveillance in Clinical Animal Pathogens (*Sistema Español de Vigilancia de Animales Enfermos* - SEVAE), aim to support veterinary practitioners in their treatment decisions (e.g. through the formulation of evidence-based antimicrobial therapy guidelines). It is worth noting that the CZ NMTP is actually a spin-off activity of a program that primarily intends to support antimicrobial stewardship by incentivizing the use of AST and evidence based antimicrobial therapy by veterinarians. Other monitoring systems (e.g. Svarm or the Norwegian Monitoring Program for Antimicrobial Resistance in bacteria from feed, food and animals (NORM-VET)) primarily intend to follow trends and detect potential AMR emergences, including to drugs which are not allowed for veterinary use, but of interest to public health (e.g. carbapenems).

*Central institutional organization* (Table 1)

Only four national monitoring systems (CZ NMTP, RESAPATH, SEVAE and SvarmPat) have steering committees which are broader than the coordination team, including diverse institutions from both public and private sectors (e.g. representatives of both private and public laboratories in the French system). Coordinating institutions are very different across systems and may be private (e.g. the agricultural knowledge and innovation center (SEGES) in Denmark or Royal GD in the Netherlands) or public (e.g. universities, food safety agencies, medicines agencies etc.).

Sweden, Denmark and the Netherlands have more than one monitoring system for AMR in clinical animal isolates, but these are only integrated in Sweden. However, collaboration between systems usually exist, such as in Denmark, where SEGES provides AST data from swine to the national monitoring system coordinated by the Technical University of Denmark (DTU) and the Danish Veterinary and Food Administration (VFA).

*Laboratory network* (Table 2)

Seven systems (out of 15) perform AMR monitoring on isolates collected from a single laboratory. Other systems are based on a network of laboratories, usually made up of a limited number of laboratories, except the RESAPATH, German National Resistance Monitoring in Bacterial Pathogens of Animals (*GERM*-Vet) and SEVAE, which operate through 71, 30 and 22 laboratories, respectively. Networked laboratories either belong to the same institution (e.g. the Department of Agriculture, Food and the Marine (DFAM) in Ireland), or comprise independent laboratories, belonging to both private and public sectors (e.g. SEVAE and RESAPATH) or with a joint public/private status (CZ NMTP). The National Reference Laboratory (NRL) for AMR in the animal sector is involved in six systems (out of 15).

All laboratory networks, except in the SEVAE, include one or two central laboratories. In RESAPATH, the two central laboratories (both belonging to ANSES) are responsible for AMR monitoring in different animal species. Central laboratories may have diverse missions, depending on the system: analysis of diagnostic specimens, re-testing isolates of surveillance interest from field laboratories, re-testing and performing complementary molecular analyses on isolates with specific phenotypes and organizing proficiency testing (PT) on AST.

*Monitoring procedures*

All systems are primarily based on a passive monitoring procedure, i.e. AST results come from samples, that are routinely submitted by field veterinarians. However, two of them also include an active monitoring component (SvarmPat and Technical University of Denmark / Danish Veterinary and Food Administration (DTU/VFA) system), where diseased animals are sampled specifically for the purpose of AMR monitoring (and would likely not be sampled otherwise). These active monitoring components aim to fill knowledge gaps and generate more representative AMR data than by passive monitoring. They remain project-based and monitoring priorities can change over time.

*Laboratory techniques* (Table 3)

Regarding bacterial identification, the most commonly used method was the Matrix Assisted Laser Desorption Ionization - Time of Flight (MALDI-TOF) (by 14/15 systems), followed by Analytical Profile Index (API) galleries (by 3/15 systems). Among national monitoring systems based on a laboratory network and which do not re-identify all bacterial species at a central laboratory, the SEVAE, CZ NMTP and DFAM system have developed agreements or standard operating procedures, so that all member laboratories use the same bacterial identification method. In the CZ NMTP and DFAM system, PT is also in place to ensure the performance of participating laboratories in bacterial identification. Conversely, no standard or recommendation is provided to field laboratories in the RESAPATH and Finnish Veterinary Antimicrobial Resistance Monitoring and Consumption of Antimicrobial Agents (FINRES-Vet).

Regarding AST, broth microdilution is the reference method in 12 systems, followed by disk diffusion for four systems. Both methods are used as part of the FINRES-Vet, depending on the animal species. Broth microdilution is also used in the DFAM system for confirmatory testing and in the Veterinary and Food Laboratory / University of Life Sciences (VFL/ULS) system (Estonia) for testing colistin resistance. Eight countries follow the standards of the Clinical and Laboratory Standards Institute (CLSI) and interpret results according to its veterinary clinical breakpoints (when available). Different alternatives are used by countries when veterinary breakpoints are not available (a situation reported as frequent): epidemiological cut-off values (ECOFFs) of the European Committee on Antimicrobial Susceptibility Testing (EUCAST), epidemiological cutoff values (ECVs) of the CLSI, EUCAST or CLSI human clinical breakpoints, ECOFFs of the veterinary guidelines of the Antibiogram Committee of the French Society of Microbiology (CA-SFM), clinical breakpoints suggested by pharmaceutical companies, minimum inhibitory concentration (MIC) 90%, or internal ECOFFs (i.e. determined on internal MIC distributions). On the other hand, NORM-Vet and Svarm/SvarmPat follow the EUCAST guidelines and its ECOFFs (when available), while RESAPATH follows the AST technique and ECOFFs (when available) recommended in the veterinary guidelines of the CA-SFM. In case of missing ECOFFs from their respective standards, RESAPATH does not provide any interpretation, NORM-Vet and Svarm/SvarmPat use internal ECOFFs (when possible) or CLSI ECVs (when available), while Svarm/SvarmPat may also use CLSI clinical breakpoints.

For the six systems that operate on a laboratory network without systematically re-testing all isolates centrally (FINRES-Vet, CZ NMTP, DTU/VFA, DFAM, SEVAE and RESAPATH), a single AST standard is used. To guarantee the quality of AST results (as well as harmonization when there is a laboratory network and no central re-testing of all isolates), laboratories are either accredited on the AST technique and/or participate in PT in 13 systems. PT can be organized by the NRL, the central laboratory, or an institution from a different country, such as the VETQAS®, proposed by the Animal and Plant Health Agency in the United Kingdom. Other quality control measures like the use of reference strains with a defined MIC range are also used, hence all systems have some level of quality control.

*Surveillance data* (Table 4)

Animal species, bacterial species, antimicrobial and AST result are always collected. Data on specimen are collected in 12/15 systems and production type in 7/13 monitoring systems (excluding the two systems focusing on companion animals). Six systems collect information on prior antimicrobial treatment or reason for performing AST. National monitoring systems collect different volumes of data, from a few hundred to about 55000 isolates. The coordinating institutions own their surveillance data, except in the CZ NMTP and SEVAE, where data are the property of farmers. In the case of surveillance networks, systems always manage to collect quantitative AST results, and not only interpreted results.

*Surveillance communication* (Table 5)

For 12 systems, data are analyzed every year leading to the publication of an annual report. For those systems, there is a lag of four to 11 months from production of AST data to reporting for the respective calendar years. In the SEGES system and GD Animal Health Surveillance System, data analysis is carried out more frequently, with proportions of resistance calculated and reported on their website, so that more timely information can be used by antimicrobial prescribers and users. Targeted audience for these reports usually consists of veterinarians, relevant governmental bodies, farming organizations, AMR experts and organizations responsible for the development of treatment guidelines.

*Evaluation*

The RESAPATH and DFAM system were the only two monitoring systems that had been evaluated. The RESAPATH was evaluated two times (in 2010 and 2018), using the *Outil d’Analyse des Systèmes d’Information en Santé* (OASIS). For the DFAM system, this was done once in 2019, as part of a country visit by the ECDC and the Directorate-General for Health and Food Safety, to support the development and implementation of the Irish strategy for tackling AMR based on a 'One Health' approach (European Centre for Disease Prevention and Control and Directorate-General for Health and Food Safety, 2019). Only RESAPATH monitors performance indicators every year (listed in Supplementary Material 1), such as the *Proportion of laboratories obtaining a score above or equal to 31/36 at the AST PT organized by ANSES*, which should be of at least 95%.

**SWOT analyses**

Eleven SWOT analyses were produced (one per country), available in Supplementary Material 2. Eight themes were frequently reported and used to describe and analyze the results: 1. Public awareness & policies, 2. Flexibility & utility of the system, 3. Data access & sampling, 4. Data management & analysis, 5. Harmonization, 6. Representativeness, 7. Coverage, 8. Collaboration & Integrated surveillance, and 9. Sustainability & resources.

*Major strengths of participating systems*

The flexibility & utility of the system were reported as a major strength in nine countries out of 11. All of them highlighted their system had a broad scope, making it possible to monitor a diverse range of animal species, bacterial species and antimicrobial combinations, of relevance to the local epidemiological situation. Utility for veterinary practice (through the production of antimicrobial treatment guidelines or other educational material targeting veterinary professionals and farmers) was reported as a strength by three countries. Another frequently reported strength (n=10) was the level of harmonization of the AST analyses performed within the monitoring system, with most participating laboratories being accredited for AST. Geographical coverage was reported as good (n=5) or unknown (n=1).

Most participating countries (n=9) reported that a strength of their system was the very good collaboration they had with other AMR monitoring stakeholders or partners, including those in the human sector (n=5) and in healthy animals (n=3), ministries of agriculture (n=3), veterinary research institutes (n=2) or private industry (n=1). Five countries also reported their system relied on a small team, thereby facilitating communication and coordination.

*Weaknesses of participating systems*

Data management & analysis appeared as a major weakness across participating countries. Five countries reported a lack of efficient data management tools (e.g. for data cleaning and data extraction), while three countries reported poor data quality, such as incomplete or invalid metadata (e.g. previous antimicrobial use or age category). Capacity for storing isolates collected through the monitoring system was reported as an issue in only one country.

Another weakness shared across systems was representativeness, i.e. the ability to obtain sufficient and representative data for each combination of animal species/bacteria, which was reported as low (n=9) or unknown (n=2) in most countries. In most systems, this was related to the use of passive sample collections to monitor AMR.

*Opportunities of participating systems*

Most participating countries (n=8) considered the societal context, in terms of public awareness and national policies, as an opportunity for their monitoring system. Six countries mentioned an increasing level of public awareness on AMR, and five reported AMR was a policy priority in their country. Three countries claimed their system was supported by national or EU Action plans on AMR, and four countries had national legislation or programs in place to enforce or encourage the use of AST in the veterinary sector, thus contributing to an increase in the volume of data submitted to the monitoring system.

While collaboration between sectors was perceived as a strength in most participating countries, four countries reported there was an opportunity to improve the One Health integration of their system. Six countries also reported EARS-Vet as an opportunity to learn about practices and solutions from other countries that could be applicable to their own system.

*Threats of participating systems*

Almost all participating countries (n=9) reported the economic vulnerability as the main threat to their monitoring system, with a regular decrease in available financial and human resources. Three countries reported that lack of funding prevented them from performing more advanced data analyses or improving surveillance representativeness. Of note, two countries also reported a lack of skilled AMR experts in animal health in their country.

Various threats to data access & sampling were also reported, including issues around samples sent abroad for AST (n=3), or the use of alternative techniques (e.g. PCR or rapid AMR tests) preventing access to more conventional AST results (n=2). The development of large and competitive private laboratory companies was perceived as a threat in five countries, although three countries had good collaborations with these laboratories, and perceived them as an opportunity to further grow their surveillance network.

Discussion

To our knowledge, this is the first review of national monitoring systems for AMR in diseased animals describing system structures and operations, and analyzing their performance with a standardized approach. We identified 12 countries with at least one national monitoring system for AMR in diseased animals, among 27 surveyed countries. This led to a description and analysis of 15 systems in 11 European countries thanks to a questionnaire and SWOT analyses.

A strength of our approach was to include in the study almost all countries of the EEA (only Iceland, Bulgaria, Liechtenstein and Luxemburg are missing). This was facilitated by the EU-JAMRAI network of partner institutions and collaborating stakeholders, which facilitated contact with AMR experts in 27 countries. It enabled the identification of monitoring systems, which may not be easily identified through online searches, when no report is publicly available or only available in local language (as in Estonia, the Czech Republic and in Spain). However, no information could be retrieved for Latvia, Lithuania, Malta, Slovakia and Slovenia, despite several attempts to establish collaboration through the network and the questionnaire and SWOT analysis were not completed for the United Kingdom.

The survey questionnaire allowed the provision of a broad overview of the structure and operations of national monitoring systems, by covering areas, which were not limited to microbiology, but also funding, regulation, institutional organization, procedures, laboratory networks, communication, and evaluation. Various methods exist to assess the performance of monitoring systems (Calba et al., 2015), but a simple one was adopted in this study, i.e. SWOT analyses. This was a pragmatic choice, to be able to collect key information in a short amount of time, considering that 15 monitoring systems were included. Still, as SWOT analyses were completed by the experts working in the evaluated monitoring system, collected information could be biased. However, this risk was considered low because the aim was not to give a score and compare the performance of monitoring systems, and due to the presence of an external facilitator who previously administered the questionnaire to describe the system.

*Identification of national monitoring systems*

The review clarified grey areas reported in a previous systematic literature review (Schrijver et al. 2017), by confirming the absence of AMR monitoring system in diseased animals in Romania and Croatia, and that the VAV system in Spain and ITAVARM in Italy are no more in operation. Moreover, previous reviews indicated inconsistent results regarding the existence of an AMR monitoring system covering clinical animal isolates in Poland (Ferreira and Staerk, 2017; Schrijver et al., 2018). In this study, contacted experts in Poland indicated there was no such monitoring.

Many Southern and Eastern European countries do not have any national monitoring system for AMR in bacterial pathogens of animals (Figure 1), emphasizing a major gap in AMR monitoring in Europe. On the other hand, the 12 countries with one or more national monitoring systems represent an opportunity to launch EARS-Vet.

*Description and analysis of national monitoring systems*

Our survey showed the diversity of organizations and operations of monitoring systems and may be particularly valuable to countries planning to establish or improve their system, by learning from the experience of other countries. As all systems had their own strengths and weaknesses, a lesson to learn may be that there is no single best way to monitor AMR in bacterial pathogens of animals and that each system needs to be adapted to its national context, capacities and objectives.

Despite their differences, many systems shared common weaknesses, e.g. in data management and representativeness, and common threats, such as economic vulnerability and data access. Moreover, only two monitoring systems underwent evaluations, although this is an important practice to allow more transparent interpretation of outputs, more objective decision-making and resource allocation, as well as improvements in system design and enhanced acceptance of system outputs by stakeholders (Peyre et al., 2019). However, our analysis showed that solutions exist to these frequent challenges. For instance, several national monitoring systems succeeded in collaborating with the private sector to collect more AST data and improve representativeness. Thus, public-private partnerships appear as an opportunity to improve representativeness and tackle the threat of data access, attributed to the development of more competitive private diagnostic laboratories, whose AST results are not currently captured by the monitoring system. In France, a “win-win approach” was developed where laboratories (including private ones) share their data in exchange of technical support and free PT. It enabled to build a very large network of public and private laboratories. In Denmark, good collaboration between the industry (SEGES) and the public sector (DTU) illustrates that both may experience benefits with the animal industry showing transparency, without "hiding" potential AMR problems, and the public sector being able to publish and analyze data in national reports.

Thus, our review of national AMR surveillance systems is expected to serve countries planning to build or improve their system(s), by learning from others’ experience. It also contributed to the consolidation of a preliminary EARS-Vet network, thanks to numerous interactions with key experts from national monitoring systems. Such a network represents an opportunity to address frequent challenges of monitoring systems collectively and in a coordinated way.

*Moving towards EARS-Vet*

This review generated key information to advise the development of AMR surveillance in clinical animal isolates in Europe and more specifically to advance on the definition of the EARS-Vet surveillance framework. Indeed, EARS-Vet would need to collect accurate, representative and harmonized AST results produced and communicated by national monitoring systems.

First, we showed that coordinating institutions own their AST data in all but two countries. This should facilitate the development of an EARS-Vet data sharing agreement. Moreover, all systems collect quantitative AST results, namely MICs for broth microdilution and inhibition zone diameters for disk diffusion, which would facilitate the re-calculation of proportions of non-wild type (or resistant) isolates, should interpretation criteria change over time.

Second, most national monitoring systems are based on laboratories that are accredited on the AST technique and/or participate in PT and all of them implement quality assurance. Therefore, the capacity of national systems to produce accurate AST results is considered as high. Still, the development of a European PT, as done in the framework of EARS-Net, should be considered.

Third, data representativeness is a frequent weakness of national monitoring systems, linked to the passive monitoring procedure they follow. However, representativeness is rarely assessed in practice. In the Netherlands, it was shown that passive monitoring led to biased estimates of resistance to clindamycin, chloramphenicol, erythromycin and kanamycin in *Staphylococcus pseudintermedius* (Broens et al., 2019). The same result was obtained in Denmark for clindamycin (Larsen et al., 2015). On the other hand*,* a social-science study in France based on 66 interviews of veterinary practitioners showed that culture and AST are carried out in nearly all suspicions of bacterial infections in chicken and turkey production, limiting the possibility for bias in these animal species (Bourély et al., 2018). More investigations on the value of passive monitoring approaches are needed and common indicators of representativeness should be developed to advise the comparability of AMR data between countries (Mader et al., 2021a). Finally, 9 from 15 monitoring systems do not collect information on reasons for requesting AST or if sampled animals have already been treated with antimicrobials. Common efforts are needed by countries to collect this information more consistently to address important sources of possible bias.

Regarding harmonization, a major challenge is the diversity of AST procedures used by countries and the lack of many veterinary clinical breakpoints and ECOFFs. Therefore, it is necessary to define EARS-Vet standards and a harmonization strategy. EARS-Vet should follow the example of EARS-Net by accepting quantitative AST results produced by both disk diffusion and broth microdilution. However, for antimicrobials for which disk diffusion is not accurate (e.g. colistin), EARS-Vet should accept only MIC data. Regarding the interpretation of AST results, EU-JAMRAI experts suggest using EUCAST ECOFFs, although more countries currently use CLSI veterinary clinical breakpoints. The reason for this is that for many drug-bug combinations, animal- and infection-specific clinical breakpoints are missing and will likely not be established in the short term. Moreover, EUCAST ECOFFs enable early detection of changing AMR trends and would facilitate the integration of EARS-Vet with the EFSA monitoring in zoonotic and indicator bacteria from healthy food-producing animals. Although many EUCAST ECOFFs are currently missing for the combinations to be monitored in EARS-Vet (Mader et al., 2021b), ECOFFs remain easier to produce than clinical breakpoints. As EUCAST and CLSI are based on the same broth microdilution technique (at least for non-fastidious organisms: ISO 20776-1 (2019), which represent the majority of the bacterial species included in the EARS-Vet surveillance scope (Mader et al., 2021b)), most systems would not need to change their AST procedures to enable AST interpretation with EUCAST ECOFFs. However, it should still be explored if concentrations currently tested in national monitoring systems would allow interpretation with EUCAST ECOFFs, which may not be the case when only limited concentrations are tested. Regarding laboratories which use disk diffusion, they would have to adapt their method to the EUCAST methodology so that harmonized AST data can be collected by EARS-Vet. Although EUCAST ECOFFs would be the reference interpretation criteria for EARS-Vet surveillance, it would remain possible to calculate proportions of clinical resistance for the specific combinations of animal species / bacterial species / specimen where a CLSI clinical breakpoint is available, for the subset of countries following the CLSI standard, with the aim to provide more relevant information in a clinical perspective.

Thus, the current landscape of AMR monitoring in the EEA shows many gaps but also an opportunity to launch EARS-Vet, as 15 national monitoring systems are in place with strong capacity in AST. Thanks to a thorough understanding of their practices, a pragmatic harmonization strategy could be proposed for AST. This work, combined with the definition of the EARS-Vet scope (Mader et al., 2021b), provides key elements of the EARS-Vet surveillance framework, to support the generation of stronger evidence on AMR levels in bacterial pathogens of animals in Europe.

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Table 1: Name, regulation, organization and funding sources of 15 national monitoring systems for antimicrobial resistance in bacterial pathogens of animals (2020 as the reference year)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Name of monitoring system** | **Regulated system** | **Funding sources** | **Steering institutions** | **Coordinating institutions** | **Status of coordinating institutions** |
| **Finland** | Finnish Veterinary Antimicrobial Resistance Monitoring and Consumption of Antimicrobial Agents (FINRES-Vet) | No | Regular budget of coordinating institutions | Finnish Food Authority and University of Helsinki | Finnish Food Authority and University of Helsinki | Public |
| **Sweden** | Swedish Veterinary  Antibiotic Resistance Monitoring (Svarm) | No | Regular budget of the coordinating institution | National Veterinary Institute | National Veterinary Institute | Public |
| **Sweden** | Swedish Veterinary Antibiotic Resistance Monitoring - farm animal pathogens (SvarmPat) | No | Dedicated budget enveloped for specific projects | National Veterinary Institute and Farm & Animal Health (private farming company). Additional organizations may be involved depending on project. | National Veterinary Institute and Farm & Animal Health | Public |
| **The Czech Republic** | Czech National Monitoring of Target Pathogens´ Antimicrobial Resistance  (CZ NMTP) | Yes | Regular budget of coordinating institutions; AST data production supported by the Czech government, which subsidizes AST to veterinarians. | State Veterinary Administration, State Veterinary Institutes, Veterinary Research Institute, Institute for State Control of Veterinary Biologicals and Medicines, Chambers of Veterinary Surgeons, farmers' associations and National Public Health Institute | State Veterinary Institute in Jihlava | Public/private |
| **Norway** | Norwegian Monitoring Program for Antimicrobial Resistance in bacteria from feed, food and animals (NORM-VET) | No | Regular budget of coordinating institutions | Norwegian Food Safety Authorities and the Norwegian Veterinary Institute | Norwegian Food Safety Authorities and the Norwegian Veterinary Institute | Public |
| **Denmark** | Technical University of Denmark / Danish Veterinary and Food Administration\*/\*\* (DTU/VFA) | No | Regular budget of the coordinating institution and supported by dedicated public funding. | Technical University of Denmark and Danish Veterinary and Food Administration\*/\*\* | Technical University of Denmark and Danish Veterinary and Food Administration | Public |
| **Denmark** | University of Copenhagen (UC)\* | No | Regular budget of the coordinating institution | University of Copenhagen | University of Copenhagen | Public |
| **Denmark** | Agricultural knowledge and innovation center (SEGES)\* | No | Regular budget of the coordinating institution | Agricultural knowledge and innovation center | Agricultural knowledge and innovation center (SEGES) | Private |
| **The Netherlands** | University of Utrecht (UU)\* | No | Entirely supported by dedicated public funding. | University of Utrecht | University of Utrecht | Public |
| **The Netherlands** | GD Animal Health Surveillance System | No | Hours for collecting, processing and reporting data are subsidized via the Dutch animal Health monitoring; public financial support to pathological examinations on farm animals, which are an important source of AST results; financial support from producer/interbranch organizations and government. | Royal GD | Royal GD | Private |
| **Germany** | National Resistance Monitoring in Bacterial Pathogens of Animals (GE*RM*-Vet) | Yes | Regular budget of the coordinating institution; Specific public funding allocated to the Federal Office of Consumer Protection and Food Safety to perform AST. | Federal Office of Consumer Protection and Food Safety | Federal Office of Consumer Protection and Food Safety | Public |
| **Ireland** | Department of Agriculture, Food and the Marine (DFAM)\* | No | Regular budget of the coordinating institution | Department of Agriculture, Food and the Marine | Department of Agriculture, Food and the Marine | Public |
| **Spain** | Spanish Antimicrobial Resistance Surveillance in Clinical Animal Pathogens (*Sistema Español de Vigilancia de Animales Enfermos* - SEVAE) | No | Regular budget of coordinating institutions; AST data production supported by the Spanish government, which subsidizes AST to veterinarians. | Spanish Agency of Medicines and Medical Products | Spanish Agency of Medicines and Medical Products | Public |
| **Estonia** | Veterinary and Food Laboratory / University of Life Sciences (VFL/ULS)\* | No | Regular budget of the coordinating institution | Veterinary and Food Board, Ministry of Rural Affairs | Veterinary and Food Laboratory, University of Life Sciences | Public |
| **France** | French surveillance network for antimicrobial resistance in diseased animals (RESAPATH) | No | Regular budget of the coordinating institution | Public and private diagnostic laboratories, Ministry in charge of Agriculture, veterinary professional organizations, French Agency for Food, Environmental and Occupational Health & Safety. | French Agency for Food, Environmental and Occupational Health & Safety | Public |

\*Acronyms of coordinating institutions were used to identify monitoring systems without official name for the purpose of this study (see Table 1).

\*\*During 2020, under the administration of the VFA, the coordination of this monitoring system has been gradually taken over by the Statens Serum Institut and the University of Copenhagen. DTU does however still supply data, e.g. for cattle pathogens.

AST: Antimicrobial Susceptibility Testing

Table 2: Description of the laboratory networks of 15 national monitoring systems for antimicrobial resistance in bacterial pathogens of animals (2020 as the reference year)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Name of surveillance programme** | **Presence of a network of field diagnostic laboratories** | **Number of networked laboratories** | **Status of networked laboratories** | **Presence of a central laboratory** | **Laboratory activities of the central laboratory** | **Is the central laboratory (or the unique laboratory in the absence of network) the National Reference Laboratory for AMR in the animal sector?** |
| **Finland** | FINRES-Vet | Yes | 5 | Public | Yes | Diagnostic activities, reference activities and complementary molecular analyses. | Yes |
| **Sweden** | Svarm | No | - | - | - | - | Yes |
| **Sweden** | SvarmPat | No | - | - | - | - | Yes |
| **The Czech Republic** | CZ NMTP | Yes | 3 | Public/Private | Yes | Diagnostic activities, reference activities, complementary molecular analyses and central strain collection of all isolates. | No |
| **Norway** | NORM-VET | Yes | 2 | Public or private | Yes | Diagnostic activities, reference activities, collecting isolates from one collaborating private field laboratory, isolates being re-identified and re-tested by AST and complementary molecular analyses. | Yes |
| **Denmark** | DTU/VFA\* | Yes | 2 | Public or private | Yes | Confirmation of diagnostics (e.g. MALDI-TOF) and serotyping of some pathogens | No |
| **Denmark** | UC\* | No | - | - | - | - | No |
| **Denmark** | SEGES\* | No | - | - | - | - | No |
| **The Netherlands** | UU\* | No | - | - | - | - | No |
| **The Netherlands** | GD Animal Health Surveillance System | No | - | - | - | - | No |
| **Germany** | GE*RM*-Vet | Yes | 30 | Public or private | Yes | Diagnostic activities (not sure?), reference activities, collection of isolates from field laboratories which are all re-identified and re-tested by AST and complementary molecular analyses. | No |
| **Ireland** | DFAM\* | Yes | 6 | Public | Yes | Diagnostic activities, reference activities, collection of isolates from field laboratories when they exhibit specific phenotypes which are re-identified and re-tested by AST and complementary molecular analyses. | Yes |
| **Spain** | SEVAE | Yes | 22 | Public or private | No | - | - |
| **Estonia** | VFL/ULS\* | No | - | - | - | - | Yes |
| **France** | RESAPATH | Yes | 71 | Public or private | Yes (two central laboratories) | Reference activities, collection of isolates from field laboratories when they exhibit specific phenotypes which are the re-identified and re-tested by AST and complementary molecular analyses. | No |

\*Acronyms of coordinating institutions were used to identify monitoring systems without official name for the purpose of this study (see Table 1).

AST: Antimicrobial Susceptibility Testing; MALDI-TOF: Matrix Assisted Laser Desorption Ionization - Time of Flight

Table 3: Laboratory techniques and standards used in 15 national monitoring systems for antimicrobial resistance in bacterial pathogens of animals (2020 as the reference year)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Name of surveillance program** | **All labs follow the same bacterial species identification method** | **Method for bacterial identification** | **All labs follow the same AST method** | **AST method** | **AST standard** | **Primary interpretation criteria (when available)** | **AST accreditation** | **Labs participate in PT on AST** | **Phenotypes routinely confirmed at molecular level** |
| **Finland** | FINRES-Vet | No | MALDI-TOF | No | BMD for farm animals and disk diffusion for companion animals | CLSI | CBP | Yes, for FFA labs | Yes, all labs participate in VETQAS® PT | MRSA, MRSP, colistin resistance and carbapenem resistance by PCR |
| **Sweden** | Svarm | Yes (only one laboratory) | MALDI-TOF | Yes (only one lab) | BMD | EUCAST | ECOFF | Yes | Yes | MRSA, MRSP, colistin resistance, carbapenem resistance, ESBL and AmpC confirmed by PCR and/or WGS |
| **Sweden** | SvarmPat | Yes (only one lab) | MALDI-TOF | Yes (only one lab) | BMD | EUCAST | ECOFF | Yes | Yes | MRSA, MRSP, colistin resistance, carbapenem resistance, ESBL and AmpC confirmed by PCR and/or WGS |
| **The Czech Republic** | CZ NMTP | Yes (checked by PT) | MALDI-TOF | Yes | BMD | CLSI | CBP | Yes | Yes | MRSA and ESBL confirmations by PCR |
| **Norway** | NORM-Vet | Yes (the central laboratory re-identifies all bacterial species) | MALDI-TOF | Yes (the central laboratory re-tests all bacterial species) | BMD | EUCAST | ECOFF | Yes | (All isolates are re-tested centrally) | MRSA, MRSP, colistin resistance, vancomycin resistance, carbapenem resistance, ESBL and AmpC confirmed by PCR and/or WGS |
| **Denmark** | DTU/VFA\* | Yes | MALDI-TOF | Yes | BMD | CLSI | CBP | Yes | Yes | Project dependent |
| **Denmark** | UC\* | Yes (only one lab) | MALDI-TOF | Yes (only one lab) | BMD | CLSI | CBP | No | No | None |
| **Denmark** | SEGES\* | Yes (only one lab) | Colony morphology, selective agars, or agglutinations. If necessary, MALDI-TOF is carried out at DTU. | Yes (only one lab) | BMD | CLSI | CBP | Yes | Yes | None |
| **The Netherlands** | UU\* | Yes (only one lab) | MALDI-TOF | Yes (only one lab) | BMD | CLSI | CBP | No | Yes (PT organized by the NRL) | MRSA and MRSP confirmations by PCR |
| **The Netherlands** | GD Animal Health Surveillance System | Yes (only one lab) | MALDI-TOF | Yes (only one lab) | BMD | CLSI | CBP | No | Yes (PT organized by the NRL and VetQAS® PT) | MRSA confirmation by PCR |
| **Germany** | GE*RM*-Vet | Yes (the central laboratory re-identifies all bacterial species) | MALDI-TOF | Yes (the central laboratory re-tests all isolates) | BMD | CLSI | CBP | Yes | (All isolates are re-tested centrally) | MRSA, colistin resistance and ESBL confirmed by PCR |
| **Ireland** | DFAM\* | Yes (ensured by an SOP and checked by PT) | API galleries | Yes | Disk diffusion (BMD to confirm specific phenotypes) | CLSI | CBP | No | Yes (VETQAS® PT) | - |
| **Spain** | SEVAE | Yes (ensured by a signed agreement) | MALDI-TOF | Yes | BMD | CLSI | CBP | No | No | None |
| **Estonia** | VFL/ULS\* | Yes (only one lab) | API galleries or MALDI-TOF | Yes (only one lab) | Disk diffusion (BMD to test colistin resistance) | CLSI | CBP | Yes | No | MRSA and colistin resistance confirmed by PCR |
| **France** | RESAPATH | No | API galleries or MALDI-TOF | Yes | Disk diffusion | CA-SFM | ECOFF | Only some labs | Yes (PT organized by ANSES) | MRSA, MRSP, colistin resistance, carbapenem resistance and ESBL confirmed by PCR and/or WGS |

\*Acronyms of coordinating institutions were used to identify monitoring systems without official name for the purpose of this study (see Table 1).

WGS

AMR: Antimicrobial Resistance; BMD: Broth Microdilution; ANSES: French Agency for Food, Environmental and Occupational Health and Safety; API: Analytical Profile Index; AST: Antimicrobial Susceptibility Testing; CA-SFM: Antibiogram Committee of the French Society of Microbiology; CBP: Clinical Breakpoints; CLSI: Clinical & Laboratory Standards Institute; ECOFF: Epidemiological Cut-Off Values; ESBL: Extended Spectrum Beta-Lactamase; EUCAST: European Committee on Antimicrobial Susceptibility Testing; FFA: Finish Food Authority; Labs: Laboratories; MALDI-TOF: Matrix Assisted Laser Desorption Ionization - Time of Flight; MRSA: Methicillin-Resistant *Staphylococcus aureus*; MRSP: Methicillin-Resistant *Staphylococcus pseudintermedius*; NRL: National Reference Laboratory; PCR: Polymerase Chain Reaction; PT: Proficiency Testing; SOP: Standard Operating Procedure; UH: University of Helsinki; WGS: Whole Genome Sequencing.

Table 4: Collected data and frequency of data analyses in 15 national monitoring systems for antimicrobial resistance in bacterial pathogens of animals

|  |  |  |  |
| --- | --- | --- | --- |
| **Country** | **Name of surveillance program** | **Surveillance data collected, apart from bacterial species, antimicrobial and AST result** | **Volume of isolates included in the monitoring (exact number and year or approximate range)** |
| **Finland** | FINRES-Vet | Animal species, breed, age, sex, date of sampling, specimen, if the animal was having an antimicrobial treatment at time of sampling and if yes, what antimicrobial. | 3650-3950 |
| **Sweden** | Svarm | Animal species, date, specimen and production type (dairy/beef) for cattle and poultry (broiler/layer, submitting veterinarian, owner/herd registration number if applicable. | 4000-6000 |
| **Sweden** | SvarmPat | Project-dependent. | Project-dependent |
| **Czech Republic** | CZ NMTP | AST date, laboratory identification, sample regional identification, epidemiological unit, animal species, production type and specimen. | 1300-1600  (for the period 2017-2020) |
| **Norway** | NORM-VET | Animal species, gender, age, production type, epidemiological unit, veterinarian or veterinary clinic, owner and owner location, specimen, disease or reason for asking an AST, date, identification number | 200-600 |
| **Denmark** | DTU/VFA\* | Date, farm identification number, herd number, animal species, specimen, date of sampling. | Project-dependent |
| **Denmark** | UC\* | Animal species, specimen, disease or reason for asking an AST, date of sampling. | 600 |
| **Denmark** | SEGES\* | Date, farm identification number, animal species, specimen, bacterial serotype (when relevant), date of sampling. | 500 |
| **The Netherlands** | UU\* | Date, animal species, age, location, specimen, disease, previous treatment, travel history | 7800 (in 2020) |
| **The Netherlands** | GD Animal Health Surveillance System | Date, animal species, age, location, specimen, disease, production type, if the sample has been directly submitted or if it comes from a necropsy performed at Royal GD. For poultry: treatment history. | 8676 (2020) |
| **Germany** | GE*RM*-Vet | Animal species, specimen, age, production type, clinical signs, if the animal was having an antimicrobial treatment at time of sampling and if yes, what antimicrobial, farm postal code, sample date. | 2500-3000 |
| **Ireland** | DFAM\* | Animal species, breed, age, sex, data, date of sampling, specimen, if the animal was having an antimicrobial treatment at time of sampling, production type (e.g. dairy or beef) | 7700 (2018) |
| **Spain** | SEVAE | Date, laboratory identifier, farm identifier, veterinary clinic identifier, regional identifier, epidemiological unit and animal species. | Not yet known at the time of writing as the monitoring system started in 2020. |
| **Estonia** | VFL/ULS\* | Farm identifier, animal species, age, if the animal was having an antimicrobial treatment at time of sampling and if yes, what antimicrobial. | Project dependent |
| **France** | RESAPATH | Laboratory identifier, zip code and town of the farmer or companion animal owner, AST date, animal species, production type, age category, specimen and disease. | 55401 (in 2018) |

\*Acronyms of coordinating institutions were used to identify monitoring systems without official name for the purpose of this study (see Table 1).

AST: Antimicrobial Susceptibility Testing

Table 5: Communication activities of 15 national monitoring systems for antimicrobial resistance in bacterial pathogens of animals

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Country** | **Name of the surveillance program** | **Communication tools** | **Frequency of surveillance report publication** | **Lag** **between AST data production and report publication** | **Target audience of communication activities** |
| **Finland** | FINRES-Vet | Surveillance reports, magazines for veterinarians and farmers | Once a year (since 2018) | November (since 2018) | Veterinary practitioners, farmers and journalists |
| **Sweden** | Svarm | Surveillance reports, factsheets, presentations at annual stakeholder meetings before the release of the report, presentations of results during lectures | Once a year | 6 months | National Veterinary Institute, professional associations producing treatment recommendations, individual veterinarians |
| **Sweden** | SvarmPat | Surveillance reports, factsheets, presentations at annual stakeholder meetings before the release of the report, presentations of results during lectures | Once a year (although some projects collect data for several years before reporting) | 6 months | National Veterinary Institute, professional associations producing treatment recommendations, individual veterinarians |
| **The Czech Republic** | CZ NMTP | Surveillance reports, magazines for veterinarians and farmers. | Once a year | 6 months | Veterinary practitioners, farmers, national authorities, Czech pharmaceutical industry, researchers, One Health network |
| **Norway** | NORM-VET | Annual surveillance reports, annual meetings when delivering the report, meetings with the Norwegian Food Safety Authority and the industry, on NVI website (and sometimes in magazines for veterinarians or farmers) | Once a year | 9 months (however, isolates included in the report may have been collected over several years) | Norwegian Food Safety Authority, farming industry, Ministry in charge of Agriculture, researchers, veterinary practitioners |
| **Denmark** | DTU/VFA\* | Surveillance reports and other publications | Once a year | 1 year | Veterinary practitioners, national authorities and stakeholders producing treatment policies/guidelines |
| **Denmark** | UC\* | Surveillance reports and other publications | Every two years | 1-2 years | Veterinary practitioners, national authorities and stakeholders producing treatment policies/guidelines |
| **Denmark** | SEGES\* | Surveillance reports and on their website | 4 times a year | 1 month for quarter reports on their website and 9 months for the joint report with DTU Vet | Veterinary practitioners, farmers, national authorities and stakeholders producing treatment policies/guidelines |
| **The Netherlands** | UU\* | Surveillance reports to Ministries, presentations at meetings and conferences, in magazines for veterinarians, scientific papers | Once a year | 4-5 months | Veterinary practitioners, national authorities in charge of producing treatment guidelines and the government |
| **The Netherlands** | GD Animal Health Surveillance System | Surveillance reports, on their website, in scientific publications, in magazines for veterinarians or farmers | Every 3 or 6 months depending on the animal species | 4-5 months | Veterinary practitioners, government, pharmaceutical industry, national authorities in charge of producing treatment guidelines. |
| **Germany** | GE*RM*-Vet | Surveillance reports, at meetings and conferences, on their website, in scientific papers, in magazines for veterinarians and farmers | Once a year | 1 year | Veterinary practitioners, government, medicines agencies |
| **Ireland** | DFAM\* | Surveillance reports and local meetings with veterinarians | Once a year | Usually <1 year | Veterinary practitioners, farmers and government |
| **Spain** | SEVAE | Planned to be in surveillance reports, on their website and on a mobile application | Planned to be once a year | Unknown yet | Private vets, farmers and national authorities |
| **Estonia** | VFL/ULS\* | Surveillance reports sent to the Ministry of Rural Affairs. | Once a year | 5-6 months | National authorities (Veterinary and Food Board and State Agency of Medicines) |
| **France** | RESAPATH | Surveillance reports, annual RESAPATH meetings for the release of the report, scientific publications, on the RESAPATH website | Once a year | 11 months | French Agency for Food, Environmental and Occupational Health & Safety, Ministries in charge of Agriculture and Health, veterinarians, epidemiologists, microbiologists |

\*Acronyms of coordinating institutions were used to identify monitoring systems without official name for the purpose of this study (see Table 1).

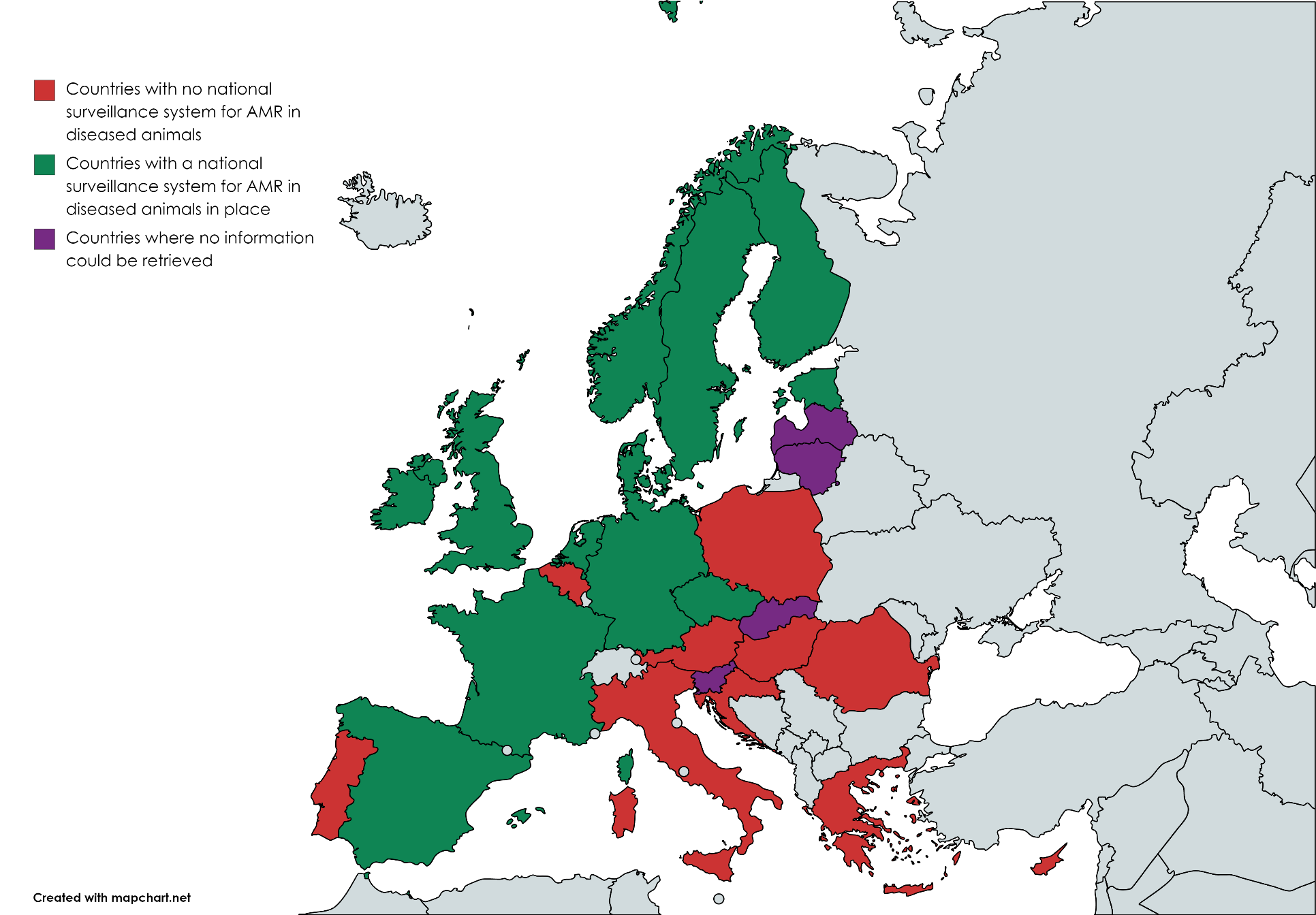


Figure 1: Map of Europe showing the countries that have at least one national monitoring system for antimicrobial resistance (AMR) in bacterial pathogens of animals (in green), no such system (in red), or where information is missing (in purple) among countries affiliated to the European Union Joint Action on Antimicrobial Resistance and Healthcare Associated Infections (EU-JAMRAI) and as of 2020.