National Collaborating Centre for Infectious Diseases

Centre de collaboration nationale des maladies infectieuses

Progress on Integrated Antimicrobial Resistance and Antimicrobial Use Surveillance in Canada (2014-2019)

December 2020

PREPARED BY:

Simon J. G. Otto, DVM PhD, Misha Miazga-Rodriguez, MSc MPH, Lynora M. Saxinger MD

Progress on Integrated Antimicrobial Resistance and Antimicrobial Use Surveillance in Canada (2014-2019)

December 2020

Simon J. G. Otto DVM PhD[1,2,3], Misha Miazga-Rodriguez MSc MPH[1,2], Lynora M. Saxinger MD[4]

[1] HEAT-AMR (Human-Environment-Animal Transdisciplinary AMR) Research Group, School of Public Health, University of Alberta

[2] AMR-One Health Consortium

[3] Thematic Area Lead, Health Environments, Centre for Health Communities, School of Public Health, University of Alberta

[4]Faculty of Medicine and Dentistry, University of Alberta

Contact us at:

National Collaborating Centre for Infectious Diseases
Rady Faculty of Health Sciences,
University of Manitoba
Tel: (204) 318-2591
Email: nccid@umanitoba.ca
www.nccid.ca

This is NCCID Project number 560.

ISBN: 978-1-927988-67-1

Production of this document has been made possible through a financial contribution from the Public Health Agency of Canada through funding for the National Collaborating Centre for Infectious Diseases. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada.

Table of Contents

List of Tables

List of On-Line Appendices

Acronyms

AMR	antimicrobial resistance
AMS	antimicrobial stewardship
AMU	antimicrobial use/usage
BC	British Columbia
C3SN	Canadian Cow-Calf Surveillance Network
CaDNetASR	Canadian Dairy Network for Antimicrobial Stewardship and Resistance
CAHI	Canadian Animal Health Institute
CAHSS	Canadian Animal Health Surveillance System
CanFASP	Canadian Feed-cattle Antimicrobial Surveillance Program
CANWARD	Canadian Ward Surveillance
CARSS	Canadian AMR Surveillance System
CCVO	Canadian Council of Chief Veterinary Officers
CIPARS	Canadian Integrated Program for Antimicrobial Resistance Surveillance
CNISP	Canadian Nosocomial Infection Surveillance Program
CVMA	Canadian Veterinary Medical Association
DFO	Department of Fisheries and Oceans
EARSNet	European Antimicrobial Resistance Network
ECDC	European Centre for Disease Control
EU	European Union
F/P/T	federal/provincial/territorial
GAP AMR	WHO's Global Action Plan for AMR
GLASS	WHO Global Antimicrobial Resistance and Use Surveillance System
IQVIA	A private data, technology and analytics company
NCCID	National Collaborating Centre for Infectious Diseases
P/T	provincial/territorial
PEI	Prince Edward Island
PHAC	Public Health Agency of Canada
PICNet	Provincial Infection Control Network of BC
SEARO	South East Asia Regional Office (WHO)
VASR	Veterinary Antimicrobial Sales Reporting
WHO	World Health Organization

Definitions

Surveillance program ***requirements***: the eight broad program requirements to achieve national, integrated AMR/AMU surveillance.

Surveillance program ***components***: the individual program aspects within each of the eight broad surveillance program requirements.

Surveillance program ***elements***: the seven common characteristics evaluated for each surveillance program component.

Stage of program ***development*****:** the five-stage ranking system applied to the seven surveillance program elements for each surveillance program component.

Executive Summary

Introduction

Antimicrobial resistance (AMR) is a recognized global threat to health security. Integrated One Health surveillance of AMR and antimicrobial use (AMU) must underpin efforts to protect human, animal, and crop health. In 2014, the National Collaborating Centre for Infectious Diseases (NCCID) published a report commissioned to assess the status of AMR/AMU surveillance in Canada including the authors' recommendations to address gaps in Canada. In 2016, the Canadian Council of Chief Veterinary Officers (CCVO) released a report evaluating options to strengthen AMU surveillance in animals in Canada that mapped within the AMU surveillance recommendations of the NCCID report. There have been numerous steps taken in Canada to address AMR since the release of these reports. The objective of this project is to assess the progress made towards the recommendations of these reports by:

1. Cataloguing AMR/AMU surveillance programs currently operating in Canada nationally and provincially.

2. Describing the scope of these programs.

3. Evaluating what progress has been made to address the gaps identified in the 2014 NCCID and 2016 CCVO reports to achieve integrated AMR/AMU surveillance in Canada.

Methods

Federal, provincial, and territorial AMR/AMU surveillance programs were identified by knowledge and networks of the investigators, a scan of grey literature, and a detailed environmental scan. Google, Google Scholar, and Scopus searches were used to identify programs reporting data on AMU and AMR surveillance at the national, provincial, and territorial level in Canada. A list of Canadian subject matter experts on AMR/AMU surveillance was collated from individuals who have participated in work related to AMR and AMU surveillance with the NCCID, the CCVO, and their contacts, and individuals from human and animal health spheres in Canadian professional networks with the authors as well as their contacts. We conducted semi-structured interviews with key-informant experts across Canada to ensure that publicly available information was representative and complete for their jurisdiction.

For the evaluation step, we found no suitable existing methods that would allow robust and granular assessment of current surveillance elements. We identified tools in the literature and adapted and combined them into an evaluation matrix for assessment of specific integrated AMR/AMU surveillance program requirements and components. We adapted an exemplar situation analysis tool developed by the World Health Organization to quantify the relative stages of program development. The adapted terminology for describing the stages of program development were: 1) Exploration, 2) Program Adoption, 3) Initial Implementation, 4) Full Operation, and 5) Sustainable Operation. We modified another published tool created to assess the sustainability of public health programs. The domains from

this tool were adapted to the following seven common program elements for our evaluation: 1) Funding, 2) Organizational Capacity, 3) Partnerships, 4) Program Adaptability, 5) Communication, 6) Strategic Planning, and 7) Enabling Policy. We combined the five stages of program development with the seven elements of program sustainability into a matrix with definitions for each.

The 2014 NCCID report contained 10 broad recommendations to improve integrated AMR/AMU surveillance in Canada (see Appendix 1). The 2016 CCVO report also provided direction for strengthening AMU surveillance in animals, with components encompassed within the NCCID recommendations. We modified the NCCID recommendations to 8 core surveillance requirements, with components under each to better reflect the current state of integrated AMR/AMU surveillance, incorporating findings from the 2016 CCVO report and information from the environmental scan and interviews. For each component we then assigned one of the five stages of program development to each of the seven common program elements based on our evaluation of literature and information from the interviews through iterative discussion within the investigation team. Areas that were identified as uncertain were confirmed with follow-up conversations with key informants with knowledge about the specific programs. A draft summary of the methods and results was circulated to key interview respondents for review and validation, including representatives from the Canadian Integrated Program for AMR Surveillance (CIPARS), the Canadian AMR Surveillance System (CARSS), the co-chairs of the Surveillance Task Group of the Federal-Provincial-Territorial (F/P/T) AMR Steering Committee, the co-authors of the 2014 NCCID report, and the NCCID sponsors.

Results & Discussion

Six national, twenty-two provincial and one territorial AMR/AMU surveillance programs were reviewed. Thirty-three invitations were sent for interviews (including secondary contacts identified in the first round of interviews), and 29 individuals were interviewed. The six national programs include CARSS, CIPARS, the Canadian Nosocomial Infection Surveillance program (CNISP), and three pathogen-specific programs. There have been improvements in synthesized reporting of AMR and AMU in Canada with the development of CARSS to integrate, synthesize and report data, but this represents a summary of national data, with complete data remaining in reporting from respective programs. Strategic expansion of CNISP (newly added community and northern hospitals) and CIPARS (feedlot and dairy cattle and AMU in crops and aquaculture) are positive steps. However, significant gaps remain in the integration and comprehensive coverage of current animal and human AMR/AMU surveillance programs that limit the timeliness of and the ability to action upon reporting. Human pathogen data are limited to important nosocomial pathogens with some non-standardized antibiogram data from the provincial-territorial level. Broad representation of human health in community, long-term care and northern Canada is limited. Coverage of the animal sector in all provinces and territories, veterinary pathogen data, and surveillance in water and soil remain important One Health gaps. Of the provincial surveillance programs, all but two are focused on human health, with British Columbia and Québec collecting animal AMU data. The only province systematically collecting and reporting animal AMR data is Québec.

More sustained resources and funding are needed to support new and existing comprehensive surveillance initiatives at all levels of government. It is important to continue to leverage and coordinate efforts of stakeholders outside of government, such as those in academia and the food animal production industries with research projects and programs. Alone, however, these external efforts will not sustain or allow for the needed expansion and integration of current programs. This is compounded by a lack of new federal investment in AMR/AMU surveillance in the past decade and the lack of F/P/T policy supporting standardized reporting of AMR and AMU data in the human and animal health sectors. It is crucial that F/P/T governments commit to providing provide adequate leadership, money, infrastructure, technical expertise and supporting policy to facilitate the development and integration of comprehensive, One Health, integrated AMR/AMU surveillance in Canada.

Introduction

Antimicrobial resistance (AMR) is acknowledged by the World Health Organization (WHO) as a global threat to health security (3). Surveillance trends of AMR across Canada demonstrate increasing rates of infection or colonization by specific resistant organisms such as methicillin-resistant *Staphylococcus aureus* in the community, vancomycin-resistant enterococci in hospitals, carbapenemase producing organisms in both settings, and global evolving resistance in community pathogens (4). Increasing transmission of resistant organisms and overall resistance rates underscore the importance of antimicrobial stewardship (AMS) to preserve the effectiveness of antimicrobials by minimizing selection pressure. Robust surveillance of AMR organisms and antimicrobial use (AMU) is fundamental to deploying effective, evidence-based policy, stewardship, and control efforts.

Surveillance is one of the pillars of the WHO's Global Action Plan for AMR (GAP AMR) (5). This plan was endorsed by World Health Member States, including Canada, in 2015. In 2017, *Tackling Antimicrobial Resistance and Antimicrobial Use: A Pan-Canadian Framework for Action* was published as a critical step to creating and implementing a domestic action plan to address AMR in Canada and support the WHO GAP AMR (6). This AMR Framework, as well as the soon-to-be released Action Plan, were created with One Health principles and include four main pillars: surveillance, infection prevention and control, stewardship, and research and innovation. One Health recognizes that the health of humans, animals, and the environment are inseparable (7), and therefore promotes interdisciplinary design and implementation of program, policies, legislation, and research to achieve better health outcomes (6, 7).

Across Canada, aspects of national, provincial/territorial (PT), and local or regional AMU and AMR surveillance programs have been operational in various forms for more than 25 years. The recognized core national programs, the Canadian Nosocomial Infection Surveillance Program (CNISP) and the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS), collect data on resistance and resistant organisms including select human nosocomial pathogens and zoonotic (animal or animal product derived) foodborne pathogens, as well as on elements of AMU data in both humans and animals. This surveillance has yielded valuable data; however, previous analyses of Canada's AMR and AMU surveillance programs have noted important gaps that limit the comprehensiveness and quality of the data collected (8-11). Identified issues include a lack of integration of surveillance programs across Canada at national and provincial/territorial levels, resulting from challenges in data sharing, inconsistencies in how data are collected, analyzed, and reported, and limited centralized infrastructure and support (10). The most significant omissions noted in past assessments of surveillance data include weak or incomplete human community-based AMR data, animal pathogen AMR data, and a lack of comprehensive AMU data for humans and animals. Finally, extant human surveillance data focuses on larger, urban hospitals, with a relative lack of data from rural, northern and Indigenous communities and hospitals (8-10).

Surveillance for AMR and AMU for animals is more limited (11, 12). Data on AMR are typically limited to pathogens of concern for human health coming from food animals, excluding animal pathogens for livestock and companion animals. Agricultural AMU data has been limited to regional/national

distribution volumes and sentinel farm surveillance. The collation of more comprehensive data is limited due to the complexity of the drug distribution system in Canada and the presence of past exemptions in the importation and usage of antimicrobials, known as the "Own Use Importation" and "Active Pharmaceutical Ingredients" (10, 11). Data for AMU are collected from sentinel farms by CIPARS and drug distribution data supplied to CIPARS by the Canadian Animal Health Institute (CAHI) (8, 11). Monitoring of AMR in the environment, such as soil and water, is another missing component of national and provincial surveillance programs but is increasingly seen as integral to understanding trends and routes of resistance transmission and a key component of the One Health concept[1].

In 2014, the National Collaborating Centre for Infectious Diseases (NCCID) commissioned an analysis of the AMR/AMU surveillance landscape in Canada (8). Ten recommendations on policy, stewardship, and surveillance resulted from this report (see the Appendix 1). In 2016, the Canadian Council of Chief Veterinary Officers (CCVO) released a report evaluating options to strengthen AMU surveillance in animals in Canada that focused on three types of data: federal, provincial, and territorial (F/P/T) antimicrobial distribution/sales data, veterinary antimicrobial purchase/sales/prescription data, and animal owner antimicrobial purchase/administration data (11). The CCVO report did not make specific recommendations on how to proceed as it recognized that there was not a clear policy direction or objective for AMU surveillance in animals in Canada and that this area is still to be addressed. In this current review, these elements of AMU surveillance in animals were included within our examination of the progress made on the recommendations in the 2014 NCCID report.

The objective of this project is to assess the progress made towards the 2014 recommendations by:

1. Cataloguing AMR/AMU surveillance programs currently operating in Canada nationally and provincially.

2. Describing the scope of these programs.

3. Evaluating what progress has been made to address the gaps identified in the 2014 NCCID and 2016 CCVO reports to achieve integrated AMR/AMU surveillance in Canada.

[1] See for example, discussions recorded in the 2019 proceedings, *Multi-sectoral Stakeholder Meeting on AMR/AMU Surveillance.* Available at: https://nccid.ca/multi%e2%80%90sectoral-stakeholder-meeting-on-amr-amu-surveillance/

Methods

Environmental scan

Federal, provincial, and territorial AMR/AMU surveillance programs were identified by investigator knowledge and scanning the grey literature. A detailed environmental scan was conducted between May 1 and August 31, 2019 of AMR and AMU surveillance programs in Canada. Search strategies are detailed in Appendix 2. Google, Google Scholar, and Scopus were used to search for programs reporting data on AMU and AMR surveillance at the national, provincial, and territorial level in Canada. Results from the first five result pages were scanned (13, 14). Annual reports (web based or PDFs), antibiograms, and interactive dashboards were all considered evidence of current, active surveillance programs.

Interviews with subject matter experts

A list of subject matter experts on AMR/AMU in Canada was collated from individuals who have participated in work related to AMR and AMU surveillance with the NCCID, and from human and animal health spheres in Canadian professional networks with the authors, as well as their contacts. Participants were asked to identify relevant colleagues for additional interviews. The list included experts in both animal and human surveillance, stewardship, and AMR epidemiology at a national level and from each province and territory. We conducted semi-structured interviews with key-informant experts across Canada to ensure that publicly available information was representative and complete for their jurisdiction. Thirty-minute semi-structured, informal interviews were conducted between July 16 to August 20, 2019, with an outline of topics provided to participants in advance (Appendix 3). Topics and questions were developed through iterative reviews by members of the project team, but conversations were open and allowed to develop without a strict structure. Interviews were conducted by telephone or virtual platform and documented by word processor. The main areas addressed by respondents included: 1) a description of currently operating surveillance AMR/AMU programs in their area(s) of experience; 2) their participation in or knowledge of any point prevalence surveys of AMR and/or AMU; 3) their understanding of how the pan-Canadian AMR Framework (6) and subsequent Action Plan is influencing actions within their respective organizations/jurisdictions; 4) a description of AMR/AMU surveillance programs or planned projects that are currently in development; and 5) recommendations of other experts that we should interview.

Evaluation of national integrated AMR/AMU surveillance programs in Canada

We regrouped and synthesized the surveillance recommendations and individual components from the 2014 NCCID report (8) to reflect the current AMR/AMU surveillance landscape in Canada and permit assessment of these surveillance requirements. For evaluation, we found no suitable existing methods

that would allow robust and granular assessment of current surveillance elements. We identified tools in the literature and adapted and combined them into an evaluation matrix for assessment of the stage of development of specific integrated AMR/AMU surveillance program requirements and components. First, the World Health Organization (WHO) South East Asia Regional Office (SEARO) proposed a situational analysis tool (2) to evaluate the stepwise, incremental approach of a country towards implementing the WHO Global Action Plan on AMR (5). This tool was piloted in Indonesia to report on progress in national AMR prevention and containment by identifying the relevant phase of implementation, including baseline, development, implementation, monitoring, and evaluation of progress. We adapted the tool to quantify the relative stages of program development for Canadian integrated AMR/AMU surveillance components from the NCCID report (8). The adapted stages used in our review to describe the stages of program development were: 1) Exploration, 2) Program Adoption, 3) Initial Implementation, 4) Full Operation, and 5) Sustainable Operation.

The eight surveillance **requirements** were subdivided by their specific **components**. Each component was assessed using a two-way classification rubric (Table 1). Characteristics of components were classified within seven common **elements** (Funding, Organizational Capacity, Partnerships, Program Adaptability, Communication, Strategic Planning, and Enabling Policy). The component elements were then assessed for their stage of **development** (Exploration to Sustainable Operation).

The SEARO tool pilot was used to evaluate Indonesia's broad strategic elements developed to control AMR. However, this did not allow for sufficient discrimination for the components of One Health, integrated AMR/AMU surveillance as different facets of this work could be assessed as being at varied stages of development. To achieve a more detailed, clear, and defensible assessment for our purposes, we adapted another tool that assesses the "sustainability capacity" of public health programs (1), which allowed a breakdown of relevant program aspects. Sustainability was defined as "the existence of structures and processes that allow a program to leverage resources to effectively implement and maintain evidence-based policies and activities." Schell et al. presented a conceptual framework for assessing this capacity based on the literature and concept mapping with experts in the field, with nine domains: Political Support, Funding Stability, Partnerships, Organizational Capacity, Program Evaluation, Program Adaptation, Communications, Public Health Impacts, and Strategic Planning, with high-level descriptions for each domain (14). We adapted these domains to the following seven program elements for our evaluation: 1) Funding, 2) Organizational Capacity, 3) Partnerships, 4) Program Adaptability, 5) Communication, 6) Strategic Planning, and 7) Enabling Policy (Figure 1). We made the *a priori* decision that political support and public health impacts were beyond the scope of our review of progress towards integrated AMR/AMU surveillance. We did not have a framework or data to evaluate the political support for the granular levels of the surveillance components that were evaluated in this review. We alternatively chose to evaluate the existence of policy to enable the surveillance components. Evaluating the public health impacts of AMR/AMU surveillance was excluded due in part to the parallel work and recent publication of the Council of Canadian Academies assessment of the socioeconomic costs of AMR (15). We also did not include program evaluation as there was little information available about this element for national AMR/AMU surveillance.

We combined the five stages of program development with the seven elements of program sustainability into a two-way matrix with definitions for each (Table 1). Definitions were developed through iterative discussion by the investigation team. These definitions were created in advance of program assessment to allow objective assessment of development stages for each element based on the collected information. This matrix subdivides programs into their key elements, and assesses development/progress of each component independently. This tool allows for differential evaluation of the progress towards the required components for integrated AMR/AMU surveillance in Canada. The importance of developing this detailed tool was underscored by the finding that many programs had elements assessed at varying stages of development towards the various recommendations.

The 2014 report contained 10 broad recommendations to improve integrated AMR/AMU surveillance in Canada (see Appendix 1). We modified these recommendations to eight core surveillance requirements that incorporated the findings from the 2016 CCVO report and information from the environmental scan and interviews and subdivided each into their specific components to better reflect the current state of integrated AMR/AMU surveillance in Canada. Each component element was assessed using the two-way classification rubric (Table 1). Characteristics of components were classified within the seven common elements. The component elements were then assessed for their stage of development (Exploration to Sustainable Operation). As we worked through the assessment, some definitions that did not allow clear differentiation between development stages were modified and re-applied to the program element.

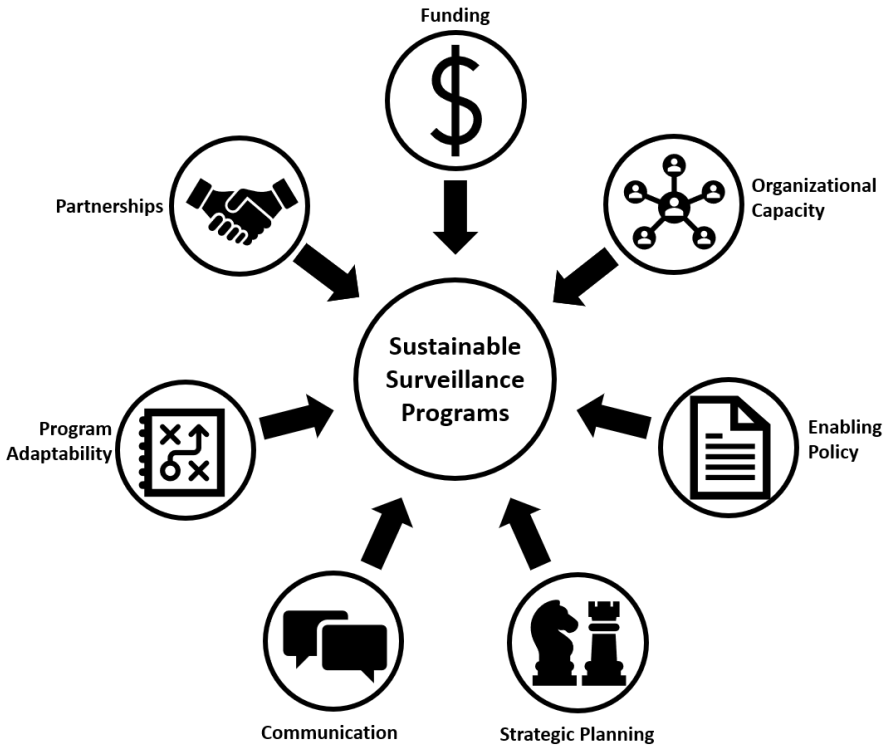

Figure 1. Program elements that were evaluated for national, integrated antimicrobial resistance and antimicrobial use surveillance programs, adapted from Schell et al. (1).

Table 1. Evaluation rubric for national, integrated antimicrobial resistance and antimicrobial use surveillance program requirements and components in Canada. The common program elements for evaluation are in the left column and the rankings for stages of program development are listed in the first row. The definitions for each criteria-ranking combination -are provided. Criteria are adapted from (1) and rankings are taken from (2).

PROGRAM ELEMENTS FOR EVALUATION	**STAGES OF PROGRAM DEVELOPMENT**				
	Exploration	**Program Adoption**	**Initial Implementation**	**Full Operation**	**Sustainable Operation**
FUNDING	no/limited funding in place to develop a pilot program	initial funding may be available and confirmed for a pilot project, but funding for broader program planning and operation is not yet available	time-limited, short-term, dedicated funding that allows for program planning and operation within a defined period	time-limited, **longer-term** dedicated funding that allows for program planning and operation within a defined period	permanent, dedicated funding that allows for long-term program planning (funding is not time-limited)
ORGANIZATIONAL CAPACITY	limited/ no dedicated resources to launch the program. Capacity for full program planning and operation is not yet available	time-limited, dedicated resources to launch the program, but capacity for full program planning and operation is not yet available	time-limited, short-term, dedicated resources to effectively manage the program within a defined period	time-limited, long-term, dedicated resources to effectively manage the program within a defined period	permanent, dedicated resources to effectively manage the program over a long-term period
PARTNERSHIPS	starting to seek formal/ informal connections between the program and key stakeholders	time-limited, formal or informal connections between the program and key stakeholders in development	short-term, time-limited, formal/ informal connections between the program and key stakeholders in place or in development	long term/ time-limited, formal/ informal connections between the program and key stakeholders	long-term, formal connections between the program and key stakeholders are in place
PROGRAM ADAPTABILITY	no ability for improvement, expansion or response to emerging threats	limited ability for improvement and expansion; no ability to respond to emerging threats	program has limited ability for improvement, expansion and response to emerging threats due to its novel nature	program can adapt for improvement, expansion and response to emerging threats within a limited scope based on available funding and resources	program is able to improve, expand and respond to emerging threats
COMMUNICATIONS	informal communication to a limited network of stakeholders, decision-makers and the public	initial development of a process for dissemination of program outcomes and activities of the pilot project to a limited network of stakeholders, decision-makers and the public	developing a process for periodic dissemination of program outcomes and activities with stakeholders, decision-makers and the public	periodic dissemination of program outcomes and activities with stakeholders, decision-makers and the public	strategic and timely dissemination of program outcomes and activities with stakeholders, decision-makers and the public
STRATEGIC PLANNING	developing program direction, goals and strategies for implementation	program direction, goals and strategies are in place for program implementation	program direction, goals, and strategies are being implemented, but there is no plan for ongoing review and updating	program direction, goals and strategies are in place for the time of the available funding and resources and have or are developing a process for review	program direction, goals and strategies are in place and subject to regular review
ENABLING POLICY	no policy exists, or is in early stages of discussion	policy is in development and has not yet been implemented; May or may not have stakeholder input	policy exists and/or is in early implementation, data sharing and standardization is limited or non-existent between F/P/T levels and a small number of stakeholders	policy exists and allows for limited data sharing and standardization between the federal, provincial and territorial levels that includes some stakeholders	policy exists and allows for effective and efficient data sharing and standardization between the federal, provincial and territorial levels that respects and includes all relevant stakeholders

We assigned one of the five stages of program development to each component element of the eight overarching surveillance requirements based on our evaluation of literature, program reports, and information from the interviews. These assignments were made through iterative discussion by the investigation team, with justifications provided in the compiled table of results. Areas that were identified as uncertain were confirmed with follow-up conversations with key informants with knowledge about the specific programs.

Validation by Experts

A draft summary of the methods and results (table of program assessments with written justifications) was circulated to key interview respondents for review and validation, December 2019 to January 2020. The reviewers included representatives from CIPARS, the Canadian AMR Surveillance System (CARSS), co-chairs of the Surveillance Task Group of the F/P/T AMR Steering Committee that is directing the surveillance pillar of the Pan-Canadian Action Plan for AMR, co-authors of the 2014 NCCID report, and the NCCID sponsors. Reviewers were asked the following questions:

1. Is the assessment of each program component element correct, based on your knowledge of the status of current programs?

2. Are the explanations for our assessments complete/correct?

3. Is the table of Provincial/Territorial AMR/AMU surveillance programs [and/or data sources] complete and accurate?

Reviewers' comments were used to amend assignments and rationale for each program component element. There were instances where reviewer rankings and justifications disagreed with those of our investigation team. We had subsequent email and telephone conversations with reviewers and key subject matter experts to clarify our knowledge (February-March 2020) and adjustments were made as applicable.

Results

Ultimately, six national, 22 provincial and one territorial AMR/AMU surveillance programs and/or data sources were reviewed, as well as other entities that contribute AMR/AMU surveillance data in Canada (see Table 2). Thirty-three invitations were sent for interviews (including secondary contacts identified in the first round of interviews); 29 interviews were conducted (see Table 3). Federal programs reviewed were CARSS, CNISP, CIPARS and three pathogen-specific surveillance programs (Canadian Tuberculosis Reporting System, AMR *Neisseria gonorrhoeae* Surveillance System, and the National Surveillance of Invasive Streptococcal Disease program). Of provincial level surveillance programs, all but two are focused on human health, with British Columbia (BC) collecting animal AMU data and Québec collecting AMR data from animal pathogens. The only province systematically collecting and reporting animal AMR data is Québec. The evaluation of the six national level programs comprise the assessment of national AMR and AMU surveillance in Canada. Provincial/territorial programs were not evaluated directly using the rubric because they largely do not contribute data to national surveillance programs, but they were considered in the larger picture of AMR and AMU surveillance in Canada.

Assessment of Progress on National AMR/AMU Surveillance programs.

Nationally, the major new development since the 2014 review was the creation of CARSS in 2015 to integrate, synthesize, and report data from human, food animal and food AMR/AMU surveillance conducted by the programs under the Public Health Agency of Canada (PHAC) (16). Existing national surveillance programs (CIPARS and CNISP) have expanded (12, 17), but no new, integrated national surveillance program to collect AMR or AMU was created since 2014. Of these programs, only CIPARS was purpose-designed for integrated, One Health, national AMR/AMU surveillance (12). Table 4 shows the summary rankings for each component of integrated AMR/AMU surveillance programs for the eight broad requirements from the 2014 NCCID and 2016 CCVO reports. Collectively, there is uneven progress towards most of the eight integrated surveillance program requirements and their components.

A significant development in integrated reporting, CARSS, was created in 2015, annually collating AMR/AMU surveillance data from national programs like CNISP and CIPARS.

CARSS reporting represents a summary of national data, with complete data included in annual CNISP and CIPARS reports.

Most areas of greater strength are within pre-existing surveillance programs (CIPARS and CNISP), which were already previous areas of strength (See Requirement 4 – national human AMR/AMU surveillance, Requirement 5 – national animal AMR/AMU surveillance, and Requirement 6 – collection of AMU indication data). Expansions within these programs are positive and fill in some of the previously identified gaps. However, important gaps remain and are addressed in respective sections below. The important recommendations highlighting development of a national, integrated AMR/AMU surveillance

program (Requirements 1, 2 and 3) are largely still in an Exploration phase, with particular emphasis on the lack of new and sustainable funding and organizational capacity. Timely, integrated reporting is partly addressed by the annual CARSS report, but it is an annual summary of data from multiple programs, and does not include complete data (Requirement 7). The legislative and policy changes to address veterinary oversight and close importation loopholes for animal antimicrobials are positive, but there is still no formal recognition of the need for One Health policy to address stewardship and surveillance beyond repeated program commitments to a One Health approach (Requirement 8).

Our evaluation was completed at a national level; however, it is important to note that some components include data from provincial and territorial programs. Discussion of P/T data sources are included where available and applicable. However, most P/T AMR and/or AMU data sources are not integrated into national surveillance programs at this time, which in itself is an important finding, demonstrating that data integration from P/T sources remains voluntary and non-standardized. For example, publicly available, public health-sourced community AMR data are very rare. Most such data exist in the form of variably reported antibiograms published by private and public microbiology laboratories (see Table 2). There is no standard for testing methodology, case definition, data collection, or reporting. Only one province, BC, collates such data within provincial public health reporting. The only exceptions to this are data collected by CNISP and the human *Salmonella* isolates provided to CIPARS for antimicrobial susceptibility testing and reporting by provincial laboratories.

Table 2: The national and provincial/territorial antimicrobial resistance and antimicrobial use surveillance programs and data sources evaluated in Canada.

Scope	Name	Associated Agency (if applicable)	Sector	Component	Link
Federal	Canadian Antimicrobial Resistance Surveillance System (CARSS)	PHAC	Human/ Agriculture	AMR/AMU	https://www.canada.ca/en/public-health/services/publications/drugs-health-products/canadian-antimicrobial-resistance-surveillance-system-2018-report-executive-summary.html
	Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS)	PHAC	Human/ Agriculture	AMR/AMU	https://www.canada.ca/en/public-health/services/surveillance/canadian-integrated-program-antimicrobial-resistance-surveillance-cipars.html
	Canadian Nosocomial Infection Surveillance Program (CNISP)	PHAC	Human	AMR/AMU	https://www.canada.ca/en/public-health/services/surveillance.html#a6
	Canadian Tuberculosis Reporting System	PHAC	Human	AMR	
	Antimicrobial-Resistant *Neisseria gonorrhoeae* Surveillance System	PHAC	Human	AMR	
	The National Surveillance of Invasive Streptococcal Disease	PHAC	Human	AMR	
	Pest Management Regulatory Agency (PMRA)	Health Canada	Agriculture	AMU	
Non-governmental	Canadian Animal Health Institute (CAHI)	trade association	Agriculture	AMU	https://www.cahi-icsa.ca/about-us
	IQVIA	private corporation	Human/ Agriculture	AMU	https://www.iqvia.com/
	Canadian Animal Health Surveillance System (CAHSS)	National Farmed Animal Health and Welfare Council	Animal	AMU	https://www.cahss.ca/
	Canadian Veterinary Medical Association (CVMA)	national veterinary association	Agriculture	AMU	https://www.canadianveterinarians.net/documents/cvma-receives-funding-to-lay-foundation-for-national-surveillance-of-amu

Scope	Name	Associated Agency (if applicable)	Sector	Component	Link
Provincial					
Alberta	Alberta Antimicrobial Stewardship Program	Alberta Health Services	Human	AMR	https://www.albertahealthservices.ca/info/Page9674.aspx
	Alberta Health Services (AHS)	Alberta Health Services	Human	Antibiograms	https://www.albertahealthservices.ca/lab/Page3294.aspx
	Dynalife		Human	Antibiograms	http://abx.dynalifedx.com/
	Calgary Lab Services (CLS)		Human	Antibiograms	http://www.calgarylabservices.com/education-research/publications/microbiology-Antibiograms.aspx
	University of Alberta Hospital (UAH)		Human	Antibiograms	http://www.antibiogram.ca/uah/
British Columbia	BC Centre for Disease Control (BCCDC)	BC Provincial Health Services Authority	Human	AMR/AMU	http://www.bccdc.ca/health-professionals/data-reports/antimicrobial-resistance-utilization
	Provincial Infection Control Network of BC (PICNet)	BC Provincial Health Services Authority	Human	AMR	https://www.picnet.ca/
	Life Labs		Human	Antibiograms	https://www.lifelabs.com/healthcare-providers/reports/antibiograms/
	Interior Health		Human	Antibiograms	https://www.interiorhealth.ca/sites/Partners/LabServices/DeptSpecific/microbiology/Documents/Antimicrobial%20Susceptibility%20Report.pdf
Manitoba	Shared Heath Manitoba	Health, Seniors, and Active Living	Human	AMR/antibiograms	https://sharedhealthmb.ca/health-providers/diagnostic/reference-material

Scope	Name	Associated Agency (if applicable)	Sector	Component	Link
Ontario	Institute for Quality Management in Healthcare	Public Health Ontario	Human	AMR	https://www.publichealthontario.ca/-/media/documents/aro-survey-2016.pdf?la=en
	Mt. Sinai Hospital		Human	Antibiograms	http://www.mountsinai.on.ca/education/staff-professionals/microbiology/microbiology-laboratory-manual/antibiogram/copy_of_department-of-microbiology
	Life Labs		Human	Antibiograms	https://www.lifelabs.com/healthcare-providers/reports/antibiograms/
	Sunnybrook Hospital		Human	Antibiograms	https://sunnybrook.ca/content/?page=antimicrobial-stewardship-antibiograms
New Brunswick	None identified				
Newfoundland	Eastern Health	Provincial Government	Human	Antibiograms	http://publichealthlab.ca/antibiogram/
Northwest Territories	None identified				
Nova Scotia	NSHA Antimicrobial Stewardship	Novia Scotia Health Authority	Human	AMR	http://www.cdha.nshealth.ca/nsha-antimicrobial-stewardship
Nunavut	None identified				
PEI	Health PEI	Provincial Government	Human	AMR	https://src.healthpei.ca/microbiology

Scope	Name	Associated Agency (if applicable)	Sector	Component	Link
Quebec	Quebec Ministry of Health	Provincial Government	Human	AMR	https://jammi.utpjournals.press/doi/full/10.3138/jammi.3.1.07
	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation Québec	Provincial Government	Animal	AMR	https://www.mapaq.gouv.qc.ca/fr/Productions/santeanimale/maladies/antibio/antibioresistance/Pages/resultats_surveillance.aspx
Saskatchewan	Saskatoon Health Authority	Government of Saskatchewan	human	Antibiograms	https://www.saskatoonhealthregion.ca/locations_services/Services/antimicrobial-stewardship/Pages/antibiograms.aspx
	Regina Health Authority	Government of Saskatchewan	human	Antibiograms	http://www.rqhealth.ca/department/laboratory-services/Antibiograms
Yukon	Yukon Hospitals	Territorial Government	Human	AMR	https://yukonhospitals.ca/yukon-hospital-corporation/tests-scans
Academic					
	Canadian Ward Surveillance (CANWARD)	Canadian Antimicrobial Resistance Alliance	Human	AMR	http://www.can-r.com/
	Canadian Cow-Calf Surveillance Network (C3SN)	University of Saskatchewan	Animal	AMU	https://research-groups.usask.ca/c3sn/index.php#Purpose

Table 3. Summary of interviewee respondent regions, affiliations and area of expertise.

Region	Organization/affiliation	Number of Interviewees	Domain of Expertise
Federal	Canadian Food Inspection Agency	1	Animal
	Public Health Agency of Canada	1	Human/Animal
Alberta	University of Calgary	1	Animal
	University of Alberta	2	Human/Animal
British Columbia	Government of British Columbia	1	Animal
	Vancouver Coastal Health	1	Human
	British Columbia Centre for Disease Control	1	Human
Manitoba	University of Manitoba	1	Human
New Brunswick	Government of New Brunswick	1	Animal
	Moncton Hospital	1	Human
Newfoundland and Labrador	Memorial University	1	Human
Nova Scotia	Nova Scotia Health Authority	1	Human
	Dalhousie University	1	Human
Northwest Territories	Government of Northwest Territories	1	Human
Nunavut	Government of Nunavut	2	Human
Ontario	Government of Ontario	1	Animal
	University of Guelph	1	Animal
	Public Health Ontario	2	Human
	Mount Sinai Hospital	1	Human
Prince Edward Island	N/A	0	
Quebec	Government of Quebec	3	Animal
Saskatchewan	University of Saskatchewan	1	Animal
	Government of Saskatchewan	2	Human/Animal
	Saskatchewan Health Authority	1	Human
Yukon	N/A	0	
Total		29	

Table 4. Evaluation of the requirements and the individual components of national, integrated antimicrobial resistance and antimicrobial use surveillance programs with progress towards an integrated, national program. Components of the eight surveillance requirements map to the specific surveillance components cross-referenced to Table A1 in Appendix 4, which also includes specific explanations for each ranking.

Surveillance Program Requirements and Components (NCCID + CCVO)	Common Program Elements for Evaluation						
	Funding	Organization Capacity	Partnerships	Program Adaptability	Communication	Strategic Planning	Enabling policy
1. National Integrated AMR/AMU Surveillance System							
1.1 Federally coordinated, cross-sectoral, integrated system of AMR/AMU surveillance	E	E	II	E	E	E	PA
1.2 Standardized F/P/T surveillance definitions, metrics and performance indicators	E	E	II	E	E	E	PA
1.3 Support for integrated provincial and territorial initiatives	E	E	II	II	E	PA	PA
2. Maintain and increase resources for existing AMR/AMU surveillance programs							
2.1 Multi-sector plan for comprehensive surveillance	E	E	II	E	E	PA	PA
3. National AMR data warehousing initiative							
3.1 AMR data warehouse (AMR NET; based on the EU model)	FO	N/A	PA	II	N/A	FO	PA
4. National Human AMR and AMU surveillance							
4.1 AMR Surveillance (Human nosocomial pathogens CNISP; foodborne pathogens in humans CIPARS)	SO	SO	SO	FO	FO	FO	II
4.2 AMR surveillance for other human pathogens (e.g., pathogens not covered by CNISP/CIPARS, community-acquired pathogens)	E	E	E	N/A	N/A	N/A	N/A
4.3 Centralized collation of hospital AMU data (CNISP is the only AMU program evaluated)	FO	FO	SO	FO	PA	FO	II

Surveillance Program Requirements and Components (NCCID + CCVO)	Common Program Elements for Evaluation						
	Funding	Organization Capacity	Partnerships	Program Adaptability	Communication	Strategic Planning	Enabling policy
4.4 Human antimicrobial Distribution and Prescribing Data (IQVIA data)	SO	SO	FO	FO	FO	FO	FO
4.5 Non-CNISP Point Prevalence Surveys of AMR and AMU in hospitals (CNAPP, academia, pharmaceutical and WHO projects)	Project Only	Project Only	N/A	N/A	N/A	N/A	N/A
5. National Animal AMR and AMU Surveillance							
5.1 Collaborative national working group on animal AMR/AMU surveillance	E	E	II	E	E	E	E
5.2 CIPARS - Antimicrobial Sales/ Distribution Data for animals	SO	SO	SO	SO	FO	SO	SO
5.3 CIPARS Farm-level AMR/AMU surveillance - feedlot cattle	SO	SO	SO	FO	FO	SO	SO
5.4 CIPARS Farm-level AMR/AMU surveillance - feedlot cattle	II	II	FO	FO	N/A	FO	FO
5.5 Canadian Dairy Network for Antimicrobial Stewardship and Resistance (CaDNetASR) - farm-level AMR/AMU data	II	II	FO	FO	N/A	FO	FO
5.6 Farm-level AMR/AMU surveillance - cow-calf	E	E	E	E	E	N/A	N/A
5.7 Veterinary or farm-level AMR/AMU surveillance for remaining food and companion animals (small animals, equine)	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Surveillance Program Requirements and Components (NCCID + CCVO)	Common Program Elements for Evaluation						
	Funding	Organization Capacity	Partnerships	Program Adaptability	Communication	Strategic Planning	Enabling policy
5.8 Department of Fisheries and Oceans collection of AMU data from aquaculture producers in Canada	FO	FO	SO	PA	FO	FO	SO
5.9 CIPARS animal clinical, abattoir and retail AMR components	SO	SO	SO	FO	FO	SO	SO
5.10 AMR Surveillance of veterinary pathogens	E	E	E	N/A	N/A	N/A	N/A
5.11 Reporting requirements for antimicrobial susceptibility data from vet labs (AMR Net)	E	E	E	E	E	E	E
5.12 AMR Surveillance in soil and water	Project only	Project only	N/A	N/A	N/A	N/A	N/A
5.13 CIPARS Crop AMU surveillance	FO	FO	FO	PA	FO	PA	FO
5.14 CIPARS Aquaculture AMU surveillance	FO	FO	FO	PA	FO	PA	FO
6. Collection of Antimicrobial Use Indication Data							
6.1 Swine/broiler chicken/turkey on-farm programs provide indication data (CIPARS)	SO	SO	SO	FO	FO	SO	SO
6.2 Beef feedlot indication data (CIPARS)	II	II	FO	FO	N/A	FO	FO
6.3 Canadian Dairy Network for Antimicrobial Stewardship and Resistance (CaDNetASR)	II	II	II	II	N/A	II	FO
6.4 Veterinary Prescribing Surveillance (CVMA SAVI)	II	II	PA	E	N/A	E	E
6.5 Human antimicrobial indication data (primarily CARSS IQVIA Data: other sources under consideration)	SO	SO	FO	PA	FO	E	PA

Surveillance Program Requirements and Components (NCCID + CCVO)	Common Program Elements for Evaluation						
	Funding	Organization Capacity	Partnerships	Program Adaptability	Communication	Strategic Planning	Enabling policy
7. Timely and Integrated National Reporting of AMR/AMU data							
7.1 CARSS - Human and Animal AMR/AMU Report	SO	SO	SO	II	FO	FO	FO
7.2 CIPARS - human and animal AMR/AMU report	SO	PA	SO	FO	FO	SO	II
7.3 CIPARS Interactive Display Dashboard for human and animal AMR/AMU reporting	II	II	SO	N/A	N/A	SO	II
8. Formal Recognition of One Health Policy for Antimicrobial Stewardship							
8.1 Policy to recognize "One Health" as a priority for Canada	E	E	E	E	N/A	N/A	E
8.2 Legislated requirement for animal antimicrobial sales reporting by all manufacturers, importers and compounders of 2019	SO	SO	SO	SO	N/A	N/A	SO
8.3 Elimination of the "Own Use Importation" provision for medically important antimicrobials	SO	SO	SO	SO	N/A	N/A	SO
8.4 Elimination of non-approved "active pharmaceutical ingredient" use and importation of medically important antimicrobials	SO	SO	SO	SO	N/A	N/A	SO

Legend: Stage of Development Rankings

E	Exploration
PA	Program Adoption
II	Initial Implementation
FO	Full Operation
SO	Sustainable Operation

A complete listing of stage of development rankings for each component element of the eight surveillance requirements and our explanations can be found in Appendix 4 Table A1. Our findings for each of the eight surveillance program requirements are as follows:

1. Progress Toward a National Integrated AMR/AMU Surveillance System (Table A1, sections 1.1-1.3).

> The goal of a comprehensive, national, integrated AMR/AMU surveillance program that reports data for timely action remains elusive. Incremental but valuable changes include annual CARSS integrated data reports, and added elements within CNISP and CIPARS within current capabilities.

Most component elements of a national, integrated AMR/AMU surveillance system remain in Exploration, particularly Funding, Organization Capacity, Communication, and Program Adaptability. There are some positive steps for Partnerships (Initial Implementation) and Enabling Policy (Program Adoption). The newest development is CARSS, introduced in 2015, which provides an integrated national report of data from several surveillance programs (16), including CNISP (17), CIPARS (12), and more specific surveillance programs for tuberculosis (18), gonorrhoea (19), and streptococcal disease (20). However, there is no new federal program that collects new data to address the key gaps noted in the 2014 NCCID report. As a result, there is still no federally coordinated, fully cross-sectoral integrated system of AMR/AMU surveillance. Partnerships, such as the F/P/T stakeholder engagement groups for the proposed pan-Canadian Action Plan for AMR, and industry and stakeholder working groups for CIPARS are at Initial Implementation and enabling policy is at Program Adoption, owing in large part to the work to develop the Action Plan that has leveraged existing partnerships. However, all other aspects remain in Exploration reflecting that a truly national, One Health, integrated AMR/AMU surveillance system does not exist in Canada. This is evident when one considers that much of the human AMR data exist at the level of Provinces and Territories, but that their reporting is completely voluntary and non-standardized (6, 8, 21). Most of the AMR data are antibiogram data held by public or private laboratories, with no standardized collection or collation methodology between laboratories or provinces. These data are generated in clinical microbiology laboratories across the country daily, but their reporting to any surveillance entity is voluntary. Although exploration for collection and reporting has occurred in various places, only BC reports these data. There is no federal or harmonized P/T (provincial or territorial) policy that requires standardized AMR or AMU reporting. Human hospital AMU and AMR data are collected for CNISP via select volunteer tertiary hospitals in many provinces (17), with new expansion into sites in Iqaluit and the Northwest Territories as well as a small number of community and rural hospitals. The only standardized provincial data come from the provinces forwarding human *Salmonella* isolates to CIPARS for antimicrobial susceptibility testing and reporting (12).

The CARSS annual report is recognized for improving both communication and integration of existing data, but the lack of a truly coordinated, integrated data collection system means that communication of comprehensive, integrated results remains in Exploration. There are a number of additions to surveillance elements within CIPARS and CNISP that have addressed previously-noted gaps. New CNISP sites in some northern and non-tertiary hospitals in Canada, for example, provide data for these

otherwise unmonitored populations. However, significant gaps remain in community-based AMR data and long-term care surveillance across the country. A project under development through the National Microbiology Laboratory, AMRNet, stands to improve the collation and reporting of community microbiology lab data once established (22), but also rests upon voluntary collaboration under its current vision. The AMRNet initiative should not be confused with the new AMR Network project recently funded by PHAC to develop a governance structure and coordinated response to AMR in Canada (23). Specific human pathogen surveillance is therefore lacking outside of the nosocomial pathogens included within CNISP and select single pathogen specific national collaborations. There are also a number of human point prevalence hospital AMU surveys (see Requirement 4), with varying degrees of overlap and redundancy, that are run by several, possibly competing public-health based, academic and pharmaceutical industry-sponsored groups. These were assessed here as time-limited projects.

The CNISP began further development of hospital AMU data assessment from participating centres. The CIPARS expanded components within their existing on-farm surveillance programs (swine, broiler chickens, and turkeys), and incorporated project-funded, time-limited components, such as the Canadian Feed-cattle Antimicrobial Surveillance Program (CanFASP) for beef feedlot cattle (24) and the Canadian Dairy Network for Antimicrobial Stewardship and Resistance (CaDNetASR) for dairy cattle (25). Both of these surveillance projects receive some program support and funding and provide data directly to CIPARS, with the intent to roll them into long-term CIPARS components if long-term funding can be secured. Annual antimicrobial distribution data reporting for food animals and crops is now a regulatory requirement under the Veterinary Antimicrobial Sales Reporting program (VASR) (26), with crop AMU data coming from the Pest Management Regulatory Agency and aquaculture data coming from the Department of Fisheries and Oceans (DFO Canada). However, there is still no coordinated AMR surveillance for companion animals and other farm commodities, nor for veterinary pathogens other than *Salmonella* in the on-farm programs and some bovine respiratory pathogens in CanFASP.

2. Maintain and Increase Resources for Existing AMR/AMU Surveillance Programs (Table A1, section 2.1)

There are partnerships to advance these existing AMR/AMU programs, and policy is being considered in the draft pan-Canadian Action Plan for AMR. However, some expansions are assessed as reliant on time-limited project funding (12). The current resource allocations (for personnel and funding) do not appear sufficient to sustain and expand integrated surveillance so the remaining components remain in Exploration. In a ten-year review, Van Katwyk et al. (2020) found little coordination by the federal and provincial governments and investments have been largely for projects (27), with the exception of the PHAC investment in a project to develop the governance for a Canadian AMR Network

There has been no new investment in integrated AMR/AMU surveillance in the past 10 years other than time-limited funded projects. Sustained, enhanced investment in resources (money and people) is required to fully achieve an integrated, national surveillance program.

(23). Complicated F/P/T governance for AMR impedes adequate funding and resourcing for surveillance data collection and reporting because there is no overarching F/P/T agreement on this responsibility (6, 8, 21).

3. National AMR Data Warehousing Initiative (Table A1, section 3.1)

There has been significant work towards this initiative at the federal level, but barriers remain at the P/T level for reasons already mentioned (primarily related to a lack of supporting policy addressing required reporting, responsibility, resources and consistency). The new AMRNet initiative may well provide significant gains in this capacity by addressing many current weaknesses, but it requires voluntary support of F/P/T data collecting groups, as well as resources and data standardization. At present, the model is in development as a completely voluntary initiative and the sustainability of funding is not clear. One hopeful development is consideration to include animal pathogens within AMRNet, but this is also in a very preliminary phase of discussion.

4. National Human AMR/AMU Surveillance (Table A1, sections 4.1-4.5)

Surveillance for AMR of specific nosocomial antibiotic resistant organisms of infection control significance, and foodborne pathogens is strong within CNISP and CIPARS (12, 17). There is some question about the adaptability of these programs and timeliness. Annual reports from both are thorough, but tend to be delayed due to the monumental effort required to compile the information (see Requirement 7). Since 2014, CNISP increased the number of sentinel hospitals from 54 to 66 in the 2018 report (28). The CNISP has been assisting hospitals in Nunavut to establish AMR surveillance programs and has recruited these hospitals and in other territories as sentinel sites. Surveillance of AMR in other human pathogens remains largely non-existent. While AMRNet may hold promise to address this, it is not yet established and particulars are not available.

Centralized collection of hospital AMU data is carried out under CNISP, which largely focuses on tertiary care hospitals, with new expansion into some northern and non-tertiary hospitals. Communication, however, is considered in Exploration because the CNISP AMU data are only reported at the level of the CARSS report (16), which is not comprehensive for the data that are collected. CNISP internal data reports are shared with CNISP members, and summaries also may be presented at meetings or published although it is not clear if there is a consistent approach. There is no updated, publicly accessible repository of CNISP reports apart from the data included in CARSS reports, as the CNISP surveillance reports available on the Infection Prevention and Control Canada website are only from 2017 forward (29).

Human antimicrobial distribution and prescribing data from the community, by diagnosis, and tertiary hospitals are collected by a private third party (IQVIA) and provided to CARSS at a cost, with limited, basic, high-level data summarized in the CARRS report (16). The CNISP also collects hospital AMU data directly from participating sites (17). There is no public-facing description of the IQVIA AMU data. In 2018, CARSS reported that the AMU data represented a sample of prescriptions from 780 hospitals. The

IQVIA data included community prescription data from 6,000 pharmacies plus community prescription and diagnosis data from 652 physicians across Canada. These AMU data are extrapolated across the entire population of pharmacies and 55,000 physicians in Canada (16). While the arrangement with IQVIA is considered to be at Sustainable Operation, the adaptability is limited by the third party participation and the CARSS budget to purchase the data. The added CNISP hospital sites in community and northern hospitals may improve hospital AMU data collection, but – as with AMR surveillance data – there remain gaps in assessment of non-tertiary, community, and long-term care populations in particular. There is also concern about long-term policy support for the costs of purchasing data annually. Elements of surveillance data that are important to promote stewardship, such as antimicrobial indication data (e.g., diagnoses and reasons for prescription and/or use), are available in various data repositories, but accessing this information would be subject to extra cost and is limited by this governance structure. It is unknown whether the forthcoming pan-Canadian Action Plan for AMR will address these issues.

There are a number of P/T AMR data sources (see Table 2), but they are not equivalent to the more comprehensive AMR programs that exist in BC and Québec (30, 31). Private and public microbiology laboratories in each province and one territory (the Yukon) compile antibiogram data for selected clinical human isolates as part of their accreditation process. Most, but not all laboratories share these data publicly and they are usually updated annually. Antibiograms for hospitals in Nunavut are currently under development with assistance from CNISP. Antibiogram data are typically displayed on a hospital or regional basis, but report formats and populations vary by hospital, region and laboratory. Depending on methodologies used, these data may not be directly comparable between laboratories unless susceptibility breakpoints or minimal inhibitory concentrations are specified, which is currently not standardized. In addition, most do not differentiate between hospital, long-term care and community isolates. The timeliness of antibiogram data ranges from quarterly reporting by some laboratories to being as long as three years out of date. Some health regions and laboratories are using mobile applications to make antibiogram data accessible to users. Notably, the British Columbia Centre for Disease Control (BCCDC) created a publicly accessible, online dashboard to display antibiogram and AMU data (30). Although antibiograms may be seen as an element of AMR surveillance, the piecemeal, voluntary, non-standardized reporting and lack of collation of these P/T data at a national level currently precludes this from being a true surveillance system. Standardization and warehousing of antibiogram data has been proposed, with some projects underway at the P/T level, but there are no current mechanisms to integrate these data into a national program, although this is the basis for the evolving AMRNet initiative. There are no agreed

A major gap lies in the lack of national reporting of human antimicrobial resistance patterns among common, community based bacterial infections. Antibiogram reports are generated in communities and regions across Canada by microbiology labs. However these data are not collated and presented on a national basis. Examples of data integration and sharing methodologies (such as the ECDC EARSNet program) exist and may underpin of the nascent AMRNet initiative in Canada.

methods for national compilation and analysis of antibiogram data from disparate regions, but the European Antimicrobial Resistance Surveillance Network of the European Centre for Disease Prevention and Control provides a model for consideration (32). Without such a structure in place, there is no ability to assess prevalence or incidence of specific organism and antimicrobial resistance parameters of interest with trends over time, or how such data may relate to infection prevention and control and stewardship efforts in the provincial population at risk.

Public provincial human AMU data collection and availability are limited to BC (30) and Québec (31), with a paucity of other provincial AMU surveillance data. In this gap, several point prevalence survey systems have arisen and are ongoing in various hospital settings in Canada. We acknowledge that point prevalence data can be useful when resources are insufficient for ongoing monitoring, particularly when iterative data are collected. One such survey through CNISP focuses on hospital-acquired infections including antimicrobial resistant organism colonization and concurrent prevalence AMU, which recently published a report of trends in acute care hospitals (33). Others, including the WHO Global Antimicrobial Resistance and Use Surveillance System (GLASS) (34), the Canadian National Antimicrobial Prescribing Survey (run by the Sinai Health System - University Health Network Antimicrobial Stewardship Program and sponsored by Becton, Dickinson and Company) (35), and the Global Point Prevalence Survey system (sponsored by BioMérieux) (36), focus specifically on AMU. It seems that a perceived need for AMU data led to separate, and sometimes overlapping and competing point prevalence surveys systems campaigning to recruit hospital sites simultaneously. Differing methodologies and jurisdictions mean data from each are not comparable, resulting in fragmentation and a limited ability for national comparison and synthesis of trends. This lack of standardized AMU data reporting and availability preclude integrated analysis of how AMU affects AMR across the country or the ability to assess antimicrobial stewardship over time, either at the P/T or national level.

5. National Animal AMR/AMU Surveillance (Table A1, sections 5.1-5.13)

> CIPARS has added feedlot and dairy cattle AMR/AMU surveillance programs through time-limited projects, with long-terms options being explored. The addition of VASR, crop, and aquaculture AMU data are positive expansions. Important gaps remain in animal pathogen data and comprehensive AMU surveillance in animals and the environment.

Animal AMR/AMU surveillance is a broad category that considers a large number of animal and environmental components that would give a national surveillance program a true One Health scope. Most elements are provided by CIPARS (12) or linked surveillance initiatives with time-limited, project funding. Antimicrobial sales/distribution data are reported annually, by province and with increasing ability to breakdown by animal species. This reporting is now required by federal regulation under VASR (26). The CIPARS farm components (grow-finish swine, broiler chickens, and turkey) are largely in Sustainable Operation, with a few exceptions in Full Operation (Program Adaptability and Communication). These farm sites align with the FoodNet Canada sentinel sites in BC, Alberta, Ontario, and Québec (37). While intensive and purpose designed, these sentinel farm programs include a relatively small number of farms in the national

context and do not include complete segments of each industry. Swine surveillance is limited to the grow-finish stage and poultry to broiler meat chickens and turkeys. The commodity group coverage varies by province and the bacterial species varies by commodity; more detail can be found in the CIPARS methods (12). Farm-level AMU data are collected by herd/farm veterinarians from sentinel farms via annual questionnaires, with data reported to CIPARS. Communication relies on detailed annual reports, but an interactive data display is expected in 2021.

Feedlot cattle were added in 2019 via CanFASP through time-limited, project funding, with data collection underway in 2019 (24). This includes antimicrobial susceptibility of generic *E. coli* and *Campylobacter*, as well as bacterial pathogens of the Bovine Respiratory Disease complex, in combination with antimicrobial prescribing and dispensing data from feedlot veterinarians for feedlots in Alberta, Saskatchewan and Ontario. In 2018, the CadNetASR added dairy cattle surveillance in BC, Alberta, Ontario, Québec and Nova Scotia, also through time-limited, project funding. This includes antimicrobial susceptibility of generic *E. coli*, Shiga-toxin producing *E. coli*, *Campylobacter* and *Salmonella* spp. For AMU, they conduct quarterly "garbage can" audits of drugs used on dairy farms and combine these with veterinary prescription data from veterinary records, a veterinary records assessment, and a farm-level questionnaire similar to the other CIPARS on-farm components. These two additions have not yet reported any data. A small amount of AMR and AMU data are available for cow-calf operations for the Canadian Cow-Calf Surveillance Network, but this remains in Exploration (38). Canadian aquaculture AMU data are reported to the DFO Canada under the Aquaculture Activities Regulation (39) and made available to the public (40). These data are included within annual VASR distribution reporting (26), but farm-specific data are not included in CIPARS reporting at this time. Data for companion animals are non-existent.

The CIPARS is the only program to provide AMR data from retail meat sampling protocols through its integration with FoodNet Canada (12). AMR data are provided for non-typhoidal *Salmonella* serovars (chicken and turkey), generic *E. coli* (beef, pork, chicken and turkey), and *Campylobacter* (chicken) and represent an important link between food animals and human exposure. The CIPARS collects limited clinical AMR data for animal pathogens, including abattoir data for non-typhoidal *Salmonella* in swine, beef, chickens and turkeys. Other animal pathogen data are lacking from any national or provincial surveillance other than CanFASP and limited data in CadNetASR. There is preliminary discussion to include animal pathogens from animal diagnostic laboratories in AMRNet. From a One Health perspective, there are no data for AMR in soil and water, but the new VASR program includes crop AMU data from the Pest Management Regulatory Agency and the DFO aquaculture AMU data (12, 26).

There are no AMR data available in animal health settings at a P/T level outside of Québec. The Ministère de l'Agriculture, des Pêcheries et de l'Alimentation Québec (MAPAQ) collects AMR data from the diagnostic activities of MAPAQ laboratories and the Faculty of Veterinary Medicine of the University of Montreal (41). This includes antimicrobial susceptibility from an increasing number of animal pathogens and other organisms of importance in cattle (*E. coli*, *Salmonella* spp., *Mannheimia haemolytica*, *Histophilus somni*, *Pasteruella multocida*, and *Staphylococcus aureus* from mastitis), swine (*E. coli* and *Salmonella* spp.), and poultry (*E. coli* and *Salmonella* spp.) (42). Previously, BC was collecting

and publishing AMU data for antimicrobials from sales at farm supply stores, but this surveillance program has been discontinued for all animals with the exception of finfish aquaculture (primarily salmon), due to changes to the federal regulation requiring veterinary prescriptions for all medically important antibiotics as of December 1, 2018 (43, 44). Prior to this change, farm supply stores had the ability to sell non-prescription, medically important antimicrobials directly to animal owners and producers over-the-counter; now direct sales are no longer allowed as the result of this federal regulatory change. Within the BCCDC, there is apparently a project in the process of collecting data on AMR for companion animals, but no information is publicly available at this time.

6. Collection of AMU Indication Data (Animals and Humans) (Table A1, sections 6.1-6.5)

The CIPARS on-farm programs collect AMU indication data for grow-finish swine, broiler chickens and turkey, but have the limitations noted in Requirement 5. The CanFASP will collect these data for feedlot cattle, but indication data for dairy cattle will be limited in the CadNetASR data collection. The Canadian Veterinary Medical Association has a newly funded project through 2023, the Stewardship of Antimicrobials by Veterinarians Initiative (SAVI), to develop information sharing and confidentiality protocols and agreements to collect AMU and indication data from veterinary prescriptions and feed mills as a follow up to its initial development work in this regard (45). However, it remains to be seen what animal sectors will be included and how these data will link to a national surveillance system. Human AMU indication data come from the IQVIA and suffer from the limitations mentioned in Requirement 4. Relying on third-party collection rather than developing methods to use existing provincial pharmaceutical network data limits both adaptability and the ability to stratify data to collect AMU data in large sectors of human health, especially long-term care and Indigenous populations.

7. Timely and Integrated National Reporting of AMR/AMU Data (Table A1, sections 7.1-7.3)

The annual CARSS report is a useful tool to integrate data from the different sectors (16). The annual CIPARS report provides a comprehensive account of the surveillance components within its scope (4, 46, 47). However, at the time of this review, reports for both programs were limited to annual print (electronic PDF) reports that require a large amount of resources to compile with consequent delay in their timeliness. In particular, the scope of CARSS is limited in that the exercise of integration precludes the ability to report on all data, which is left to the supporting programs with variable reporting expectations. The CARSS reports typically include a summary of data integrated from both CNISP and CIPARS, with more detailed and complete reporting in each of these respective program reports. The CNISP reports are not publicly available other than the most recent (2017) and through the data summaries in CARSS reports (29). The CIPARS is developing an interactive data display, with potential release in 2021, which will allow users to interact with annual AMR and AMU data in real-time on a web-based platform. This will be a significant advance and could be a model for future human surveillance components.

8. Formal Recognition of One Health Policy for Antimicrobial Stewardship (Table A1, sections 8.1-8.4)

Canada made tremendous steps in 2018 to bring all animal use of medically important antimicrobials under the oversight of veterinarians with the regulatory change to move all these drugs to the prescription drug list (43, 44). This was combined with regulatory changes to restrict the "Own Use Importation" of these drugs and eliminate the use of non-approved "Active Pharmaceutical Ingredients". However, the formal recognition of One Health in antimicrobial stewardship and AMR policy remains in Exploration. The Pan-Canadian Action Plan on AMR uses One Health approaches to inform the technical and policy aspects of the plan. It has strong representation from the F/P/T human and animal agricultural sectors. However, it does not call for One Health legislation or regulation and has not successfully integrated the environmental sector in the discussions or Action Plan.

Discussion

The global and national landscape for AMR mitigation and surveillance has changed immensely since the release of the 2014 NCCID recommendations report (8) and the CCVO report on animal AMU surveillance (11). The recent study from the Canadian Council of Academies estimates dire socioeconomic consequences if Canada fails to act now to address AMR (15). The forthcoming pan-Canadian Action Plan for AMR aims to recognize the importance of integrated AMR and AMU surveillance as one of four key pillars (6) to address the "AMR tsunami" (48). (The Action Plan is still in draft form, but one co-author (Otto) is a Task Group co-chair that informed part of its development and reviewed a draft of the document in late 2019. One Health, integrated AMR/AMU surveillance is critical to be able to track resistance development and spread, inform antimicrobial stewardship policy and clinical decision-making, and to benchmark and evaluate stewardship and resistance mitigation policies and actions.

One Health, integrated AMR/AMU surveillance is critical to be able to track resistance development and spread, inform antimicrobial stewardship policy and clinical decision-making, and to benchmark and evaluate stewardship and resistance mitigation policies and actions.

Over the last six years, Canada has made incremental gains towards national, One Health, integrated AMR and AMU surveillance, with the 'surveillance patchwork' becoming somewhat more cohesive and complete. In particular, the creation of CARSS to integrate Canadian AMR and AMU data annually provides a useful, combined report of the component programs (CNISP and CIPARS) (16). However, it remains largely a data integration function with some added surveillance components under CNISP and CIPARS. There is not yet a comprehensive, fully integrated, national AMR/AMU surveillance program. Of the federal programs, CIPARS is the only one purpose-designed for integrated AMR/AMU surveillance and that includes a One Health lens and components (12). It has strong farm-to-fork components for foodborne pathogens, animal antimicrobial distribution and on-farm programs for swine, broiler chickens, turkeys and more recently, feedlot and dairy cattle. However, its current components are not completely comprehensive in that livestock sectors are only partially represented in a limited number of provinces, and there are large gaps for animal pathogen data. New feedlot and dairy components offer significant expansion for livestock coverage, but these are currently time-limited based on project funding with uncertain future resourcing. Other than reporting of crop and farmed aquaculture data, there are no other environmental components that include AMR or AMU linked to water or soil to complete the One Health transmission pathways. Increasing evidence suggests that the environment plays an important role as a reservoir for AMR maintenance (49, 50). Surveillance designed to strategically capture links between humans, animals, water, soil, and the broader environment will become increasingly important to understand and mitigate AMR dissemination and transmission.

The other flagship program, CNISP (17), includes varying combinations of AMR and/or AMU data collection into programs with broader nosocomial infection-related objectives. The integration of data

within CARSS (16) helps to bring CNISP, CIPARS and other smaller program data together, but it is a high level compilation of surveillance data and does not, for example, include everything included in the annual CIPARS reports. Human data are largely collected through CNISP (17) with a nosocomial focus in tertiary care facilities, leaving large gaps for community human pathogen AMR (including community hospital, long-term care and northern and Indigenous community representation). The CNISP has started to add some of these hospital components, but limited resources and the voluntary, non-standardized provision of data are ongoing challenges. In addition, the reliance on third-party sources for human community-based AMU data creates limitations for adaptability and long-term security of data availability.

Timely communication remains a significant challenge for AMR/AMU surveillance in Canada. Generating annual reports requires huge investments in time and human capital (4, 16) with consequent issues with timeliness. The CARSS annual reporting is more timely, but the reports contain only a snapshot of CIPARS, CNISP, and other data for the national integrated report. The proposed CIPARS interactive data platform would be a significant advancement for timely visualization and customization of national AMR and AMU data reporting, and would be able to supplement the annual CIPARS reports with more timely and interactive data accessibility. It is also not certain if this display technology will be expanded to other human surveillance reporting. However, across human and animal health, rapid data synthesis and release is required to inform stewardship and AMR mitigation efforts.

Timely communication remains a significant challenge for AMR/AMU surveillance in Canada.

Synthesis of this collective understanding of the current situation highlights three crucial areas for action for integrated AMR and AMU surveillance: 1) development of a truly comprehensive, integrated AMR/AMU surveillance program that builds on current success; 2) changes to F/P/T policy to compel standardized AMR and AMU reporting; and 3) significant investment in AMR/AMU surveillance resources (personnel and money). The direction of these three elements must be guided by development of strong underlying policy for surveillance, antimicrobial stewardship and AMR mitigation. The imminent pan-Canadian Action Plan for AMR is expected to guide these decisions (6). The evolution over the past six years suggests that improved reporting and redistribution of resources within the patchwork of F/P/T surveillance activities, while important and useful, will not culminate in a comprehensive, integrated system without a thoughtful consideration of structure and procurement and deployment of resources. The design of this system should be guided by a policy direction for stewardship that, for example, could focus on education-based approaches that use surveillance data to inform current practices. Alternatively, or in addition, stewardship efforts informed by data could be directed at development of appropriate benchmarking approaches in human and animal health. Decisions like this will drastically alter the requirements for a national, integrated AMR/AMU surveillance program (8, 11).

The current F/P/T reporting structure for animal and human AMR and AMU data is a mixture of required and voluntary reporting (6, 8, 21). However, components with regulatory requirements are largely

limited to animal antimicrobial sales/distribution reporting and human foodborne diseases (*Salmonella* and *Campylobacter*). These are important components of the system, but a significant underlying issue remains that almost all human and animal reporting relies on voluntary relationships between P/T health systems that lack standardization, with BC being the only province to collate human antibiogram data at a provincial level. Truly national surveillance requires coordinated F/P/T policy for collection of standardized data, with data sharing agreements that compel reporting to a national level and a warehouse for collection and compiled reporting. National programs like CNISP rely largely on academic IPC professionals, and liaisons with provincial public health systems to collect select AMR and AMU data, and third-party entities to provide community AMU data. Collated and synthesized human pathogen AMR data beyond antimicrobial resistant organisms of nosocomial importance (such as antibiogram data) are still lacking, as are any data on veterinary pathogens.

Hospital-based surveillance data gaps and needs are both illustrated by the proliferation of competing AMU point prevalence survey systems from academic, public health and pharmaceutical industry sponsors (33-36). These initiatives invite individual hospitals and health systems across Canada to participate. Although these survey programs are well intentioned and provide useful facility-based data, their lack of comparability of Canadian data makes them an impediment to standardized national surveillance. Of the studies that include Canada, some are international in scope, with variable methodology and sampling frames (e.g., inclusion of primary/secondary/tertiary +/-pediatric hospitals, types of wards included, countries included, government versus pharmaceutical industry sponsorship, and AMR versus AMU data). Optimally, a single system or data standard should be developed to inform Canadian antimicrobial stewardship efforts. The proposed AMRNet platform (22) (distinct from the AMR Network governance structure (23)) could help to fill many of the AMR gaps, but design, participation, and roll-out is in development and participation is expected to be voluntary. The CIPARS farm programs are robust, but still not comprehensive for the collective livestock production systems across all P/Ts. Animal pathogen data, with the exception of a few examples, and companion animal data are largely lacking.

The Canadian Council of Academies estimated that the annual direct Canadian costs of AMR in hospitals in 2018 was $1.4 billion (15). If we do nothing more to address AMR, this could reach $7 billion per year by 2050, with projected cumulative hospital costs of $120 billion and GDP loss of $388 billion. From 2013-2018, the PHAC Chief Financial Officer reported an annual estimated expenditure of $8.5 million by PHAC for programs and staffing related to AMR, representing approximately 1.4% of the annual budget (51). In context, this public health AMR containment funding represents 0.6% of the annual direct healthcare cost. We acknowledge that this does not include other F/P/T investments from the Canadian Food Inspection Agency, Agriculture and Agri-Food Canada, research funding agencies, and PT governments. However, in our opinion, this information should drive the business case for investment in AMR mitigation, antimicrobial stewardship, and comprehensive, integrated AMR/AMU surveillance to underpin these initiatives. There has been no substantial investment in AMR by the federal government in the past ten years, with particular lack of investment in coordinated national, integrated AMR/AMU surveillance (27). Current surveillance programs, with static or decreasing budgets, have relied on time-

limited project funding to expand their current programs. The PHAC-funded project to develop the governance for a Canadian AMR Network (23) is the first significant new investment in coordinated AMR mitigation, but is only a first step in a long and complex process, with thus-far limited capacity to expand components of national, integrated AMR/AMU surveillance.

The urgently required federal government spending on the COVID-19 response dwarfs the required infrastructure investments for national, integrated AMR/AMU surveillance, but these needs should not be lost in the acute pandemic. Antimicrobial resistance has been an issue for as long as we have used antimicrobials and will continue to be once the pandemic is over. It is hypothesized that that the COVID-19 pandemic could make AMR concerns worse due to altered patterns of AMU both for COVID and non-COVID conditions with rising virtual care, and possible effects of cleaning and disinfection and AMR, (52-55). Predictable resources and funding are needed to support new and existing surveillance initiatives at all levels of government. A "patchwork" of surveillance efforts from stakeholders outside of government, such as those in academia and the food animal production industries has arisen to try to fill gaps, and it will be important to continue to leverage and coordinate these research projects and programs. Alone, however, these external efforts will not sustain or allow for the needed expansion and integration of current programs. It remains to be seen if the pan-Canadian AMR Action Plan will truly be able to provide directed government support to ensure the adequate resources are available for truly comprehensive, integrated national surveillance (6).

The novel tool developed and piloted for evaluation of integrated AMR/AMU surveillance programs in this review should be used for future and ongoing, recommended evaluation of these programs. There was clear utility demonstrated with defining a temporal "stage of development" ranking, and defining program elements to evaluate based on an analysis of sustainable programs. The rubric is complex but allowed for nuanced assessment that was robust to iterative review and was ultimately a more refined and transparent way to display and engage in evaluation with stakeholders and program leads. This combination of frameworks for public health and AMR surveillance program evaluation can be used for future reviews at all F/P/T levels. One potential weakness was that in several instances our evaluation of different program components ranked highly according to our defined criteria, but may not be comprehensive. However, it became clear that missing from this evaluation was consideration of the scope and comprehensiveness of the program elements. Some elements ranked highly when using the stage of development definitions, but ultimately were too limited in scope to be considered truly comprehensive and integrated for national AMR/AMU surveillance for Canada. This aspect should be refined and considered in future, ongoing review and planning for integrated AMR/AMU surveillance in Canada, as we consider this to be an iterative process. As a future modification we propose that each program element be evaluated for scope and comprehensiveness using a ranking system (with definitions to be determined), with a proposed three-part system such as: Sufficient, Partial, or Insufficient. Definitions for these criteria would be developed with stakeholders and applied to the components listed in Table 4.

Evolution of core Canadian AMR/AMU surveillance programs and integrated annual reporting with CARSS represent clear progress towards comprehensive, integrated AMR and AMU surveillance.

However, this analysis reveals that systemic barriers remain in Canada to an effective AMR response that includes integrated AMR/AMU surveillance. Our findings align closely with those of the March 2019 PHAC coordination audit of the AMR response (51). A core issue focuses on F/P/T leadership and governance to address AMR/AMU surveillance and AMR mitigation through development of appropriate multi-stakeholder oversight groups, standardized data protocols, and data sharing agreements. The current F/P/T health structure for healthcare regulation and program delivery, as well as surveillance and animal health regulation, are complex and variable. The only programs that are truly F/P/T by design are CNISP and CIPARS, but these programs still have gaps with a truly national, integrated program remaining elusive. Failing a design-built national, integrated system with supporting policy, we are left with the option of an EU model like European Antimicrobial Resistance Surveillance Network (32) and the European Surveillance of Veterinary Antimicrobial Consumption (56) to compile PT data. However, for PT systems to contribute to national, integrated AMR and AMU surveillance, restructuring must create ongoing, centralized support for regulated collection and collation of standardized data into a central warehouse through harmonized F/P/T policy and data sharing agreements. Visible prioritization within government to address public health F/P/T governance, leadership, and funding is required. This should be done to reformat, coordinate, and integrate AMR and AMU surveillance systems across One Health sectors to create usable data systems that inform local, provincial/territorial, and national antimicrobial stewardship efforts. This requires new, dedicated, and stable surveillance infrastructure, resources and funding that must be agreed to by the F/P/T and stakeholder governance structure under the pan-Canadian Action Plan for AMR. Antimicrobial resistance is an international crisis that requires a national response; federal leadership and investment are required to make this happen.

References

1. Schell SF, Luke DA, Schooley MW, Elliott MB, Herbers SH, Mueller NB, et al. Public health program capacity for sustainability: A new framework. Implementation Science. 2013;8(15):1-9.

2. Parathon H, Kuntaman K, Widiastoety TH, Muliawan BT, Karuniawati A, Qibtiyah M, et al. Progress towards antimicrobial resistance containment and control in Indonesia. BMJ (Online). 2017;358:31-5.

3. World Health Organization. Antimicrobial Resistance: Global Report on Surveillance 2014. World Health Organization; 2014.

4. Government of Canada. Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS): 2016 Annual Report. Guelph, ON: Public Health Agency of Canada; 2019. p. 298.

5. World Health Organization. Global action plan on antimicrobial resistance. Geneva, Switzerland: World Health Organization; 2015.

6. Government of Canada. Tackling Antimicrobial Resistance and Antimicrobial Use: A Pan-Canadian Framework for Action. Ottawa, ON: Public Health Agency of Canada; 2017. p. 1-33.

7. World Health Organization. What is One Health? : World Health Organization; 2017 [Available from: https://www.who.int/features/qa/one-health/en/.

8. Grant J, Saxinger L, Patrick D, Keen P. Surveillance of Antimicrobial Resistance and Antimicrobial Utilization in Canada. National Collaborating Centre for Infectious Diseases; 2014. Report No.: 9781927988169.

9. Conly J. Antimicrobial resistance programs in Canada 1995-2010: a critical evaluation. Antimicrobial Resistance and Infection Control. 2012;1(10):1-5.

10. Casey B. A study on the status of antimicrobial resistance in Canada and related recommendations. Government of Canada; 2018.

11. Otto SJG, Leger D, Radke B, Anderson M, Pasma T, Nguon S, et al. Non-human Antimicrobial Use Surveillance in Canada: Surveillance Objectives and Options. Edmonton, AB: Canadian Council of Chief Veterinary Officers - Antimicrobial Use in Animal Agriculture Committee; 2016.

12. Government of Canada. Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) 2017: Design and Methods. Guelph, ON: Public Health Agency Canada,; 2020. p. iii, 58.

13. Fuller K, Lenton E. Grey Literature Search Plan Template. University of Toronto Libraries; 2018.

14. Godin K, Stapleton J, Kirkpatrick SI, Hanning RM, Leatherdale ST. Applying systematic review search methods to the grey literature: A case study examining guidelines for school-based breakfast programs in Canada. Systematic Reviews. 2015;4(1):1-10.

15. Council of Canadian Academies. When Antibiotics Fail: The Expert Panel on the Potential Socio-Economic Impacts of Antimicrobial Resistance in Canada. Ottawa (ON); 2019.

16. Government of Canada. Canadian Antimicrobial Resistance Surveillance System Report 2018. In: Public Health Agency Canada, editor.: Public Health Agency of Canada; 2020.

17. Government of Canada. Infographic: Canadian Nosocomial Infection Surveillance Program. Public Health Agency of Canada; 2017.

18. LaFreniere M, Hussain H, He H, McGuire M. Tuberculosis in Canada: 2017. CCDR. 2019;45(2/3):67-73.

19. Public Health Agency Canada. Report on the Enhanced Surveillance of Antimicrobialresistant Gonorrhea: Results from 2014 and 2015: Centre for Communicable Diseases and Infection Control, Infectious Disease Prevention and Control Branch, Public Health Agency of Canada; 2018 [Available from: https://www.canada.ca/en/public-health/services/publications/diseases-conditions/2014-2015-report-enhanced-surveillance-antimicrobial-resistant-gonorrhea.html.

20. Government of Canada. National Laboratory Surveillance of Invasive Streptococcal Disease in Canada - Annual Summary 2017: Public Health Agency of Canada; 2019 [Available from: https://www.canada.ca/en/public-health/services/publications/drugs-health-products/national-laboratory-surveillance-invasive-streptococcal-disease-annual-summary-2017.html.

21. Pan-Canadian Public Health Network. Antimicrobial Stewardship: Final Report to the Public Health Network Council 2016 [38]. Available from: http://phn-rsp.ca/pubs/anstew-gestan/pdf/pub-eng.pdf.

22. Government of Canada. Canadian Antimicrobial Resistance Surveillance System Report 2016. Public Health Agency of Canada; 2016. p. iv, 112.

23. AMR Network. Project: AMR Network - Developing a Coordinated One Health Approach to Antimicrobial Resistance in Canada: PHAC; 2020 [Available from: https://www.amrnetwork.ca/.

24. Hannon SJ, Brault SA, Otto SJG, Morley PS, McAllister TA, Booker CW, et al. Feedlot Cattle Antimicrobial Use Surveillance Network: A Canadian Journey. Front Vet Sci. 2020;*in review*.

25. Sanchez J, Heider L, McClure JT, Tahlan K, Dufour S, Kelton D, et al. Canadian Dairy Network for Antimicrobial Stewardship and Resistance (CaDNetASR): Surveillance of antimicrobial use and resistance to improve stewardship practices and animal health on dairy farms. Dairy Farmes of Canada; 2018.

26. Government of Canada. Veterinary antimicrobial sales reporting (VASR). In: Health Canada, editor.: Health Canada,; 2019. p. 2.

27. Van Katwyk SR, Grimshaw JM, Hoffman SJ. Ten Years of Inaction on Antimicrobial Resistance: An Environmental Scan of Policies in Canada from 2008 to 2018. Healthc Policy. 2020;15(4):48-62.

28. Government of Canada. Canadian Nosocomial Infection Surveillance Program (CNISP): Summary Report of Healthcare Associated Infection (HAI), Antimicrobial Resistance (AMR) and Antimicrobial Use (AMU) Surveillance Data from January 1, 2013 to December 31, 2017. In: Canada PHA, editor. 2019. p. iii, 38.

29. IPAC. CNISP Publications: Infection Prevention and Control Canada; 2020 [Available from: https://ipac-canada.org/cnisp-publications.php.

30. BCCDC. Antimicrobial Resistance & Utilization (Dashboard): British Columbia Centre for Disease Control; 2020 [Available from: http://www.bccdc.ca/health-professionals/data-reports/antimicrobial-resistance-utilization.

31. Dolcé L, Quach C, Thirion DJG, Bergeron L, Gonzales M, Papenburg J, et al. Surveillance of antimicrobial use in Québec acute-care hospitals: A survey. Official Journal of the Association of Medical Microbiology and Infectious Disease Canada. 2018;3(1):37-46.

32. EARS-NET. European Antimicrobial Resistance Surveillance Network (EARS-Net): Surveillance of antimicrobial resistance in Europe 2018. European Centre for Disease Prevention and Control; 2019.

33. Mitchell R, Taylor G, Rudnick W, Alexandre S, Bush K, Forrester L, et al. Trends in health care–associated infections in acute care hospitals in Canada: an analysis of repeated point-prevalence surveys. Canadian Medical Association Journal. 2019;191(36):E981-8.

34. World Health Organization. Global Antimicrobial Resistance and Use Surveillance System (GLASS) Report: Early Implementation 2020. World Health Organization; 2020. p. viii, 134.

35. Becton Dickinson and Company, Sinai Health System-University Health Network Antimicrobial Stewardship Program, National Centre for Antimicrobial Stewardship. Canadian National Antimicrobial Prescribing Survey: A Pilot Initiative 2019 [Available from: https://www.bd.com/en-ca/company/news-and-media/press-releases/mar-19-2019-canadian-national-antimicrobial-prescribing-survey--a-pilot-initiative.

36. Versporten A, Zarb P, Caniaux I, Gros M-F, Drapier N, Miller M, et al. Antimicrobial consumption and resistance in adult hospital inpatients in 53 countries: results of an internet-based global point prevalence survey. The Lancet Global Health. 2018;6(6):e619-e29.

37. Government of Canada. FoodNet Canada (formerly known as C-EnterNet): Sentinel Sites: Public Health Agency of Canada; 2015 [Available from: https://www.canada.ca/en/public-health/services/surveillance/foodnet-canada/sentinel-sites.html.

38. Campbell J, Waldner CW, April S, Gordon J, Jelinski M, Larson K, et al. C3SN: Canadian Cow-Calf Surveillance Network 2019 [Available from: https://research-groups.usask.ca/c3sn/index.php.

39. Government of Canada. Aquaculture Public Reporting. 2020.

40. Government of Canada. Marine/Freshwater Finfish Data 2018. 2018.

41. MAPAQ. Results of passive antimicrobial resistance surveillance: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation Québec; 2019 [Available from: https://www.mapaq.gouv.qc.ca/fr/Productions/santeanimale/maladies/antibio/antibioresistance/Pages/resultats_surveillance.aspx.

42. Gouvernement du Québec. Résultat de la surveillance passive de l'antibiorésistance: Rapport 2018. In: Ministère de l'Agriculture dPedlAQ, editor.: Ministère de l'Agriculture, des Pêcheries et de l'Alimentation Québec; 2019.

43. Government of Canada. Responsible use of Medically Important Antimicrobials in Animals. Health Canada; 2018.

44. Mehrotra M, Li X-L, Ireland M-J. Enhancing antimicrobial stewardship by strengthening the veterinary drug regulatory framework. Can Commun Dis Rep. 2017;43-11(Antimicrobial resistance and One Health):220-3.

45. Canadian veterinary Medical Association. Stewardship of Antimicrobials by Veterinarians Initiative 2021 [Available from: https://savi.canadianveterinarians.net/en/home/.

46. Government of Canada. Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) 2017: Figures and Tables. Guelph, ON: Public Health Agency of Canada; 2020. p. vi, 173.

47. Government of Canada. Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS): 2015 Annual Report. Guelph, ON: Public Health Agency of Canada; 2017. p. 258-.

48. Prescott JF. The resistance tsunami, antimicrobial stewardship, and the golden age of microbiology. Veterinary microbiology. 2014;171(3-4):273-8.

49. Collignon P, Athukorala PC, Senanayake S, Khan F. Antimicrobial resistance: the major contribution of poor governance and corruption to this growing problem. PLoS One. 2015;10(3):e0116746.

50. Finley RL, Collignon P, Larsson DGJ, McEwen SA, Li X-Z, Gaze WH, et al. The Scourge of Antibiotic Resistance: The Important Role of the Environment. Clinical Infectious Diseases. 2013;57(5):704-10.

51. Health Canada, Public Health Agency of Canada. Evaluation of the Coordination of Antimicrobial Resistance (AMR) Activities at the Public Health Agency of Canada. Office of Audit and Evaluation; 2019. p. x, 33.

52. Getahun H, Smith I, Trivedi K, Paulin S, Balkhy HH. Tackling antimicrobial resistance in the COVID-19 pandemic. Bulletin of the WHO. 2020;98:442-A.

53. Hsu J. How covid-19 is accelerating the threat of antimicrobial resistance. BMJ. 2020;369:m1983.

54. Strathdee SA, Davies SC, Marcelin JR. Confronting antimicrobial resistance beyond the COVID-19 pandemic and the 2020 US election. The Lancet. 2020;396(10257):1050-3.

55. Nieuwlaat R, Mbuagbaw L, Mertz D, Burrows LL, Bowdish DME, Moja L, et al. Coronavirus Disease 2019 and Antimicrobial Resistance: Parallel and Interacting Health Emergencies. Clinical Infectious Diseases. 2020;ciaa773:1-3.

56. European Medicines Agency, European Surveillance of Veterinary Antimicrobial Consumption. Sales of veterinary antimicrobial agents in 31 European countries in 2017: Trends from 2010-2017 (Ninth ESVAC report). In: ESVAC, editor. 2017. p. 109.