Evaluation of the HOTspots surveillance system

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Executive summary

Disease surveillance plays a critical role in defining and responding to the problem of antimicrobial resistance (AMR). However, surveillance of AMR in Australia is fragmented, with limited data from community settings and poor geographical representation, and lacks a comprehensive public health response mechanism. Data are not fed back to end users in a format that is conducive to local needs, nor in a timely manner. These issues are of particular relevance to northern Australia, where the rates of AMR infections are high and gaps in surveillance most prominent. Improved AMR surveillance is therefore greatly needed in the region to identify areas of high disease burden and to facilitate public health actions. In response to these urgent needs, an AMR surveillance system known as HOTspots was developed by Menzies School of Health Research in Darwin, Australia. HOTspots aims to provide AMR information for action across community and hospital settings in northern Australia. Though initial feedback from end users has been positive, an evaluation of HOTspots was conducted to assess the utility of the system and make improvements where recommended.

Several key findings and nine recommendations emerged from the evaluation. The system is simple in nature and has the flexibility to include data in a similar format from additional laboratories. The quality of the data collected is high but could be further improved through data standardisation and establishment of a quality control and assurance process. The sensitivity of the system, as indicated by comparing blood *S. aureus* isolates reported in HOTspots with those reported in the TEHS antibiogram, is high. Acceptability of the system was enhanced by the timely and representative data provided by HOTspots. Upgrading the HOTspots website and developing the capability to better support nuanced clinical and public health decision-making support would further improve user acceptability. Establishing a governance structure and stable resourcing (particularly funding and staffing) were identified as essential to the sustainability of the system. Overall, HOTspots can be considered a useful system in that it meets its objectives of improving population-level surveillance of AMR and providing representative and timely local antibiotic susceptibility data to end users.

Recommendations

High priority

1. Upgrade the HOTspots website

Feedback from end users should be incorporated to improve the design and functionality of the website's interface. Beta testing, which involves trialling a prototype product with end users, would help ensure issues are identified and addressed prior to the website going live. The volume of data that HOTspots is required to store and process needs to be supported by appropriate backend architecture.

2. Support decision-making with enhanced functionality

The evaluation identified that end users are looking for decision-making support and that this affects the acceptability of the system. The use of HOTspots as a decision-making resource was most valuable to community-based clinicians by supplying data that was previously difficult to access. In the future, it would be advisable to include enhanced functionality such as an option to create an antibiogram and explicit recommendations for antibiotic threshold levels. These additional features should be resolved concurrently to any website upgrades and need to consider carefully whether HOTspots offers complementary or conflictual advice with existing therapeutic guidelines.

3. Address legal and contractual issues

Data sharing agreements with laboratories (e.g. a memorandum of understanding) are needed to clearly demark data custodianship and ensure transparent, accountable and acceptable data sharing by all parties. Clear data custodianship also makes data more accessible, as users know how and to whom to apply for data requests. Professional advice should also be sought for matters relating to intellectual property protection.

Medium priority

4. Utilise the advisory group to address system stability

The HOTspots advisory group possess a range of professional knowledge and experience that can help guide the management of HOTspots. This group should assist in navigating the establishment of a governance structure, ongoing funding, and other resources needed to support the system. In addition, this evaluation identified some unmet and at times competing needs from different end users. The advisory group may help to address these and further delineate the aims and objectives of HOTspots.

5. Review and standardise data collection

The quality and sensitivity of HOTspots data is high but could be improved by data standardisation. Defining data specifications in a 'template' or 'dictionary' would be the simplest and most achievable method to achieve standardised data provision. This method is likely to be less effective than system integration with pathology service providers' LIS as in the case of OrgTrx, but integration is a complex process that requires considerable resources. Options could be explored with laboratory staff and information technology professionals.

6. Establish a quality assurance process

A process of quality assurance should be established to guarantee high quality of data. Quality assurance and quality control describe activities that prevent errors from entering or remaining in a data set are essential components of any surveillance system. These activities should be applied throughout the data collection, analysis and visualisation stages. They require defining quality metrics, how they will be monitored and handled when identified. Responsibility for these activities should be clearly assigned.

Low priority

7. Document the HOTspots system

A reporting protocol that describes the aims and objectives of HOTspots, stakeholders, case definitions and data reporting process is needed. This protocol would clearly stipulate what data are currently reported, the methods used and data quality. Some of this information is currently available via the HOTspots website but is more focused on the data than the system as a whole. A reporting protocol would clarify currently unexplored aspects of HOTspots, such as the inclusion of demographic or clinical data to improve end user uptake.

8. Identify resources to support end user engagement

Where time and effort is required from end users to engage with HOTspots, acceptability could be enhanced by supporting them with funding and human resources. For example, for laboratories to provide data on an ongoing basis it will require staff's time, some funding may be required to cover the associated cost. A HOTspots data manager may be able to help scientists, microbiologists or pharmacists with antibiogram preparation, and education sessions organised through NT PHN could be provided to clinicians free of charge.

9. Update HOTspots data at least annually

One of the main strengths of HOTspots is timely data. This is made possible through regular data updates and the dissemination of data through the HOTspots website, rather than through static reports. Feedback from users suggests that they would benefit from quarterly or six-monthly updates to website data, and it is suggested that updates should occur this frequently. At a minimum, data should be updated annually to inform AMR trends, as is the case with antibiograms.

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Abbreviations

ACL	Australian Clinical Labs
AGAR	Australian Group on Antimicrobial Resistance
AMR	Antimicrobial resistance
AMS	Antimicrobial stewardship
APAS	Australian Passive AMR Surveillance
AST	Antibiotic susceptibility testing
AURA	Antimicrobial Usage and Resistance in Australia
CARAlert	National Alert System for Critical Antimicrobial Resistances
CDC	Centers for Disease Control and Prevention
CRE	Carbapenem-resistant *Enterobacteriaceae*
LIS	Laboratory information system
MIC	Minimum inhibitory concentration
MSSA	Methicillin susceptible *Staphylococcus aureus*
MRSA	Methicillin resistant *Staphylococcus aureus*
NSW	New South Wales
NT	Northern Territory
NT CDC	Northern Territory Centre for Disease Control
NT PHN	Northern Territory Primary Health Network
RDH	Royal Darwin Hospital
SNP	Sullivan Nicolaides Pathology
SXT	Sulfamethoxazole and trimethoprim
TEHS	Top End Health Service
VRE	Vancomycin-resistant enterococci
QLD	Queensland
QML	Queensland Medical Laboratory
WA	Western Australia
WHO	World Health Organization

Introduction

Antimicrobial resistance is the ability of a microbe (bacteria, viruses, parasites, and fungi) to resist the effects of an antimicrobial (antibiotic, antiviral, antiparasitic, antifungal) (1). The term is often used interchangeably with antibiotic resistance and will be used to refer to bacteria with antibiotic resistance in this report. AMR infections in human health are associated with more complex and expensive drug treatments, longer hospital stays, additional medical investigations, and ultimately increased morbidity and mortality (2). Limited data are available on the health burden of AMR infection in Australia, particularly for Gram negative microorganisms such as *Escherichia coli, Klebsiella pneumoniae* and *Pseudomonas aeruginosa* (3). However, in the United States there are more than 2.8 million antibiotic-resistant infections each year, resulting in more than 35,000 deaths (4). In the European Union and European Economic Area, eight types of antibiotic-resistant bacteria were found to account for an estimated 33,110 attributable deaths in just one year, corresponding to an attributable mortality of 6.4 deaths per 100,000 population (5). A substantial proportion of this burden was caused by community-associated infections.

The health care-associated costs of AMR also lead to a significant economic burden. For example, in 2017, methicillin resistant *Staphylococcus Aureus* (MRSA) infections were attributed with US$1.7 billion in health care costs to the United States (4) and up to €1.1 billion is expected to be spent each year between 2015 and 2050 due to AMR across European Union and European Economic Area countries (6). In Australia, the economic burden of AMR in hospital-associated infection is estimated to be AUD$11.2 million for patients infected with resistant *E. coli* and as much as AUD$22.7 million due to MRSA (7). These estimates do not include costs associated with surveillance and other public health activities related to trying to control AMR itself, nor the broader societal impact (i.e. loss of productivity).

New treatments alone will not be sufficient to combat AMR; the discovery of new antibiotics has all but ceased, due principally to the low commercial return on the research and development of new antibiotics (8). An effective response to AMR therefore requires not just greater investment in the research and development of new antibiotics, but a range of interventions delivered in a coordinated approach across human health, animal health and agricultural sectors (9). Such interventions include regulatory controls to reduce indiscriminate use of antibiotics in human and animal health, infection prevention and control strategies such as screening and patient isolation to reduce transmission,

vaccine development, education and antimicrobial stewardship (AMS) to help optimise antimicrobial prescribing. Essential to providing data to develop and monitor the effects of these interventions is AMR surveillance, which can have an effect at both the individual patient and population level (9).

The critical role of surveillance in defining and responding to the AMR problem is recognised in Australia's First National Antimicrobial Resistance Strategy 2015-2019 (10) and the recently released second AMR Strategy, 2020 and Beyond (11). One of the key objectives of Australia's strategy is to develop a nationally coordinated One Health surveillance system for AMR and antimicrobial usage. In 2013 the Australian Government Department of Health funded the Australian Commission on Safety and Quality in Health Care (the Commission) to develop a national surveillance system, known as the Antimicrobial Use and Resistance in Australia (AURA) project (9). Two core surveillance programs provide AURA with AMR data: the Australian Passive AMR Surveillance program and the longitudinal dataset from the Australian Group on Antimicrobial Resistance (AGAR) program, in addition to other disease surveillance systems that collect antimicrobial susceptibility data (12).

Despite ongoing efforts to coordinate AMR data nationally, the AURA surveillance system remains fragmented and does not meet all the epidemiological criteria for a surveillance system. Challenges for AURA include the voluntary nature of data provision (there is no regulatory requirement), limited data from community settings and poor geographical representation (13, 14). The National Alert System for Critical Antimicrobial Resistances (CARAlert), which notifies public health authorities and treating clinicians of critical antimicrobial resistances that pose a serious threat to the effectiveness of last-line antibiotics, is the only public health response component of AURA (15). Furthermore, data collected by AURA are only accessible through annual reports or individual data requests.

The above-mentioned gaps and challenges of AMR surveillance are particularly unfavourable for northern Australia (i.e. above the Tropic of Capricorn), where a complex interplay of AMR drivers result in high rates of resistance (16). These include a high burden of infectious diseases and antibiotic use (17), which are underlined by the social determinants of health, such as overcrowding and socioeconomic status (18, 19), and workforce issues such as high annual turnover of health care staff and high levels of agency staff (20). Furthermore, geographic remoteness affects access to laboratory testing and health services, services that help guide appropriate antimicrobial treatment and support early diagnosis of drug-resistant infections (21), and the tropical climate may expedite the development of AMR by facilitating horizontal gene transfer, uptake of free genetic material and

bacterial growth (22). The high rates of AMR infections, and particularly community-associated infections, in northern Australia demonstrate the critical need for ensuring surveillance of AMR is geographically representative of the population and inclusive of both hospital and community settings. Improving disease surveillance in this region is needed to enhance not just the identification of pockets of high and low burden of disease but also the ability for early response to the growing threat of AMR.

In response to these urgent needs, an AMR surveillance system known as HOTspots was developed by Menzies School of Health Research in Darwin, Australia. HOTspots aims to provide AMR information for action across community and hospital settings in northern Australia. It is a collaborative project that engages directly with the end users of the system and it forms part of a broader body of work to develop an AMR strategy for northern Australia. HOTspots collates antimicrobial susceptibility data from four major pathology service providers across the region and data are made available through an open-access online website, with the intention of providing AMR data in a timely and accessible format to end users. Though initial feedback from end users has been positive, an evaluation of HOTspots has not been conducted to date. Evaluation results would be used to improve the system and inform its establishment as a cross-jurisdictional AMR surveillance system in northern Australia.

Methods

Evaluation aims

The aim of this evaluation is to assess the utility of the HOTspots system to end users. The principle evaluation questions are:

- How well does the HOTspots surveillance system meet its purpose?
- Does HOTspots accurately monitor antimicrobial resistance?
- Can HOTspots be sustained and scaled up?

Description the surveillance system

Purpose of the system

HOTspots aims to improve population-level surveillance of, and response to, AMR in hospitals and communities and inform the clinical management of patients and treatment guidelines through the timely dissemination of local antibiotic susceptibility data in northern Australia.

Operation of the system

HOTspots was developed in 2018 and is hosted by Menzies School of Health Research (Menzies). An informal advisory committee of infectious disease physicians, microbiologists and laboratory scientists, pharmacists, guideline contributors and policymakers from the region provide input to the management and strategic direction of HOTspots, which is predominantly overseen by a group of three to four epidemiologists and data managers based at Menzies.

Organisms under surveillance

HOTspots is a laboratory-based surveillance system with data-sharing agreements with four major pathology service providers in northern Australia. These providers service public and private health services in both hospital and community settings, though at the time of writing the main provider for community data had not supplied their data and is therefore not included in this evaluation. HOTspots collates data from these providers on 11 microorganisms of public health significance to northern Australia. The microorganisms and antimicrobials were chosen based on burden of disease and need for antibiotic susceptibility data to inform clinical practice, in consultation with the advisory committee. All 11 microorganisms are in Australia's list of priority microorganisms for human health and many are priority microorganisms in other systems (Table 1).

Table 1: List of priority microorganisms for human health by surveillance system

Australian priority microorganisms	WHO	CARAlert	AURA	HOTspots
Enterobacteriaceae (Principally *Escherichia coli* & *Klebsiella spp.)*	✓	✓	✓	✓
Enterococcus spp.		✓	✓	✓*
Mycobacterium tuberculosis		✓	✓	
Neisseria gonorrhoeae	✓	✓	✓	✓*
Neisseria meningitidis			✓	✓*
Salmonella spp.	✓	✓	✓	
Shigella spp.	✓	✓	✓	
Streptococcus pneumoniae	✓		✓	✓
Staphylococcus aureus	✓	✓	✓	✓
Acinetobacter baumannii complex	✓	✓	✓	✓*
Enterobacter cloacae/aerogenes			✓	
Pseudomonas aeruginosa		✓	✓	✓
Campylobacter jejuni/coli			✓	
Clostridium difficile			✓	
Haemophilus influenzae			✓	✓*^
Streptococcus agalactiae			✓	
Streptococcus pyogenes		✓	✓	✓*

WHO = World Health Organisation; CARAlert = National Alert System for Critical Antimicrobial Resistances; AURA = Antimicrobial Usage and Resistance in Australia

* No data currently being collected; ^Non-type b

Pink/red = Gram negative, purple = Gram positive, black = Gram stain not appropriate

Resources used to operate the surveillance system

The HOTspots system uses passive laboratory data, hence human resources required to operate the system are limited to those involved in data extraction, management and analysis. The system requires Stata to clean and prepare the data and a website to visualise the data. The website was custom-built over a period of approximately one year at a cost of around $13,000 Australian dollars. It was funded through the program 'Improving Health Outcomes in the Tropical North: A multidisciplinary collaboration (HOT NORTH)', which was awarded to Menzies School of Health Research by the National Health and Medical Research Council under the Northern Australia Tropical Disease Collaborative Research Programme.

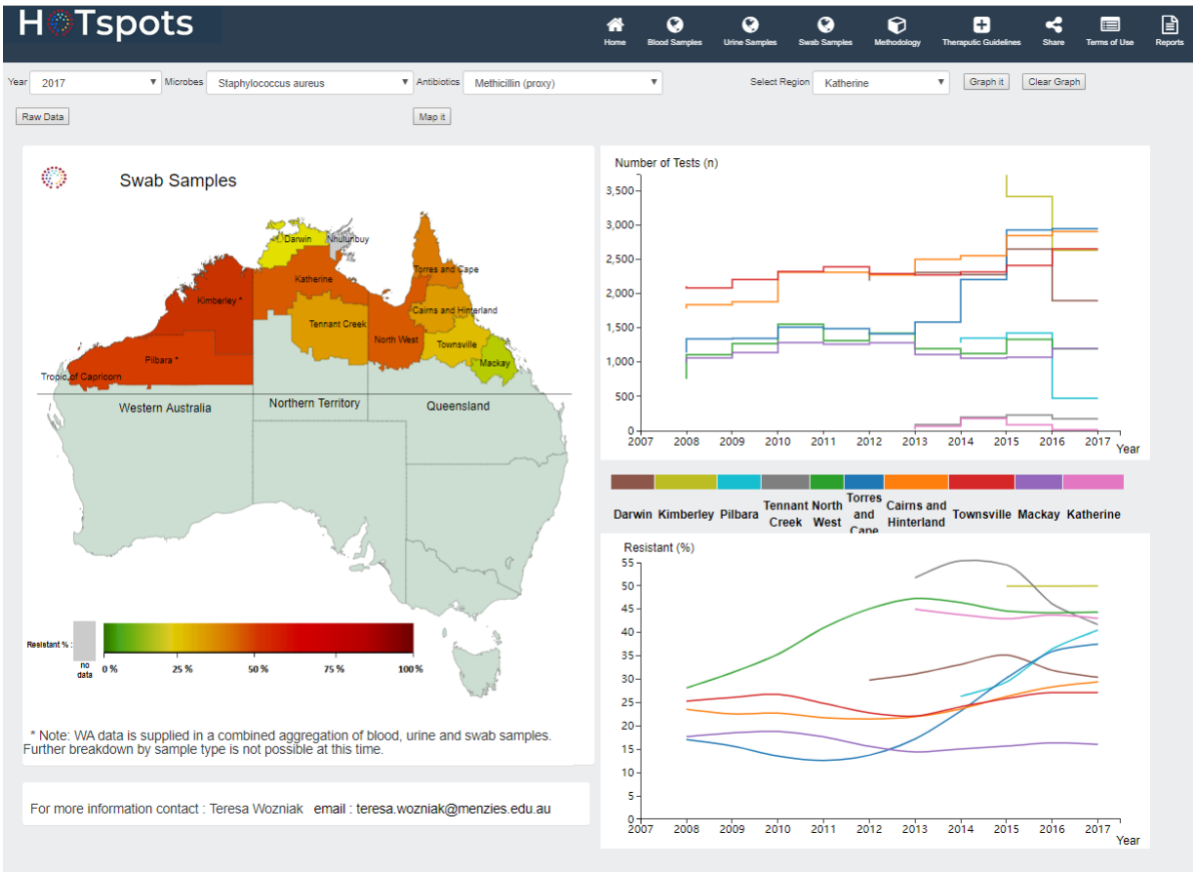

Figure 1: HOTspots website displaying *S. aureus* resistance to methicillin[a] in northern Australia.

[a] Methicillin resistance in *S. aureus* was inferred from resistance to oxacillin in laboratories in the WA, cefoxitin in NT laboratories and flucloxacillin and cefoxitin in QLD.

Evaluation design

Evaluation framework

This evaluation uses the Centers for Disease Prevention and Control (CDC) guidelines for evaluating public health surveillance systems as a framework against which to evaluate the HOTspots surveillance system (23). The CDC guidelines outline nine key system attributes (Table 2), which together provide an indication of the system's usefulness. This evaluation excludes the attribute positive predictive value, due to the difficult nature of verifying laboratory diagnoses and limited time and resources allocated to this evaluation.

Table 2: Centre for Prevention and Disease Control definitions of surveillance system attributes

Attribute	Definition
Simplicity	The system's structure and ease of operation. The surveillance system should be as simple as possible and still meet the objectives.
Flexibility	The system's ability to adapt to changing information needs or operating conditions, with little additional time, personnel or allocated funds.
Data quality	The completeness and validity of the data recorded in the surveillance system.
Acceptability	The willingness of persons and organisations to participate in the surveillance system.
Sensitivity	The proportion of cases of a disease detected by the surveillance system and/or the ability of the system to detect outbreaks, including the ability to detect change in case numbers over time.
Positive predictive value	The proportion of reported cases that actually have the health-related event under surveillance.
Representativeness	A system's accuracy in describing the occurrence of the event over time and its distribution in the population by person and place.
Timeliness	The speed between steps in the surveillance system.
Stability	The reliability (ability to collect, manage and provide data properly without failure) and availability (ability to be operational when it's needed) of the system.

Data collection and analysis

Both qualitative and quantitative data were used in this evaluation. An analysis of HOTspots data was used to assess the attributes data quality and sensitivity. Data were analysed using the statistical software Stata/IC version 15.1 (24). Qualitative data were used in the assessment of each attribute and were collected through a total of 13 focus group and one-on-one interviews with end users. In AMR that is focused on human health, stakeholders have previously been identified as prescribers and drug dispensers, scientists and microbiologists, infection prevention and control, regulatory and public-health authorities, policymakers, politicians, economists, public health experts, pharmaceutical and health insurance industry workers, and the public (25). This evaluation focuses on the end users who directly use surveillance data available through HOTspots and include prescribers and drug administrators (doctors, nurses and Aboriginal Health Practitioners), pharmacists, scientists and microbiologists, public health authorities and contributors to therapeutic guidelines.

For practicality, a combination of convenience and purposive sampling was used to recruit participants. Professional networking and education events were used to promote the evaluation and invite people to participate. Expressions of interest were also invited through an email sent to all government PHC clinics via NT PHN and to the NT CDC Bulletin distribution list. Interviewees were provided with a participant information sheet and a consent form prior to the interview. Interviews were conducted either in person or via telephone and took on average 30 minutes to complete. All interviews were audio-recorded and transcribed verbatim. Responses were manually coded against the CDC framework's surveillance system attributes.

Results

Surveillance system attributes

Simplicity

Simplicity is defined as the system's structure and ease of operation (23). It was assessed by reviewing the process of data collection and analysis, system integration, and end user's experience of the website. At the time of evaluation, data were supplied from pathology service providers as Excel files, cleaned, analysed using Stata and uploaded to the 'backend' of the HOTspots website (MySQL database), making the data collection and analysis processes of HOTspots quite simple. However, as the system will house increasingly more data, it will need to be expanded and re-evaluated.

HOTspots is not currently integrated with any other relevant systems but again, this may need to be reviewed when the system expands to include more frequent data transfers. It would be beneficial for data-sharing to integrate HOTspots with the laboratory information systems (LIS) used by participating pathology service providers and OrgTrx, the database used by APAS. However, integrating with these systems is likely to be a costly and time-consuming process and should not be an immediate priority. The structure of the HOTspots system and how it could be integrated into LIS and other established AMR surveillance systems is conceptualised in Figure 2.

End users considered the HOTspots website generally easy to navigate. However, some users did report that they would prefer that the list of available antimicrobials be shortened to where data was available, that reselecting the same drug-bug combination for different sample types was not ideal, and that their specific geographical region of interest was difficult to identify on the map.

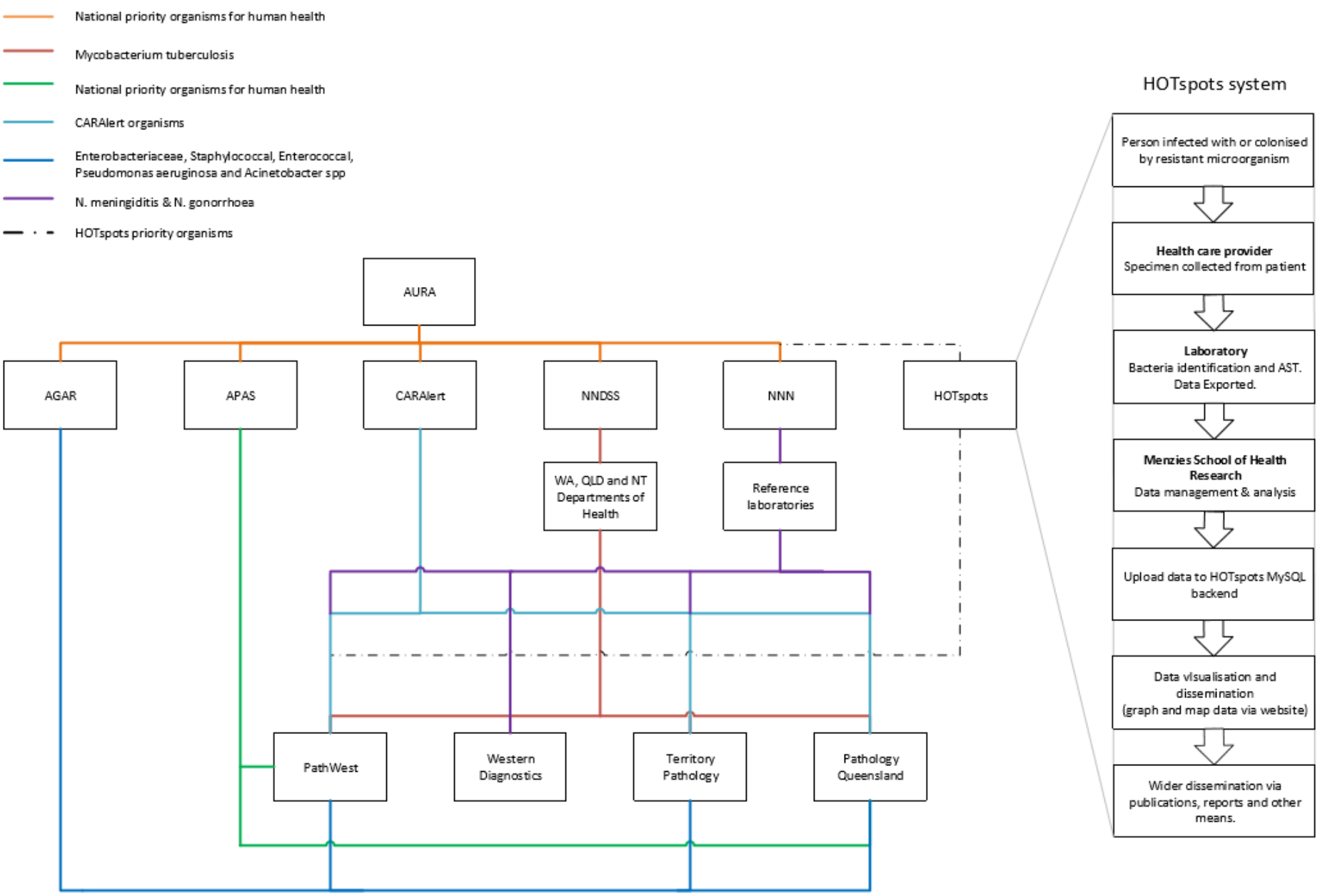

Figure 2: AMR surveillance system relationships in northern Australia

Flexibility

Flexibility is defined as the system's ability to adapt to changing information needs or operating conditions, with little additional time, personnel or allocated funds (23). An immediate priority for HOTspots is the incorporation of community data from WA and NT, which at the time of the evaluation had not yet been received. Work involved with the addition of a new laboratory to the HOTspots system would be related to how similar the data were, compared to previous data provided by pathology service providers, and whether the data were provided as minimum inhibitory concentration (MIC) values or qualitative interpretations (e.g. susceptible, intermediate, or resistant). Both MIC and interpreted data formats are acceptable, however data with MIC values would need to be interpreted by coding the correct breakpoints as per antibiotic susceptibility testing (AST) guidelines.

In 2020, it is expected that HOTspots will receive regular data updates from the four participating laboratories. There may be small variations in data with each update from the same laboratory. Changes such as the addition of new organisms or antibiotics would only require changes to 'lookup lists' and would be easily implemented. However, the ability to incorporate new variables is currently limited, as this could impact on the performance of the website by slowing it down. This is likely to occur with the addition of approximately ten new variables. Hence, while the data analysis process is considered flexible, the website platform is limited and does not permit variation outside of the existing format.

The current website also places constraints around data visualisation. For example, changing the geographical unit would require altering the map's Jason files, which would require rebuilding a substantial part of the website. Other proposed changes include selecting the year-drug-bug combination once, rather than having to re-enter these for each specimen type, as well as reducing the available options to only those that are relevant or where data are available. These modifications would also require substantial changes and effort to implement into the current website.

Data quality

Data quality is defined as the completeness and validity of the data recorded in the surveillance system (23). It was assessed by reviewing data collected by HOTspots against World Health Organisation (WHO) criteria for AMR surveillance systems (26) and through a descriptive analysis of HOTspots data. The WHO states that the core of an AMR surveillance program is an isolate-level database containing relevant demographic and microbiological details (26). HOTspots meets the WHO criteria as it is an isolate-level database that collates data on organism, site of infection, year and place of diagnosis, however the following areas for improvement were identified. Firstly, while line listed data and sample type were requested, WA data were provided in an aggregated format and sample type could not be determined. Secondly, HOTspots relies on microbiological diagnosis and does not include clinical data, hence it is possible that both swab and urine samples may not represent infection but rather colonisation or contamination. Thirdly, data provided by the participating pathology service providers were a mixture of quantitative test results (i.e. MIC) and qualitative interpretations (i.e. susceptible, intermediate, resistant). Resistant and intermediate results were combined as 'resistant' for consistency.

Capturing quantitative test results offers advantages over qualitative interpretations. The first advantage is that the interpretation of MIC values can be updated as new and more accurate breakpoints become available over time. The second advantage is that MIC values enable comparison of data across providers that may use different laboratory guidelines. Across Australia, three different AST guidelines are used: European Union Committee on Antibiotic Susceptibility Testing (27), Clinical and Laboratory Standards Institute (28) and Calibrated Dichotomous Sensitivity (29). Differences between these guidelines creates variation in AST and subsequent test results and interpretation.

Finally, HOTspots population data are currently limited to location (i.e. place of sample collection), with QLD and NT both providing data by health care facility and WA by region (e.g. Pilbara). Place of residence is also desirable for monitoring patterns of AMR, however choosing an appropriate indicator for place of residence is challenging as postcodes cover large areas in remote Australia and the population can be transitory. Age and sex were requested from pathology service providers but these were not provided due to privacy and confidentiality concerns. Information on Indigeneity is not included in pathology request forms and therefore was not requested (30).

An analysis of HOTspots data determined that between 2008 and 2017, HOTspots collated 1,869,715 clinical isolates across northern Australia. Western Australia supplied 205,919 (11%) isolates for the period 2014-2017, NT supplied 492,765 (26%) isolates for the period 2012-2017, and QLD supplied 1,171,031 (63%) isolates for the period 2008-2017 (Table 3). Data were requested for all 11 bacterial species that were identified as priority microorganisms for surveillance in northern Australia. Data availability and difficulties in data extraction limited data provided for *N. gonorrhoea* and *N. meningitidis* and they were excluded from the HOTspots website. Some pathology services providers supplied data on microorganisms with specific resistance profiles that were not requested.

By region, there were inconsistences in the number of isolates provided by pathology providers. For instance, QLD's data for *E. coli* isolates were only available from the Cairns and Hinterland regions, and *N. meningitidis* isolates were available only in the Mackay and Townsville regions. Similarly, Carbapenem-resistant *Enterobacteriaceae* (CRE) isolates from the NT were from Darwin, Katherine and Tennant Creek only. It is unclear as to why isolates for certain microorganisms only came from some regions but may be related to the practice of patients being flown from remote areas to urban centres for diagnosis and treatment.

Data were reported for each year of specimen collection for all microorganisms (Table 4). Exceptions included *N. gonorrhoea*, which for an unknown reason only had data reported for 2017, and CRE, which had data reported for the years relevant to NT only (2012-2017). Few data were reported for *N. meningitidis* between 2012-2016, in part because there were no data supplied by NT and WA only supplied data for six isolates. There was also a reduction in the number of *N. meningitidis* cases from QLD during this period that may be related to testing or a delay in notifications, but this is unclear.

Table 3: HOTspots isolates by microorganism, jurisdiction and region, northern Australia, 2008-2017

	Jurisdiction												Total
	WA		NT					QLD					
Organism	Kimberley	Pilbara	Alice Springs	Darwin	Gove	Katherine	Tennant Creek	Cairns & Hinterland	Mackay	North West	Torres & Cape	Townsville	
Staphylococcus aureus	64,309	30,191	3,448	209,892	15,962	6,132	12,124	161,925	76,083	76,186	98,753	159,947	914,952**
MRSA	*	*	1,596	70,214	4,088	2,604	6,216	39,541	12,435	31,582	27,269	40,036	235,581
MSSA	*	*	1,848	139,671	11,874	3,528	5,908	122,384	63,648	44,604	71,484	119,911	584,860
Escherichia coli	32,189	15,411	1,539	142,580	8,126	2,640	7,781	193,191	0	0	0	0	403,457
Klebsiella pneumoniae	5,242	2,303	171	38,545	1,497	550	722	40,819	16,951	7,340	10,219	50,501	174,860
CRE	0	0	0	247	0	19	38	0	0	0	0	0	304
Enterococcus faecium	27	7	0	0	0	0	0	984	179	60	24	1,225	2,506
VRE	0	0	0	0	0	0	0	542	72	18	12	619	1,263
Streptococcus pneumoniae	2,703	757	0	0	0	0	0	6,666	1,455	2,587	2,259	4,514	20,941
Acinetobacter baumannii complex	688	137	81	4,561	204	142	18	1,620	493	454	393	2,759	11,550
Pseudomonas aeruginosa	15,905	4,606	456	32,746	1,328	694	826	36,558	27,130	8,950	6,808	62,951	198,958
Haemophilus influenzae (non-type b)	1,005	355	0	0	0	0	0	17,485	4,265	5,694	6,380	13,334	48,518
Streptococcus pyogenes	23,596	6,470	0	0	0	0	0	10,603	4,422	13,623	21,247	13,952	93,913
Neisseria gonorrhoea	5	7	0	0	0	0	0	0	0	0	0	0	12
Neisseria meningitidis	3	3	0	0	0	0	0	0	23	0	19	0	48
Total isolates	145,672	60,247	5,695	428,324	27,117	10,158	21,471	469,851	131,001	114,894	146,102	309,183	1,869,715

WA = Western Australia; QLD = Queensland; NT = Northern Territory; MRSA = methicillin resistant *Staphylococcus aureus*; MSSA = methicillin susceptible *Staphylococcus aureus*; VRE = Vancomycin resistant *enterococcus*; CRE = Carbapenem-resistant *Enterobacteriaceae*

* Note: unable to be classified due to aggregated data.

** Note: there is a discrepancy of 11 isolates between the number of *S. aureus* isolates and the combined subcategories of MRSA and MSSA isolates for the Northern Territory

Table 4: HOTspots isolates by microorganism, jurisdiction and year of collection, northern Australia, 2008-2017

Organism	Year										Total
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
Staphylococcus aureus	44,164	49,380	50,551	57,519	91,535	92,095	102,923	131,957	146,010	148,818	914,952**
MRSA	9,929	11,912	12,497	13,902	23,481	24,948	28,043	32,848	38,896	39,125	235,581
MSSA	34,235	37,468	38,054	43,617	68,054	67,145	67,866	70,166	77,451	80,804	584,860
Escherichia coli	15,800	15,439	16,828	18,949	43,485	42,195	64,104	58,576	61,102	66,979	403,457
Klebsiella pneumoniae	10,781	10,244	12,013	11,634	17,993	17,574	22,777	23,460	23,390	24,994	174,860
CRE	0	0	0	0	19	19	38	114	38	76	304
Enterococcus faecium	131	143	202	388	284	329	229	229	226	345	2,506
VRE	15	27	69	215	179	255	137	132	123	111	1,263
Streptococcus pneumoniae	1,890	2,048	1,617	1,901	1,826	1,609	3,010	2,242	2,301	2,497	20,941
Acinetobacter baumannii complex	524	627	660	618	1,370	1,340	2,012	1,423	1,656	1,320	11,550
Pseudomonas aeruginosa	12,757	12,512	13,857	14,219	14,278	15,141	21,157	28,702	33,290	33,045	198,958
Haemophilus influenzae (non-type b)	4,559	4,587	4,384	5,480	4,689	4,033	4,464	4,534	6,129	5,659	48,518
Streptococcus pyogenes	4,251	4,729	5,200	5,653	5,728	6,307	19,030	13,620	14,597	14,798	93,913
Neisseria gonorrhoea	0	0	0	0	0	0	0	0	0	12	12
Neisseria meningitidis	5	11	8	5	2	2	2	2	1	10	48
Total isolates	94,862	99,720	105,320	116,366	181,190	180,625	239,708	264,745	288,702	298,477	1,869,715

WA = Western Australia; QLD = Queensland; NT = Northern Territory; MRSA = methicillin resistant *Staphylococcus aureus*; MSSA = methicillin susceptible *Staphylococcus aureus*; VRE = Vancomycin resistant *enterococcus*; CRE = Carbapenem-resistant *Enterobacteriaceae*

** Note: there is a discrepancy of 11 isolates between the number of *S. aureus* isolates and the combined subcategories of MRSA and MSSA isolates for the Northern Territory

Next, data were analysed by sample type. Swab and urine samples made up 79% of samples provided, while blood samples made up just 4% of samples provided (Table 5). Western Australia did not supply disaggregated data and sample type was reported as 'combined'. It is unknown exactly what is in the 'combined', 'other' and 'non-urine' categories (13% of all samples). For this reason, 'other' and 'non-urine' samples are excluded from the HOTspots website. Sputum samples are also excluded due to the inability to distinguish infection from colonisation.

Table 5: HOTspots isolates by sample type and organism, northern Australia, 2008-2017

Organism	Sample type							Total
	Combined	Blood	Urine	Swab	Sputum	Other	Non-urine	
Staphylococcus aureus	94,457	24,469	17,419	744,307	11,753	22,547	0	914,952**
MRSA	0	6,439	3,673	217,341	2,953	5,175	0	235,581
MSSA	0	18,030	13,703	526,955	8,800	17,372	0	584,860
Escherichia coli	40,715	25,091	315,868	13,080	1,734	5,982	987	403,457
Klebsiella pneumoniae	6,503	11,090	131,484	14,491	5,889	5,179	224	174,860
CRE	0	0	209	95	0	0	0	304
Enterococcus faecium	32	250	1,509	259	21	435	0	2,506
VRE	0	113	787	144	18	201	0	1,263
Streptococcus pneumoniae	2,847	1,842	171	4,122	10,414	933	612	20,941
Acinetobacter baumannii complex	656	1,063	3,045	4,931	891	824	140	11,550
Pseudomonas aeruginosa	17,545	5,060	52,776	90,096	21,559	9,087	2,835	198,958
Haemophilus influenzae (non-type b)	1,140	706	361	12,841	31,029	2,221	220	48,518
Streptococcus pyogenes	24,737	1,201	292	61,331	153	870	5,329	93,913
Neisseria gonorrhoea	12	0	0	0	0	0	0	12
Neisseria meningitidis	5	21	0	7	10	4	1	48
Total	188,649	70,793	522,925	945,465	83,453	48,082	10,348	1,869,715

WA = Western Australia; QLD = Queensland; NT = Northern Territory; MRSA = methicillin resistant *Staphylococcus aureus*; MSSA = methicillin susceptible *Staphylococcus aureus*; VRE = Vancomycin resistant *enterococcus*; CRE = Carbapenem-resistant *Enterobacteriaceae*

** Note: there is a discrepancy of 11 isolates between the number of *S. aureus* isolates and the combined subcategories of MRSA and MSSA isolates for the Northern Territory

The validity of HOTspots data is influenced through the process of data collection, analysis, and visualisation. Laboratories throughout Australia are required to be accredited by the National Association of Testing Authorities and participate in the quality assurance program of the Royal College of Pathologists Australasia, so the validity of data collection is high. During the data analysis phase, duplicate isolates are removed from data extracts, variables are recoded, and where required breakpoints are coded as per 2017 CLSI laboratory guidelines. The dataset is then transferred internally to the Menzies Data Management team and uploaded to the backend MySQL database. Here there is a staging table where a few simple validation checks are performed (e.g. percentage values cannot be greater than 100). There are no checks to determine whether data are correctly pulled from MySQL to the appropriate fields in the website. Errors and inconsistencies were identified by the HOTspots team between the final Stata dataset uploaded to MySQL and data on the website. These errors were subsequently rectified by the Menzies Data Management team.

Acceptability

Acceptability is defined as the willingness of persons and organisations to participate in the surveillance system (23). HOTspots is intended to be used in different ways by different end users. For example, it is intended that HOTspots data be used by clinicians to support the clinical management of patients with suspected infections. For pathology providers, HOTspots may be used to standardise and analyse data and create antibiograms, and for public health authorities to use data in public health responses to changes in resistance patterns. Finally, for guideline contributors and policymakers, the data contained in HOTspots would be valuable to update guidelines and inform health policies. The acceptability of these intended uses was assessed through interviews with end users, through which a number of themes emerged.

Both clinicians and pathology providers expressed time as a barrier to accepting and using the HOTspots surveillance system. For clinicians, limited time to refer to antibiotic prescribing resources during patient consultations was an identified barrier. This meant that if they were going to refer to a resource to guide clinical decisions, it would likely be the Therapeutic Guidelines.

> "Many doctors can't be bothered to open up the Therapeutic Guidelines because it takes too much time, they go off what they last remember… I would say for the general practitioner, there isn't utility at the moment and that's partly because it's another system and another thing that you have to log into and there's quite a learning curve to be able to get information out that's useful. And then probably the information that you get out a lot of the time is questionable value anyway." – *antibiotic prescriber 3*

For laboratory staff, data extraction and collation was discussed as a time-consuming process which is dependent on several factors including the organism being surveyed, the method used during AST and how the result is recorded. Susceptibility testing of all HOTspots microorganisms (except *Neisseria spp.* and *Streptococcus spp.*[b]) is currently performed using a standardised automated broth microdilution equipment (e.g. instruments called Vitek or Phoenix). A software package is required to enable direct data extraction from the machine to the LIS, including the MIC value. Other non-

[b] *Neisseria spp.* and *Streptococcus spp*. require manual AST methods; they are too fastidious and slow growing to produce a growth concentration high enough to be detected by automated systems.

automatic susceptibility methods used by laboratories include disc diffusion and broth dilution tests. Disc diffusion measures qualitatively (i.e. in zone sizes that are equivalent to a susceptible or non-susceptible) whilst manual broth dilution or Etest provide an MIC value, but the results may not be easily extracted from the LIS as they are currently recorded in the 'comments' field. Both disc diffusion and manual broth dilution tests are performed infrequently due to their time-consuming nature.

> "We don't actually collect MICs. It's something we would like to do in the future. So with the upgrades of the laboratory information systems that's happening across the board, more of the laboratory information systems can store that and send us the MIC data." – *APAS representative*

The inclusion of clinically important microorganisms such as *N. gonorrhoea*, which relies on genotypic AST, was another factor affecting acceptability. To include data on *N. gonorrhoea*, HOTspots would need to incorporate molecular surveillance data in addition to phenotypic data. For public health authorities, acceptability was increased for microorganisms that were already notifiable and reported to the NT Centres for Disease Control. Currently, HOTspots collates susceptibility data on *Streptococcus pyogenes, Streptococcus pneumoniae,* and *N. meningiditis*, which are notifiable diseases but are not associated with significant resistance.

Acceptability of HOTspots as a surveillance system was also influenced by the detail and information provided on the website. End users expressed a need for the map's geographical unit to be closer to patients' residential location in order to accurately identify AMR 'hot spots' and to target policies and interventions. Information on sub-populations by location, such as prisons and aged care homes, where rates of AMR vary was suggested as useful information to guide policies. It was noted that Central Australia data should be included as therapeutic guidelines, policies and medicines management activities are NT-wide. Providing both demographic data and behavioural risk factors would greatly improve the ability to effectively target AMR policy and programs. In particular, clinicians thought that representing individual patients by location would enable an early detection of outbreaks or emerging pathogens of interest. Currently, HOTspots does not contain identifiable

data to support the above mentioned activities as pathology service providers have raised privacy and confidentiality concerns as a barrier to providing more granular data.

Easily accessible susceptibility data were important to clinicians working in both hospitals and community clinics. Community-based clinicians have limited access to susceptibility data, both through delays in individual pathology results caused by remoteness as well as the limited availability of population susceptibility data in the community setting. Clinicians working in the community therefore perceived greater value in engaging with HOTspots surveillance system.

> "I haven't used it yet with an individual patient… but sometimes when we've got a guesstimated organism, like if we've got a urinary tract infection we assume it's *E. coli*, …that's helpful to know that there's a reasonable amount of resistance… Pathology will only be sent out on certain days of the week when there's planes. So if there's stuff that's been done by the nurses earlier in the week, it might not have actually been sent out in the couple of days before you [doctor] get there. And then once it is sent out there's obviously delays between when we get the results." – *antibiotic prescriber 4*

In contrast, hospital-based clinicians have access to susceptibility data either by directly contacting the hospital laboratory or through antibiograms. They perceived the HOTspots surveillance system as less acceptable compared to community-based clinicians.

Using HOTspots as a decision-making tool emerged as a strong theme in the interviews. The first subtheme is website navigation. End users described difficulties with data visualisation, identified errors and reported frustration with website navigation which include mobile-phone incompatibility. The second subtheme was inappropriate or unsolicited use of HOTspots. Clinicians were concerned that other health professionals such as nurses and Aboriginal Health Practitioners would misinterpret the data and that discrepancies between information in HOTspots and recommendations in therapeutic guidelines may create variation in practice. Clinical practice variation is known to be reduced when clinical guidelines are adhered to (31).

> "Aboriginal Health Practitioners and Remote Area Nurses are fantastic at doing something that doctors are bad at, which is following protocols and minimising variations in care... General Practitioners are very guilty of…kind of prescribing by how I feel today or.. influenced by other nefarious things like drug company advertising or whatever it happens to be. So I would be concerned and a risk would be that by providing additional information there might be additional variation in care without any improvement in the quality of people's outcomes." – *antibiotic prescriber 3*

Guideline contributors were interested to have access to decision-making resources such as HOTspots, specifically with reference to recommendations for thresholds levels for switching antibiotic treatment. There were less perceived benefits for infection prevention and management and therefore less acceptability. For example, infection prevention and management conduct surveillance and reporting of some health care associated infections such as *S. aureus* bacteraemia but it is less clear how HOTspots could be beneficial here. Pharmacists, policymakers and pathology service providers were interested in the potential ability of HOTspots to produce an antibiogram or a more detailed antibiogram (e.g. down to ward level), to support decision making.

Sensitivity

The sensitivity of a surveillance system may refer to the proportion of cases of a population detected by the system or to the ability to detect outbreaks, including the ability to monitor changes in the number of cases over time (23). As clinical specimens are submitted to microbiological laboratories for diagnostic rather than for surveillance purposes, the sampling method adopted by HOTspots is passive and a fraction of cases may not be collated. Figure 3 conceptualises the steps in surveillance that determine the case fraction that would be collated by HOTspots.

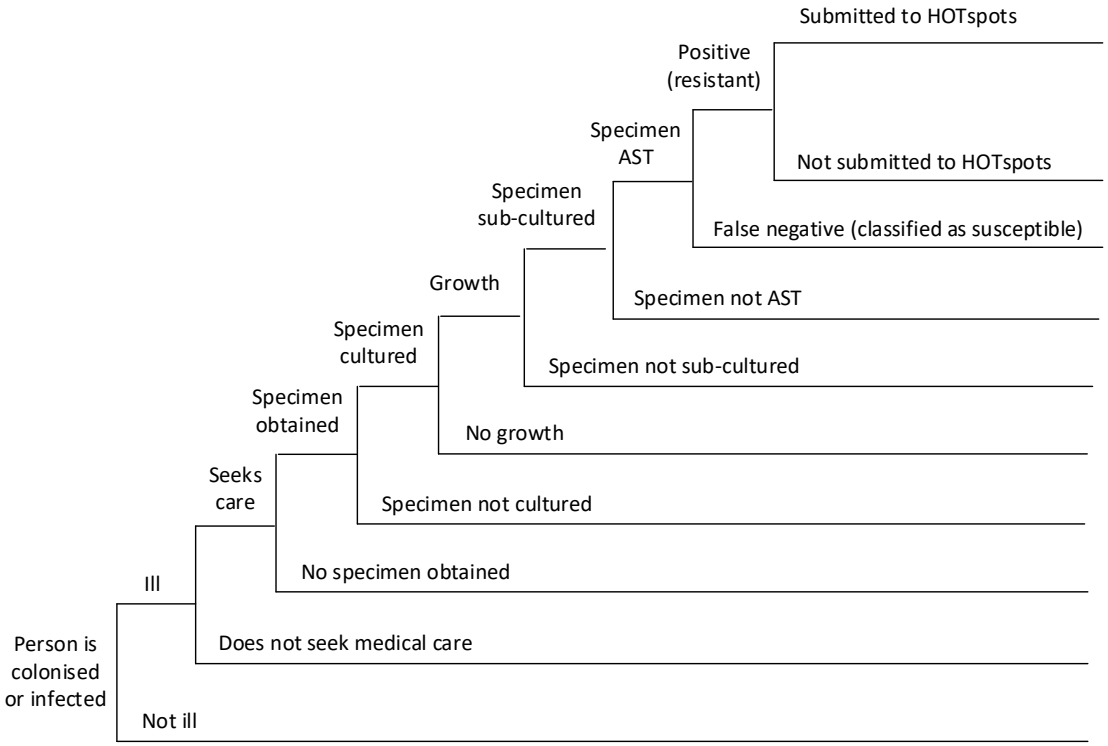

Figure 3: Case fraction collated by HOTspots

Determining the sensitivity of the entire system is difficult as the case fraction will vary for each organism and jurisdiction under surveillance due to differences in case definitions, population demographics, health service delivery and diagnostic capacity. The evaluation of sensitivity therefore focusses on *S. aureus* in the NT to provide an indication of the sensitivity of HOTspots. *Staphylococcus aureus* was chosen because of its clinical significance and the relatively large number of isolates that are available to be cultured and tested.

Determining sensitivity requires the use of similar case definitions between HOTspots and a gold standard, or "an external source of data that are assumed to be accurate and can be used to validate the data collected by the system" (32). To quantify the sensitivity of HOTspots, the proportion of *S. aureus* blood isolates collated by HOTspots was compared to those reported in the Top End Health Service (TEHS) antibiogram. Data represented in both HOTspots and the TEHS antibiogram are comparable as they use the first isolate per patient, per year, for microbe-antimicrobial combinations. In the TEHS antibiogram, MRSA is divided into healthcare-associated MRSA (which is equivalent to multi-resistant MRSA for the purpose of the antibiogram) and non-multi-resistant MRSA (33). These were combined for the purpose of a comparison with HOTspots MRSA, which includes both multi-resistant and non-multi-resistant MRSA.

The TEHS antibiogram lists several antibiotics against which *S. aureus* isolates are tested for susceptibility, however the sensitivity analysis was limited to the following antibiotics: methicillin (a term used generally to refer to some penicillins and cephalosporins, but to more specific antibiotics[c] in this analysis), sulfamethoxazole and trimethoprim (SXT), and clindamycin. This selection was made based on the clinical significance of these antibiotics in the treatment of *S. aureus* in Australia. Dicloxacillin or flucloxacillin (penicillinase-resistant penicillins) are the first-line treatment for skin and soft tissue infections (or for patients with hypersensitivity to penicillin, cefalexin), SXT or clindamycin are used as second-line treatment (34). At the time of the evaluation, HOTspots did not contain data from community clinics so this could not be used in the assessment of sensitivity. However, due to the geographical isolation of Royal Darwin Hospital (where most TEHS antibiogram data come from), there are likely to be many community-associated MRSA patients being treated in hospital. Given the high rates of community-associated MRSA in northern Australia (35, 36), including these data is essential to HOTspots achieving high MRSA sensitivity. Susceptibility results of HOTspots and the TEHS antibiogram are summarised in Table 7.

[c] HOTspots defines methicillin resistance as resistance to oxacillin (WA data), cefoxitin (NT data), and flucloxacillin and cefoxitin (QLD data). The TEHS antibiogram defines methicillin resistance as resistance to cephalothin, cefazolin, flucloxacillin, ceftriaxone, and amoxycillin-clavulanate.

Table 7: Antibiogram showing the percentage susceptible of HOTspots and Top End Health Service *Staphylococcus aureus* blood isolates collected in 2017

Data source	Organism	Isolates (n)	Ampicillin	Amoxicillin-clavulanate	Benzylpenicillin	Cefazolin	Ceftriaxone	Ciprofloxacin	Clindamycin	Daptomycin	Erythromycin	Flucloxacillin	Fusidic acid	Gentamicin	Linezolid	Multi-drug-resistant	Methicillin	Nitrofurantoin	Oxacillin	Rifampicin	Sulfamethoxazole-trimethoprim	Teicoplanin	Tetracycline	Vancomycin
HOTspots (NT only)	MSSA	840	-	-	-	-	-	98	83	95	83	-	-	98	100	0	100	100	100	-	98	100	97	100
	MRSA	448	-	-	-	-	-	84	59	100	59	-	-	84	100	0	0	100	6	-	78	100	88	100
TEHS antibiogram	MSSA	1,585	9	100	9	100	100	99	81	-	81	100	95	100	-	-	-	-	-	100	99	-	-	100
	MRSA*	930	0	0	0	0	0	92	72	-	72	0	92	94	100	-	-	-	-	99	82	-	-	100

TEHS = Top End Health Service; NT = Northern Territory; MRSA = methicillin resistant *Staphylococcus aureus*; MSSA = methicillin susceptible *Staphylococcus aureus*

* Combined non-multi-resistant MRSA and healthcare-associated MRSA

From the analysis it was determined that in 2017 there were 1,288 *S. aureus* blood isolates provided from NT to HOTspots and there were 2,515 *S. aureus* blood isolates reported in the NT TEHS antibiogram. Of the methicillin susceptible *Staphylococcus aureus* (MSSA) isolates provided to HOTspots, 83%, 100% and 98% of isolates were susceptible to clindamycin, methicillin and SXT respectively, compared to 81%, 100% and 99% of TEHS antibiogram MRSA isolates. Of the MRSA isolates provided to HOTspots, 59%, 0% and 78% of isolates were found to be susceptible to clindamycin, methicillin and SXT respectively, compared to 72%, 0% and 82% of TEHS antibiogram MRSA isolates. Percentage agreement was calculated using the formula:

$$M = 1 - [(\sum R - A) / \sum R)]$$

Where M denotes percent agreement, R denotes the reference or gold standard susceptibility (for given organism and antibiotic), and A denotes the susceptibility (for given organism and antibiotic) as reported by HOTspots. The average percent agreements for MSSA and MRSA were 100% and 92.4% respectively. Differences in the percent agreement of susceptible isolates for MRSA may be due to differences in: the time period of data collection between HOTspots (01/01/2017 - 31/12/2017) and the TEHS antibiogram (six months prior to 01/04/2017); the difference in MRSA with 'all MRSA' used in HOTspots and 'non-multi-resistant MRSA and healthcare-associated MRSA' used in the TEHS antibiogram; the number of isolates tested between HOTspots and the TEHS antibiogram; or the difference in geographical coverage, as TEHS doesn't include the hospitals at Tennant Creek or Alice Springs, though the number of isolates from Tennant Creek are likely to be negligible. Overall, the HOTspots system demonstrates high sensitivity to detect resistant *S. aureus* isolates in the NT.

Representativeness

Representativeness is defined as a system's accuracy in describing the occurrence of the event over time and its distribution in the population by person and place (23). As a laboratory-based system, the representativeness of HOTspots is dependent on the participation of laboratories in northern Australia. While it is difficult to determine the exact population serviced by HOTspots, it could be assumed that if all providers in NT, QLD and WA, above the Tropic of Capricorn, participate in surveillance then they represent an accurate estimate of the true population denominator. To our knowledge, the pathology service providers operating in northern Australia include Territory Pathology, Pathology Queensland, Sullivan Nicolaides Pathology (SNP), Western Diagnostics, PathWest, Australian Clinical Laboratories (ACL) and Queensland Medical Laboratory (QML) Pathology. These are a mixture of private and public providers, with some providers servicing hospitals and others servicing the community or a mixture of both (Table 8). The types of patients affected, and infections caused have been shown to be different between community and hospital associated strains of resistant microorganisms (37). It is therefore important that HOTspots include data from both hospital and community providers in order to be representative of the northern Australia population.

HOTspots currently includes data from Territory Pathology, PathWest and Queensland Health. It is expected that data from Western Diagnostics will also be contributed in the near future. Together, these providers cover most public hospital and community settings as far north as Kununurra in WA (38), all four public hospitals in NT's top end (39), all public hospitals and some community settings in QLD and with time (current delay in data receipt) almost all community-level data across WA and NT (40). Therefore, the HOTspots surveillance system is highly representative of the population of northern Australia.

Table 6: Summary of pathology service providers in northern Australia

Pathology service provider	**Jurisdiction**	**Laboratories and collection centres**	**Private or government-owned provider**	**Hospital or community service**
PathWest	WA	23 laboratories and >50 collection centres as far north as Kununurra	Government-owned	Hospital (public) & community
Western Diagnostics	WA & NT	10 laboratories across WA and two in the NT. >200 collection centres	Private (but also services public hospitals)	Hospital (public and private)
Territory Pathology	NT	6 laboratories	Government-owned	Hospital (public)
ACL	NT	1 laboratory	Private	Hospital (private)
SNP	NT & QLD	5 collection centres in the NT & approx. 63 collection centres in northern QLD	Private	Community
QML	QLD	24 laboratories in QLD and >600 collection centres across QLD & NSW	Private	Hospital (private) & community
Pathology Queensland	QLD	35 laboratories & 38 pathology collection centres	Government-owned	Hospital (public) & community

WA = Western Australia; QLD = Queensland; NT = Northern Territory; NSW = New South Wales; ACL = Australian clinical Labs; SNP = Sullivan Nicolaides Pathology; QML = Queensland Medical Laboratory

Timeliness

Timeliness typically refers to the speed between steps in the surveillance system (23), however for the purpose of this evaluation timeliness was defined as the time between the production of data (i.e. the point at which AST is performed and results become available) to the point at which this information is made available to end users. Stakeholders were asked how frequently data should be updated through the HOTspots website and how often they would like to access AMR reports.

There was consensus among end users that four to twelve-monthly data updates would be timely, given that antibiograms are recommended to be made available on an annual basis (41). Pathology service providers reported that data extracts to other AMR surveillance systems such as APAS are done on a monthly basis. It may therefore be easier for pathology services to concurrently supply data to HOTspots but this would only further enhance the system's timeliness.

> "We only get our antibiogram about… once a year, sometimes once every couple of years. Quarterly is actually pretty fast." – *pharmacist 2*

> "The AMS Committee look at things monthly because they have access to the data through NT labs... In primary health care you're looking at much longer timelines so if you can get something quarterly that would be great… We used to get our antibiogram once a year… Having something more frequently would be fantastic." – *policymaker 1*

The speed at which HOTspots is able to make data available to end users is an advantage over existing AMR surveillance systems such as AURA and AGAR. These systems rely on annual reports or ad hoc publications to disseminate AMR data and often report data from previous years (42).

Stability

Stability typically refers to the reliability (ability to collect, manage and provide data properly without failure) and availability (ability to be operational when it's needed) of the system (23). As a new, voluntary system, the main factors that affect HOTspots' stability are governance, legal issues such as contractual agreements, funding and operational resources. Leadership and governance are key challenges for national communicable disease control, since Australia lacks a national communicable disease control governance structure or coordinating body (43). HOTspots is currently governed by Menzies School of Health Research staff and an advisory committee, and could benefit from a more formal governance model. Examples of governance models for surveillance systems include:

- Funded and overseen by government.
- Funded and overseen by an independent, not-for-profit entity.
- Commercially funded but overseen by a professional group or society.
- Funded and overseen by a commercial entity.

An example of a government model is AURA, which is funded by the Australian Government Department of Health and overseen by the Commission. Commercially funded governance models for AMR surveillance systems include AGAR, which began as a commercially funded program overseen by a professional society, and SENTRY, which is a multinational program that was initially funded by GlaxoSmithKline and is now sponsored by a number of pharmaceutical companies. Though perhaps not truly independent of government, PHNs could take on a leadership role in AMR governance through a model funded and overseen by an independent and not-for-profit organisation.

Sustainability of HOTspots requires legal advice on how best to formalise ongoing agreements with laboratories. As a passive, laboratory-based surveillance system, HOTspots is reliant on the voluntary and regular supply of data from pathology service providers, and currently does not have formal agreements for ongoing data provision. Data custodianship and intellectual property protection are likely to be the most important factors in negotiating such agreements. HOTspots could be registered as a patent, trademark or design to protect the idea, advantages and disadvantages to each type of and intellectual property protection these need to be considered (44).

HOTspots also requires essential resources to ensure stability. These include human resources, IT infrastructure, and funding to cover ongoing costs. With regards to human resources, HOTspots requires staff who understand both the data and how to analyse it. Without the appropriate person, it is difficult to query or validate the data. Staff need to be able to communicate effectively with laboratory personnel and assist with data requests, potentially including the creation of antibiograms. It would be advisable to gain IT and project management expertise to oversee the technology that is required to integrate HOTspots with other relevant and established systems such as OrgTrx and LIS.

> "I think the IT side cannot be underestimated. It's huge… having our IT speak to different IT people and finding the right person to speak to is really tricky. The biggest issue that we have is firewalls... Because it's patient information there's a lot of channels you've got to go through and there's secure firewalls on either end and you've got to... have their gateway people talk to our gateway people to actually get those VPNs to work." – *APAS representative 1*

Securing ongoing funding for HOTspots is a significant resource required for sustainability. At present, funding is sourced from either grants or philanthropic donations made to the program manager. More sustainable funding options are needed to facilitate long-term planning and reduce overheads by freeing up time from reporting or writing grant applications. Funding is particularly important given that HOTspots is a voluntary system and any costs related to participating could reduce acceptability to stakeholders. Potential costs associated with HOTspots are the development and maintenance of the website and staff salaries. Securing funding should be a priority of the working group, which would include ongoing financial support that may be supplemented, but is not reliant on, grant funding.

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