Current Tropical Medicine Reports (2024) 11:167–178
https://doi.org/10.1007/s40475-024-00326-y

REVIEW

Bacteraemia in Tropical Australia: A Review

H. E. Ratnayake[1] · D. P. Eisen[1] · O. A. Adegboye[2,3] · A. Pak[4] · E. S. McBryde[5]

Accepted: 6 July 2024 / Published online: 2 August 2024

Abstract

Purpose of Review This review discusses the trends of bacteraemia and their outcomes in tropical regions of Australia. Bacteraemia can frequently lead to severe sepsis and potentially life-threatening consequences. Epidemiology of bacteraemia is ever evolving.

Recent Findings This review outlines the current patterns of bacteraemia in tropical regions of Australia, focusing on their outcomes and associated risk factors. The most frequently reported causes of bacteraemia were *Staphylococcus aureus* and *Escherichia coli*. There has been an increase in published incidence of Group A *Streptococcus*, methicillin-resistant *Staphylococcus aureus* and *Burkholderia pseudomallei* bacteraemia cases, while *Streptococcus pneumoniae* bacteraemia exhibited a declining trend. Factors specific to tropical environments and the higher representation of Indigenous populations in these areas were identified as contributing to the elevated incidence rates.

Summary Bacteraemia was found to be an increasing healthcare burden to the Australian tropical regions. Ideally, linkage of existing data from healthcare settings could be utilised to obtain more accurate, comprehensive and up to date information of trends and patterns of bacteraemia.

Keywords Bacteraemia · Tropical Australia · Epidemiology · Infectious diseases · Public health · Pathogens

Introduction

Bacteraemia can frequently lead to severe sepsis and potentially life-threatening consequences. According to the Global Burden of Disease Study, bloodstream infections have caused more than 2 million deaths globally in 2019 [1]. Furthermore, bacteraemia is increasing globally and is predicted to increase in the future [2–5]. The drivers of increasing bacteraemia rates are manifold including changes in host characteristics, changes in pathogens and changes in healthcare systems and technologies [6, 7]. Environmental factors like temperature, rainfall, humidity also play a role [8, 9]. So, it is not surprising that there are regional differences in trends of bacteraemia and its outcomes. Knowledge on local pathogens causing bacteraemia and their temporal variations is helpful for individualising patient management with well selected empirical antibiotic treatment, and for early detection of outbreaks [6, 10].

This review describes the trends of bacteraemia and their outcomes in tropical regions of Australia. Many studies conducted in tropical Australia were focused on a single organism in a single setting. This review synthesises these studies and visualises the trends of common organisms in tropical Australia.

Tropical regions of Australia include Northern region of Western Australia, Northern Territory and Northern Queensland (Fig. 1). These regions have an average warm temperature all year round. In addition, these regions have a high proportion of Indigenous people. Northern Territory has the highest proportion of Indigenous people (30.3%) while Queensland and Western Australia have a proportion

✉ H. E. Ratnayake
himali.ratnayake@my.jcu.edu.au

1 College of Medicine and Dentistry, James Cook University, Townsville, QLD, Australia

2 Menzies School of Health Research, Charles Darwin University, Northern Territory, Australia

3 Public Health and Tropical Medicine, College of Public Health & Tropical Medicine, James Cook University, Townsville, QLD, Australia

4 Centre for the Business and Economics of Health, The University of Queensland, Brisbane, Australia

5 Australian Institute of Tropical Health and Medicine, James Cook University, Townsville, QLD, Australia

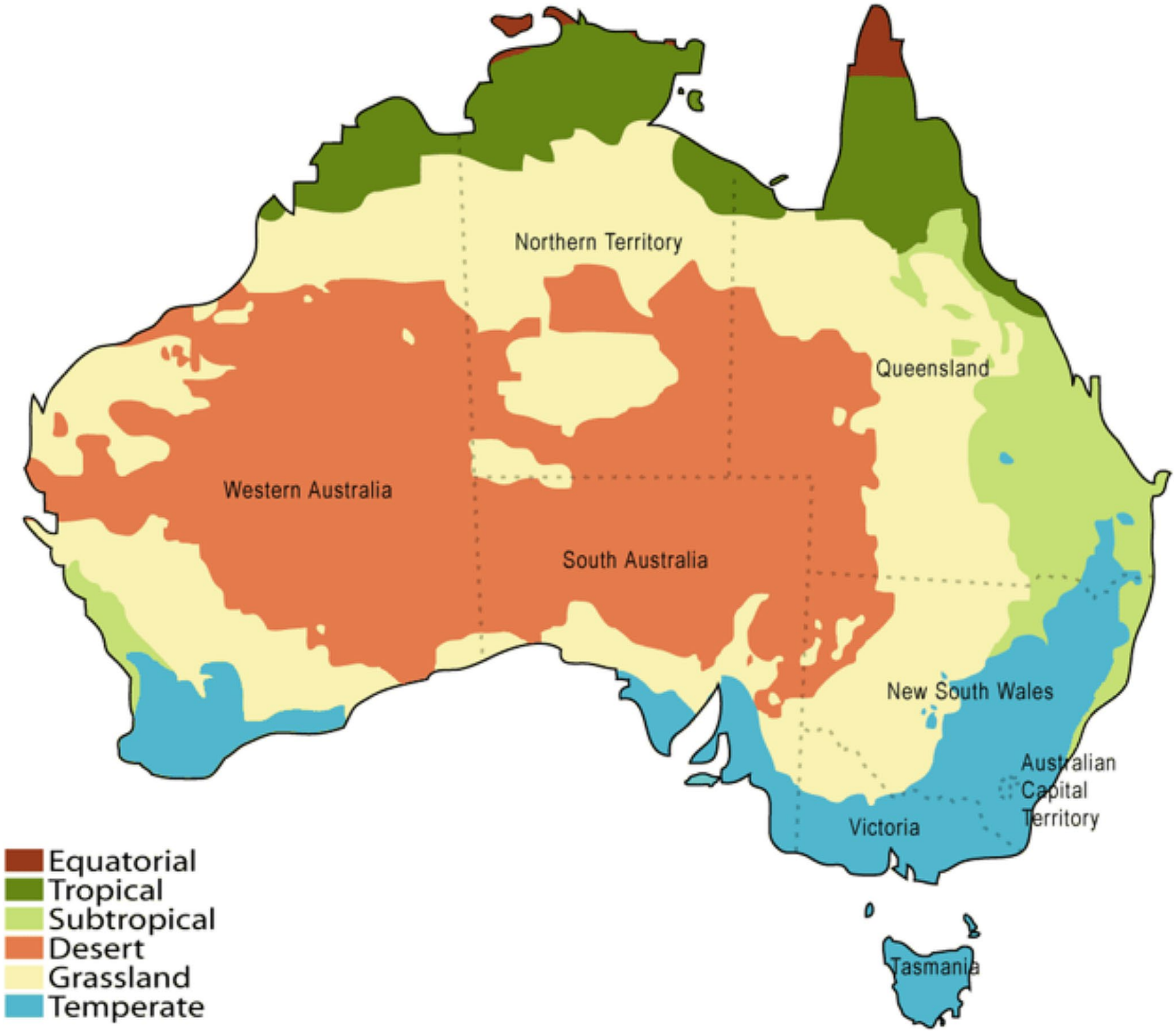

Fig. 1 Tropical regions of Australia. The Australian Bureau of Meteorology climate classification by Martyman under CC BY-SA 3.0 [11]

of 4.7% and 4.1% respectively [12]. Bacteraemia is recognized to correlate with comorbidities and low socioeconomic status, both of which are prevalent among Indigenous populations. Consequently, tropical regions face elevated risks of bacteraemia compared to other regions [13].

Methodology

Search Strategy

Published literature was assessed through PubMed, EMBASE, Scopus and Web of Science from 1995 until November 2023 to identify studies on bacteraemia conducted in Australian tropical settings. The search terms used were 'bacteraemia', 'bacteremia', 'blood stream infection', 'Australia', 'Northern Territory', 'Queensland' and 'Western Australia'. Furthermore, the common pathogens causing bacteraemia were searched by their pathogen name; '*Staphylococcus aureus'*, *'methicillin resistant staphylococcus aureus'*, 'MRSA', 'Group A *Streptococcus'*, *'Streptococcus pyogenes'*, 'Group B *Streptococcus'*, *'Streptococcus pneumoniae'*, *'Escherichia coli'*, *'Klebsiella'*, *'Burkholderia pseudomallei*', '*Salmonella'* and *'nontyphoidal Salmonella'*. Studies conducted before 1995 were excluded.

Analysis

We found a high variability in the units used to present incidence data in the studies reviewed. Therefore, we converted

all findings to incidences calculated 'per 100,000 population per year' using either the population information reported on the article or using Australian Bureau of Statistics census data [14, 15]as shown in Table 1.

Results

In this section epidemiological trends, severe outcomes and risk factors of common organisms causing bacteraemia in tropical settings will be discussed.

Staphylococcus aureus Bacteraemia

S. aureus was the commonest cause of bacteraemia in tropical Australia [17, 18, 20]. The annual incidence of *S. aureus* bacteraemia in tropical Australia ranged between 17 and 96 per 100,000 population during the period 2000 to 2019 according to the studies conducted in Northern Territory and Northern Queensland [16–21] (Table 1). The rates were lower in children which was around 10 to 20 cases per 100,000 population [22, 23]. High incidence of *S. aureus* bacteraemia was observed among the Indigenous patients compared to non-Indigenous [16, 19, 23, 31]. Many long-term studies conducted during 2000 to 2020 in tropical Australia revealed a decline in *S. aureus* bacteraemia [17, 20, 22]. This could be attributable to infection control measures in healthcare settings [20]. It is notable these findings run counter to the global trends. According to a systematic review, in the global setting, there were variable trends for *S. aureus* bacteraemia with no significant change in the incidence across the included countries from 2000 to 2020 [32].

Incidence rates of *S. aureus* bacteraemia in tropical Australia were found to be higher than that of the national rates. Annual incidence of *S. aureus* bacteraemia in Australia between 1999 and 2010 ranged from 11.2 to 35 per 100,000 population [31, 33], whereas the annual incidence of *S. aureus* bacteraemia in tropical Australia was as high as 96.6 per 100,000 population in some parts [17]. The latter study was conducted in the Northern Territory and described a high proportion of Indigenous people and numerous comorbidities.

Crude mortality rate of *S. aureus* bacteraemia in tropical Australia, ranged between 4 and 8% [16, 18]. Interestingly, a study conducted in Australia and New Zealand revealed a low mortality rate (7%) for Indigenous patients compared to non-Indigenous (17%) [31]. The probable explanation for this could be that Indigenous patients had a younger average age of acquisition of the infection [31].

MRSA Bacteraemia

The annual incidence of MRSA bacteraemia in tropical Australia ranged between 3.8 and 17 per 100,000 population within 2004 to 2015 [16, 18, 20–22] (Table 1). MRSA has different strains which can be differentiated based on resistance to non-methicillin antibiotics. Multiresistant MRSA (mrMRSA) exhibit resistance to multiple classes of antibiotics and are comparatively common in hospitals, whereas Non-multiresistant MRSA (nmMRSA) remain susceptible to some classes of antibiotics (cotrimoxazole, clindamycin and macrolides) and are comparatively common in the community.

Studies conducted in different tropical settings reported different trends of MRSA bacteraemia. The 10-year study conducted in Northern Queensland found that overall incidence of MRSA did not change significantly over the study period. However, mrMRSA significantly reduced during this period ($P=0.04$) while nmMRSA increased, which was not statistically significant ($P=0.125$) [20]. A paediatric study conducted in Northern Queensland from 2001 to 2010 revealed an increase in the number of MRSA bacteraemia during the study period [22].

Northern Australia, as noted by Murray et al. (2004), experienced a surge in community-onset MRSA bacteremia [21]. This increase in community-acquired MRSA infections has been noted throughout Australia. [33, 34]. A study conducted in 17 Australian hospitals revealed that 40% of the *S. aureus* bacteraemia episodes were hospital onset MRSA while 12% were of community onset [33]. Crowded living conditions, poor hygiene and heavy use of broad-spectrum antibiotics are proposed mechanisms by which there is increasing emergence of community acquired MRSA [35].

MRSA bacteraemia was found to be more prevalent among Indigenous people [19, 31]. Female sex and remote residence were significantly associated with resistant strains of MRSA compared to sensitive strains [16]. Mortality rates of MRSA ranged between 2% (MSSA) to 4.5% (MRSA) [16].

Group A *Streptococcus* (GAS) Bacteraemia

GAS bacteraemia is an invasive disease which frequently leads to life threatening consequences such as septicaemia and streptococcal toxic shock syndrome (STSS). Incidence of GAS bacteraemia among the general population in tropical Australia ranged between 7.45 and 20 per 100,000 population per year [17, 20, 24–26, 36] (Table 1). A high incidence rate for GAS bacteraemia was observed among Indigenous populations. Three large studies conducted in North Queensland and Northern Territory during 1996 to 2014 period revealed that the incidence among Indigenous

Table 1 Results of studies conducted in tropical Australian settings (1996–2023)

Region	Reference	Setting	Sample size, sample characteristics	Time period	Incidence/ Trend/ important findings as reported	Incidence per 100,000 population per year (calculated using Australian Bureau of Statistics population data)
***Staphylococcus aureus* bacteraemia**						
Northern Territory	[16]	3 Top End hospitals in Northern Territory serving population of 176,000 during the study period.	Total number of *S. aureus* bacteraemia cases was 607 (MSSA = 478, nmMRSA = 239, mMRSA = 90).	2006–2007 (1 year)	The annual incidence in general population is 65/100,000/year compared to 172/100,000/year for Aboriginal population and 30/100,000/year for non-aboriginal population.	Published as per 100,000/year
Northern Territory	[17]	Royal Darwin Hospital serving 160,000 of population during the study period.	7800 episodes of bacteraemia out of which 2784 (35.7%) were due to *S. aureus.*	1999–2019 (21 years)	Incidence decreased from 96.6/ 100,000/year in 1999 to 86.4/100,000/year in 2019 ($p = 0.570$)	Published as per 100,000/year
Northern Territory	[18]	Royal Darwin Hospital serving 100,000 population during the study period.	Mean age 40.5 (0–90) years. 257 bacteraemia episodes out of which 73 were *S. aureus* bacteraemia (MSSA = 54, mrMRSA = 17, nmrMRSA = 2).	Year 2000 (1 year)	163 episodes per 100,000 hospital admissions	73 episodes per 100,000 population per year (100,000 was used as the denominator as reported in the article).
Northern Queensland	[19]	Queensland public hospitals (Public hospitals account for 70% hospital patient days).	4,807 *S. aureus* bacteraemia episodes. Of that, 3532 (73.5%) community onset episodes and 1275 (26.5%) hospital onset episodes. Of community onset bacteraemia 2974 MSSA bacteraemias (84.3%).	2005–2010 (6 years)	21% increase in relative risk (RR) of bacteraemia with MSSA (95% credible interval, 1.15–1.26) and a 24% increase in RR with nmMRSA (95% credible interval, 1.13–1.34) with a 10% increase in the indigenous Australian population proportion.	Incidence is 29.3/100,000/year (The number of *S. aureus* bacteraemia cases were adjusted to include patients admitted to private hospitals as the article stated that public hospitals account for 70% hospital patient days. Queensland population according to 2006 census data were used as the denominator) [15].
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes of which 952 (20.9%) were due to *S. aureus*.	2000–2009 (10 years)	Annual incidence decreased from 92.23/100,000 bed days in the year 2000 to 51.92/100,000 bed days in the year 2009 ($P < 0.01$).	Overall incidence for the study period is 66.42/100,000/year (2006 census data were used for the denominator). Annual incidence decreased from 83.46 to 45.34/100,000/year ($p < 0.01$) (2001 and 2011 census data were used for the denominator respectively) [15].
Northern Territory	[21]	Patients admitted to Royal Darwin Hospital serving 150,000 population. during the study period.	121 episodes of community onset *S. aureus* bacteraemia (MSSA = 98, MRSA = 23).	1998–2001(4 years)		Overall incidence for the study period is 20.17/100,000/year (150,000 was used as the denominator as reported in the article).
Northern Queensland	[22]	Townsville University Hospital.	Children under 16 years of age. 44 episodes of *S. aureus* bacteraemia.	2001–2010 (10 years)	6.3% *S. aureus* bacteraemias. Incidence decreased from 17.3/100,000 bed days in the year 2001 to 8.1/100,000 bed days in the year 2010.	Incidence decreased from 17.5 to 10.5/100,000/year (the numbers may not be very accurate as they were taken from a graph).
Northern Territory	[23]	Royal Darwin Hospital. Total population < 15 years is 39,000.	Children less than 15 years. 44 episodes of *S. aureus* bacteraemia	2007–2010 (4 years)	Overall incidence for the study period is 27.9/100,000/year	Published as per 100,000/year.

Table 1 (continued)

Region	Reference	Setting	Sample size, sample characteristics	Time period	Incidence/ Trend/ important findings as reported	Incidence per 100,000 population per year (calculated using Australian Bureau of Statistics population data)
MRSA bacteraemia						
Northern Territory	[16]	3 Top End hospitals in Northern Territory serving population of 176,000 during the study period.	Total number of *S. aureus* bacteraemia cases were 607 (nmMRSA = 239, mMRSA = 90).	2006–2007 (1 year)	The annual incidence is 16/100,000/year.	Published as per 100,000/year
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes out of which 204 (4.5%) were due to MRSA.	2000–2009 (10 years)	No significant trend in the overall incidence of MRSA. Significant reduction of mMRSA ($r = -0.651$; $P = 0.042$). Non-significant increase in nmMRSA ($P = 0.125$)	Overall incidence for the study period is 14.23/100,000/year (2006 census data were used for the denominator) [15].
Northern Queensland	[19]	Queensland public hospitals (Public hospitals account for 70% hospital patient days).	4,807 *S. aureus* bacteraemia episodes. Of that, 3532 (73.5%) community onset episodes and 1275 (26.5%) hospital onset episodes. Of community onset bacteraemias mMRSA = 255(7.2%) nmMRSA = 303(8.6%)	2005–2010 (6 years)	21% increase in relative risk (RR) of bacteraemia with MSSA (95% credible interval, 1.15–1.26) and a 24% increase in RR with nmMRSA (95% credible interval, 1.13–1.34) with a 10% increase in the indigenous Australian population proportion.	Overall incidence for the study period for resistant strains; MRSA = 2.38/100,000/year mMRSA = 1.09/100,000/year NmMRSA = 1.29/100,000/year (The number of MRSA bacteraemia cases were adjusted to include patients admitted to private hospitals as the article stated that public hospitals account for 70% hospital patient days. Queensland population according to 2006 census data were used as the denominator) [15].
Northern Territory	[18]	Royal Darwin Hospital serving 100,000 population during the study period.	Mean age 40.5 (0–90) years. 257 bacteraemia episodes (mrMRSA = 17, nmrMRSA = 2).	Year 2000 (1 year)	Number of MRSA cases (mMRSA + nmMRSA) is 19.	Overall incidence for the study period is 19/100,000/year (100,000 was used as the denominator as reported in the article).
Northern Territory	[21]	Patients admitted to Royal Darwin Hospital serving 150,000 population during the study period.	121 episodes of community onset *S. aureus* (COMRSA) bacteraemia (MRSA = 23).	1998–2001(4 years)	Out of the 23 cases of MRSA bacteraemia, 15 cases of COMRSA. Incidence of COMRSA increased from 9% in 1998 to 20% in 2001.	Overall incidence of MRSA for the study period is 3.8/100,000/year. Incidence of COMRSA is 2.5/100,000/ year (150,000 was used as the denominator as reported in the article).
Northern Queensland	[22]	Townsville University Hospital.	Children under 16 years of age. 12 cases of MRSA bacteraemia.	2001–2010 (10 years)	Proportion of MRSA bacteraemia cases is 1.7%. Increase in the number of cases from 0 to 3 cases during the period	Incidence of MRSA increased from 0 to 5/100,000/year (the numbers may not be very accurate as they were taken from a graph).
Group A *Streptococcus* (GAS) bacteraemia						
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes of which 136 (3%) were due to GAS bacteraemia.	2000–2009 (10 years)		Overall incidence for the study period is 9.49/100,000/year (2006 census data were used for the denominator) [15].
Northern Territory	[17]	Royal Darwin Hospital serving 160,000 of population during the study period.	7800 bacteraemia episodes of which 504(6.46%) were due to GAS bacteraemia.	1999–2019 (21 years)	Significant increase in incidence from 12.2 episodes/100,000/year in 1999 to 20.4/100,000/year in 2019 ($p = 0.006$).	Published as per 100,000/year.

Table 1 (continued)

Region	Reference	Setting	Sample size, sample characteristics	Time period	Incidence/ Trend/ important findings as reported	Incidence per 100,000 population per year (calculated using Australian Bureau of Statistics population data)
Northern Queensland	[22]	Townsville University Hospital.	Children under 16 years of age.18 cases of GAS bacteraemia.	2001–2010 (10 years	Proportion of GAS bacteraemia was 2.6%. Rate remained stable over the study period.	Incidence rate ranged between 0 to 7/100,000/year (the numbers may not be very accurate as they were taken from a graph).
Northern Queensland	[24]	Northern Queensland	Median age was 39 years (range 1 month to 88 year). 109 iGAS episodes.	1996–2001(5 years)	Out of 109 iGAS episodes, 94% ($n=102$) were blood stream infections.	Overall incidence of GAS bacteraemia for the study period is 15.41/100,000/year (2001 census data were used) [15].
Northern Territory	[25]	Royal Darwin Hospital (RDH), Katherine District Hospital (KDH) and Gove District Hospital (GDH)	Mean (SD) age of 42.1 (22) years. 295 confirmed cases of GAS bacteraemia over the study period.	1998–2009 (12 years)	The annual age-adjusted incidence was 15.2 /100 000/year overall and 59.4/100 000/year in Indigenous Australians.	Published as per 100,000/year.
Northern Queensland	[26]	Far North Queensland.	Median (interquartile range) age 60 (48–71) years.286 episodes of GAS bacteraemia identified during the study.	2014–2020 (7 years)	Mean annual incidence in the total population was 14.5/100,000 population compared to 49.2/100,000 in the Indigenous population.	Published as per 100,000/year.
Group B *Streptococcus* (GBS) bacteraemia						
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes out of which 87 (1.9%) were GBS bacteraemia	2000–2009 (10 years)		Overall incidence of GBS bacteraemia for the study period is 6.07/100,000/year (2006 census data were used for the denominator) [15].
Northern Queensland	[27]	Townsville University Hospital and Health service.	Mean age (SD) 66.3 (16.9) years.164 GBS cases	2010–2020 (10 years)	Incidence was 12.48/100 000/year for the Indigenous population compared to 4.84/100 000/year for the non-Indigenous population	Overall incidence of GBS bacteraemia for the study period is 11.44/100,000/year (2006 census data were used for the denominator) [15]
Streptococcus pneumoniae bacteraemia						
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes out of which 221 *S. pneumoniae* bacteraemia episodes.	2000–2009 (10 years)	Significant negative trend from 30.74/100,000 bed days in the year 2000 to 10.28/ 100,000 bed days in 2009.	Overall incidence is 15.42 per 100,000 per year. Decreased incidence from 16.6 in 2000 to 10.4 in 2009/100,000/year (2006 census data were used for the denominator) [15].
Northern Territory	[17]	Royal Darwin Hospital serving 160,000 of population.	7800 episodes of bacteraemia out of which 423 (5.42%) were due to *S. pneumoniae.*	1999–2019 (21 years)	Significant decline in the incidence from 18.6/100 000/year in 1999 to 9.6/100 000/year in 2019 ($p=0.002$).	Published as per 100,000/year
Northern Queensland	[22]	Townsville University Hospital.	Children under 16 years of age. 59 episodes	2001–2010 (10 years)	Incidence rate decreased from 11.54/10 000 bed days in year 2001 to 1.8/100 000 bed days in year 2010.	Incidence rate decreased from 11.5 to 2/100,000/year (the numbers may not be very accurate as they were taken from a graph).
***Escherichia coli* bacteraemia**						
Northern Territory	[18]	Royal Darwin Hospital serving 100,000 population.	Mean age 40.5 (0–90) years. 257 bacteraemia episodes.	Year 2000 (1 year)	*E. coli* caused 19% of bacteraemia. 145 episodes per 100,000 admissions.	Incidence rate is 48/100,000/year (100,000 was used as the denominator as reported in the article).

Table 1 (continued)

Region	Reference	Setting	Sample size, sample characteristics	Time period	Incidence/ Trend/ important findings as reported	Incidence per 100,000 population per year (calculated using Australian Bureau of Statistics population data)
Northern Territory	[17]	Royal Darwin Hospital serving 160,000 of population during the study period.	7800 episodes of bacteraemia out of which 1632 (20.9%) were due to *E. coli.*	1999–2019 (21 years)	Significant increase in incidence from 30.1/100,000/year to 74.7/100,000/year ($p < 0.001$).	Published as per 100,000/year
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes out of which 707 (15.58%) were due to *E. coli.*	2000–2009 (10 years)		Overall incidence for the study period is 49.33/100,000/year (2006 census data were used for the denominator) [15].
Northern Queensland	[22]	Townsville University Hospital.	Children under 16 years of age. 22 episodes.	2001–2010 (10 years)	3.2% *E. coli* bacteraemia. Stable fluctuating trend.	Stable between 0 to 8/100,000/year (the numbers may not be very accurate as they were taken from the graph).
***Klebsiella* bacteraemia**						
Northern Territory	[17]	Royal Darwin Hospital serving 160,000 of population.	7800 episodes of bacteraemia out of which 416 (5.33%) were due to *Klebsiella.*	1999–2019 (21 years)	Significant increase in incidence from 9.12 episodes per 100,000/year to 17.7 episodes per 100,000/year ($p < 0.001$).	Published as per 100,000/year
Northern Territory	[18]	Royal Darwin Hospital serving 100,000 population.	Mean age 40.5 (0–90) years. 257 bacteraemia episodes.	Year 2000 (1 year)	12 cases. 36.3 per 100,000 admissions	Incidence is 12 episodes per 100,000 per year (100,000 was used as the denominator as reported in the article).
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes out of which 256 (5.64%) were *K. Pneumoniae* bacteraemia.	2000–2009 (10 years)		Overall incidence for the study period is 17.86/100,000/year (2006 census data were used for the denominator) [15].
***Burkholderia pseudomallei* bacteraemia**						
Northern Territory	[18]	Royal Darwin Hospital serving 100,000 population.	Mean age 40.5 (range 0–90) years. 257 bacteraemia episodes.	Year 2000 (1 year)	16 cases. 48.48 per 100,000 admissions	Incidence is 16 episodes per 100,000 per year (100,000 was used as the denominator as reported in the article).
Northern Queensland	[20]	Townsville University Hospital	4536 bacteraemia episodes out of which 42 *B. pseudomallei* bacteraemia episodes.	2000–2009 (10 years)		Overall incidence is 2.93/100,000/year (2006 census data were used for the denominator) [15].
Northern Territory	[17]	Royal Darwin Hospital serving 160,000 of population.	7800 episodes of bacteraemia out of which 491 (6.29%) were due to *B. pseudomallei.*	1999–2019 (21 years)	Non-significant increase in incidence from 12.7/100,000/year to 19/100,000/year ($p = 0.087$).	Published as per 100,000/year
Northern Queensland	[28]	Cairns Hospital	Median age (interquartile range)52 (42–64) years.321 melioidosis cases	1998–2020 (23 years)	223/321 (69.5%) were bacteraemias. Incidence of melioidosis increased from 4.1/100,000/year in 1998 to 15.0/100,000/year in 2020 ($p = 0.007$)	Overall incidence for the study period is 3.46/100,000/year (280,000 was taken as the denominator as reported in the study).
Northern Queensland	[29]	Laboratory based at Townsville University Hospital	292 cases of Melioidosis	1996–2020 (25 years)	197/292 (71%) were bacteraemia cases	Highest incidence was 9.15 per 100,000 per year reported from Townsville and North West (according to a figure presented).
Northern Queensland	[30]	Cairns Hospital	477 melioidosis cases	1998–2023 (25.5 years)	332 out of 477 (70%) bacteraemia cases	Overall incidence was 4.5 per 100,000 per year (290,000 was taken as the denominator as reported in the study).

Table 1 (continued)

Region	Reference	Setting	Sample size, sample characteristics	Time period	Incidence/ Trend/ important findings as reported	Incidence per 100,000 population per year (calculated using Australian Bureau of Statistics population data)
***Salmonella bacteraemia and Nontyphoidal Salmonella* (NTS) bacteraemia**						
Northern Queensland	[22]	Townsville University Hospital.	Children under 16 years of age. 25 episodes of *Salmonella* bacteraemia.	2001–2010 (10 years)	Proportion of *Salmonella* bacteraemia is 3.6%. Declining trend, from 7.7/10 000 bed days in 2001 to 3.6/10 000 in 2010	Declining trend from 7 to 4/100,000/year (the numbers may not be very accurate as they were taken from the graph).
Northern Territory (Nontyphoidal Salmonella)	[17]	Royal Darwin Hospital serving 160,000 of population.	7800 episodes of bacteraemia out of which 183 (2.35%) were due to NTS bacteraemia.	1999–2019	Significant increase in incidence from 2.07/100,000/year to 9.51/100 000/year ($p < 0.001$).	Published as per 100,000/year

population was 4–10 times higher compared to the total population incidence [24–26]. A paediatric study conducted in Northern Queensland from 2001 to 2010 revealed a relatively lower rate of incidence of GAS bacteraemia fluctuating between 0 and 7 per 100,000 population over the study period [22].

A significant rise in GAS bacteraemia was observed in Northern Territory during 1999 to 2019 period [17] while it was stable in Northern Queensland during 1996 to 2009 [36]. A steep rise in the reported incidence of invasive GAS (iGAS) disease across Australia was observed during 2018 to 2022 period from a large study [37]. This increase in reported case numbers could be due to increased case detection rate as a result of iGAS becoming a nationally notifiable disease during the period 2005 to 2021 in Australia [38]. Increasing incidence rates were observed in global literature as well [24, 39]. Likewise, Indigenous communities were at increased risk of infection with GAS globally [40, 41]. This can be explained by the strong relation of this pathogen to the social determinants of health, where Indigenous communities experience more socioeconomic disadvantages comparatively [26, 42].

Having chronic diseases like diabetes, chronic kidney disease, cardiac diseases and receiving dialysis were risk factors for GAS bacteraemia [26]. According to literature from tropical Australia, crude mortality rate of GAS bacteraemia ranged between 5.6 and 13.8% [24–26, 36]. Proportion of cases requiring ICU admissions varied from 15.0 to 23.6% while STSS was reported from 6.6 to 16.3% of these patients [25, 26]. Antimicrobial resistance was present in 19.2%, most commonly to tetracycline [26].

Group B *Streptococcus* (GBS) Bacteraemia

Group B Streptococcus frequently causes morbidity and mortality among vulnerable populations, such as pregnant mothers, newborns, and the elderly [36]. GBS bacteraemia can lead to sepsis, pneumonia and meningitis. Studies conducted in Northern Queensland from 1996 to 2020 revealed a rise in incidence from 4.3 to 11.4 per 100,000 per year [20, 27, 36]. The incidence of GBS bacteraemia was about 2.5 times higher among the Indigenous population compared to non-Indigenous population [27]. However, another high-risk group was the non-Indigenous older females [36]. One important observation throughout the studies was that GBS bacteraemia was deviating from being predominantly a neonatal and maternal infection to become a non-neonatal and non-pregnant infection [27, 36]. This change was observed in studies conducted globally [43–47]. Another interesting observation was that as age advanced, a switch from Indigenous cases to non-indigenous became apparent [27].

Presence of comorbidities was a risk factor for GBS bacteraemia [27]. Crude mortality rate was 3.6% [36] with an increased risk among males and immunosuppressed patients [27].

Streptococcus pneumoniae Bacteraemia

S. pneumoniae bacteraemia was found to be the commonest bacteraemia among children in tropical Australia [22]. Three recently conducted studies in tropical Australia between 2000 and 2019 revealed a reduction in reported *S. pneumoniae* bacteraemia [17, 20, 22] (Table 1). This decrease can largely be attributed to the successful pneumococcal vaccination programs in tropical Australia [20]. There was insufficient research on *S. pneumoniae* bacteraemia from tropical Australia to describe the associated risk factors and mortality.

Escherichia coli and *Klebsiella pneumoniae* Bacteraemia

E. coli was found to be the commonest gram-negative organism causing bacteraemia in Australian tropical regions

[17, 18, 20]. The incidence of *E. coli* bacteraemia in the general population ranged between 19 and 48 per 100,000 per year during 2004 to 2020 in tropical Australia [17, 18, 20, 22]. There was conflicting evidence on trends of *E. coli* bacteraemia reported from tropical Australia. One study reported a 2.5 fold increase in the incidence of *E. coli* bacteraemia from 1999 to 2019 surpassing the number of *S. aureus* bacteraemia at the end of the study period [17]. But a more stable trend was observed in the paediatric population according to a study conducted in Northern Queensland from 2001 to 2010 [22]. However, an increas in incidence was observed globally for *E. coli* bacteraemia especially in European countries [48, 49].

E. coli was noted to have a decrease in its susceptibility to gentamicin over the study period [20]. Crude mortality rate of *E. coli* bacteraemia was found to be around 10% [18].

Klebsiella spp. were found to be frequent pathogens causing gram negative bacteraemia in tropical Australia ranging between 3 and 18 per 100,000 per year during 1999 to 2019 [17, 18, 20, 22] (Table 1). A significant increase in the incidence of Klebsiella bacteraemia was reported from Northern Territory [17].

Burkholderia pseudomallei Bacteraemia

B. pseudomallei is an organism predominantly found in tropical and subtropical regions causing melioidosis. This has a strong seasonal preference, occurring in wet season [50]. Bacteraemia is a common consequence of melioidosis. In Northern Queensland and Northern Territory of Australia the incidence of *B. pseudomallei* bacteraemia ranged between 3 and 19 per 100,000 per year during 1998 to 2020 with an increase in incidence over that period [17, 18, 20, 28–30, 51] (Table 1). History of diabetes, excessive alcohol intake, immunosuppression, male sex, low socioeconomic status and wet season presentation were found to be associated with occurrence of *B. pseudomallei* bacteraemia [18, 28, 30].

Melioidosis leading to bacteraemia was significantly associated with ICU admission and mortality [30].

Non-typhoidal *Salmonella* (NTS) Bacteraemia

NTS is a common isolate among the immunocompromised patients and is the commonest gram negative cause of bacteraemia in sub-Saharan Africa where HIV prevalence is high [52]. There were few studies in tropical Australia that described NTS bacteraemia, with conflicting findings. There was an increasing trend over time in the incidence of NTS bacteraemia throughout all age groups, according to a study conducted in the Northern Territory [17]. But a paediatric study conducted within the same period in Northern Queensland revealed a declining trend [22]. There was an increase in the incidence of invasive nontyphoidal *Salmonella* (iNTS) in another study conducted in Queensland with high rates among males, infants, and elderly people [53].

Discussion

Bacteraemia is increasing worldwide. This review describes the recent trends of bacteraemia in Australian tropical regions, their outcomes and risk factors.

The common organisms causing bacteraemia did not change largely among the studies conducted in tropical regions of Australia over the past 2 decades. According to the reviewed studies, the major organisms causing bacteraemia were *S. aureus*, Group A *Streptococcus*, *S. pneumoniae*, *E. coli* and *Klebsiella* out of which, *S. aureus* and *E. coli* were the commonest [17, 18, 20]. Outside of Australia, *S. aureus* and *E. coli* dominated the temperate regions like Europe and North America, *E. coli* being the leading cause of bacteraemia in Europe and *S. aureus* being the leading cause of bacteraemia in North America [54].

MRSA bacteraemia has been increasing globally according to many of the studies reviewed. In addition, increasing incidence of community acquired MRSA was observed in tropical Australia. High rates of comorbidities and high number of people per household amongst other components of socioeconomic disadvantage in the Indigenous community could be possible explanations for this.

High incidence rate of GAS Bacteraemia was found to be an increasing burden to the health care system due to frequent life threatening complications and ICU admissions. Improving the socioeconomic status and preventive strategies for noncommunicable diseases especially among Indigenous people who are at high risk is a timely need in this regard. Declaring iGAS a nationally notifiable disease in Australia and the global efforts in development of a vaccine to prevent GAS infections are two affirmative initiatives currently [55].

An increasing global trend was reported for GBS infections as also reflected in this review [47, 56]. The switch from being a neonatal pathogen to an adult pathogen which was observed in tropical Australia could be due to the increasing incidence of comorbidities among older population. This trend was observed in global literature as well [47, 57]. As for many of the organisms discussed previously, an Indigenous predominance was observed for this organism too, which can be attributed to the high incidence of chronic illnesses like diabetes and obesity among Indigenous people [27, 58]. However, the fact that advanced age caused a tendency towards non-Indigenous cases reflected the probable increase in risk factors for GBS bacteraemia

among non-Indigenous and the relatively younger age distribution among Indigenous Australians.

S. pneumoniae which is a common organism causing bacteraemia in children and older adults was found to be decreasing in Australian tropical settings [17, 20, 22]. The introduction of an additional pneumococcal vaccine booster for Indigenous children which was implemented in year 2001 could be the likely reason for this [17]. Vaccine related decline of invasive pneumococcal disease in both children and adults was prominent in global literature too [59, 60].

E.coli and *Klebsiella spp.* were found to be the commonest gram negative organisms causing bacteraemia [17]. Both these organisms were observed to be increasing in tropical Australia during 1999 and 2019 [17]. Incidence of bacteraemia due to both these organisms increased with age in the global literature [61, 62]. Therefore, general increase in life expectancy and associated increase in comorbidities could explain the observed increasing incidence.

We highlighted increasing patterns of *B. pseudomallei* in this review. Similarly, it has been observed to be on the rise in several other tropical countries [63, 64]. Bacteraemia due to *B. pseudomallei* caused high healthcare burden with high ICU admissions and high mortality rates. As this organism is commonly found in soil and mud, preventive strategies at the community level such as educating people on wearing protective gear while working in high risk environments, especially during the wet season could be beneficial [65].

According to global evidence, NTS is a major cause of bacteraemia in African regions due to its strong association with HIV infection [66–68]. NTS bacteraemia rates are comparatively low in tropical Australia but have been increasing [17, 53]. This can be explained by the strong association of this disease with socio-economic status, poverty, poor housing conditions, food insecurity, chronic diseases and co-infections which are prevalent among the Indigenous community that is disproportionately distributed in Australian tropical regions [53].

Although this review described most epidemiological aspects relevant to bacteraemia in tropical settings of Australia, there were some limitations. Scarcity of research evidence on some organisms made it difficult to generalise the findings to the whole tropical Australia. Some studies were conducted at different time periods, making comparison difficult.

Conclusion and Recommendations

In conclusion, bacteraemia was found to be an increasing healthcare burden to the Australian tropical regions. Environmental factors unique to tropical regions partly contributed to this. The fact that tropical regions had a disproportionately high Indigenous population also caused tropical regions more vulnerable for high incidence of blood stream infections. Indigenous Australians were found to have higher incidence of bacteraemia irrespective of the causative organism, reflecting the socioeconomic disadvantages experienced by them. Measures to reduce the socioeconomic inequalities in tropical Australian settings is urgently needed. Vaccination as a public health measure was highly successful with a consistent decline in *S. pneumoniae* bacteraemia. Likewise, the importance of notification with regard to disease control showed this measure by increased reported cases.

Although a number of studies were conducted in tropical regions describing bacteraemia, inconsistent findings amongst the studies was common. This was probably due to differing methodology, different locations and different time periods. Ideally, linkage of existing data from healthcare settings could be utilised to obtain more accurate, comprehensive and up to date information of trends and patterns of bacteraemia.

Acknowledgements We thank Mr Stephen Anderson, the Research and Learning Librarian at James Cook University Townsville, Bebegu Yumba campus.The first author is funded by the Australian Institute of Tropical Health and Medicine and James Cook University, Australia PhD programme. We thank Dr. Rojelio Mejia for reviewing the paper.

Author Contributions HR and EM conceived the idea and design; created the manuscript outline. HR, EM, DE, OA, AP contributed to the method. HR wrote the introduction, methods section, results section, discussion and prepared the Table 1. EM, DE, OA and AP made critical comments, suggested final edits and revisions and supervised the writing. All authors reviewed and approved the final manuscript.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions
Open Access funding enabled and organized by CAUL and its Member Institutions

Data Availability No datasets were generated or analysed during the current study.

Declarations

Ethical Approval Not applicable.

Human and Animal Rights This article does not contain any studies with human or animal subjects performed by any of the authors.

Competing Interests The authors declare no competing interests.

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