

Environment and NTM

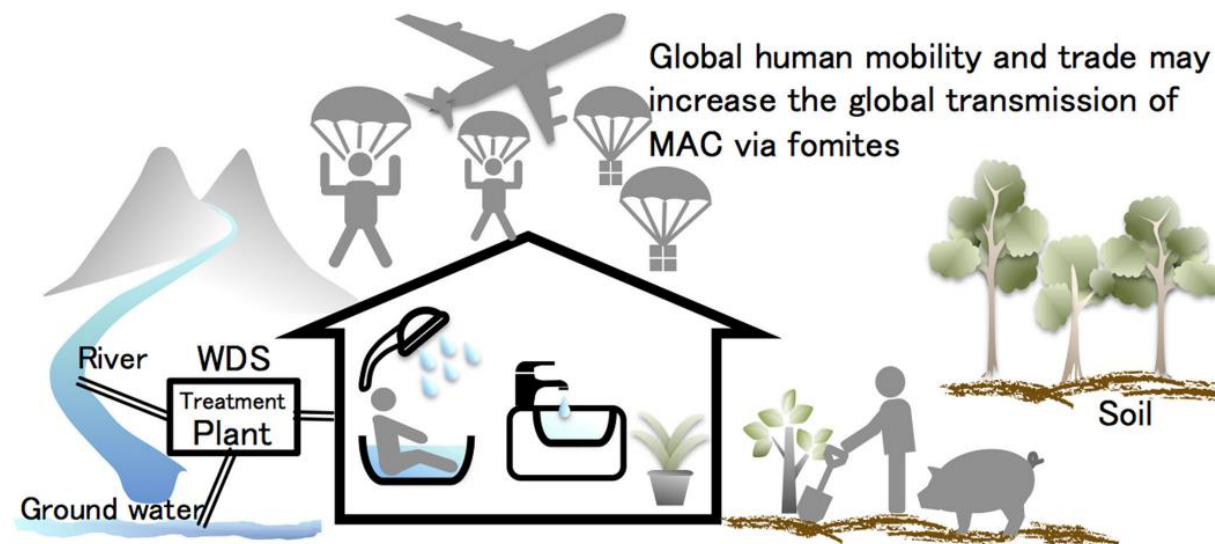
Prof Rachel Thomson

Greenslopes Clinical School

School of Medicine

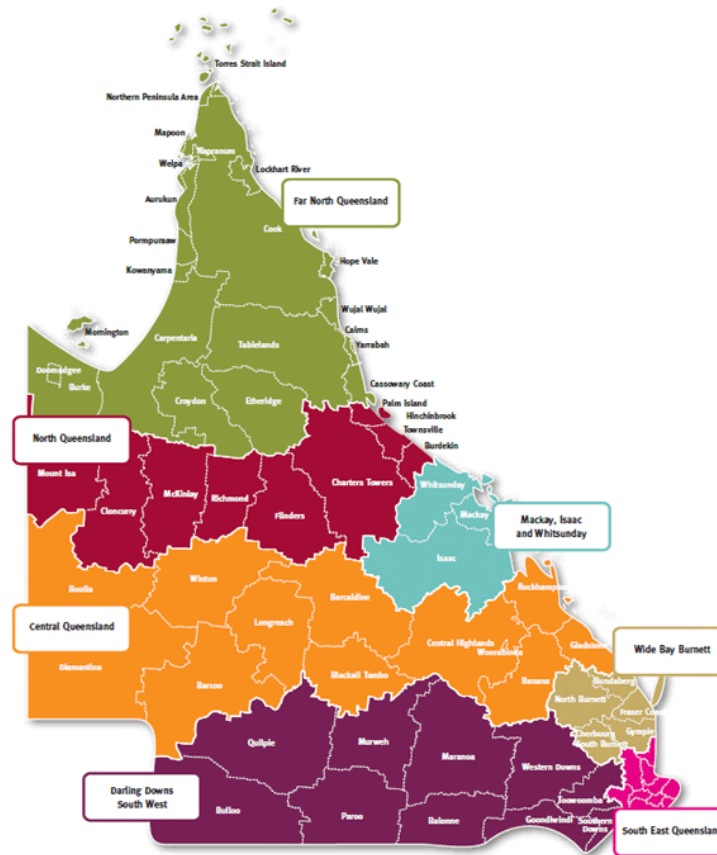
Introduction

- NTM are ubiquitous in the environment.
- Household and hospital tap water, bathrooms, potting soil, garden soil are household dust
- Mycobacterial transmission routes include aerosols from water, soil, dust and patients coughing
- Recent global increase in NTM diseases suggests that the transmission of NTM is likely to be linked with human activities.
- Understanding the geospatial epidemiology helps to inform potential sources of infection and outbreak investigation



Queensland

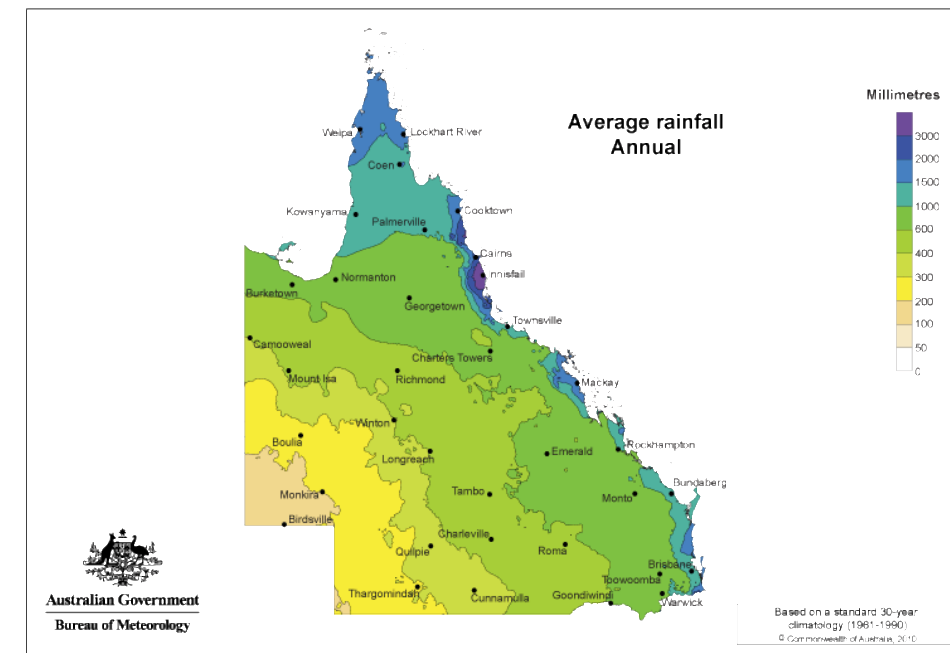
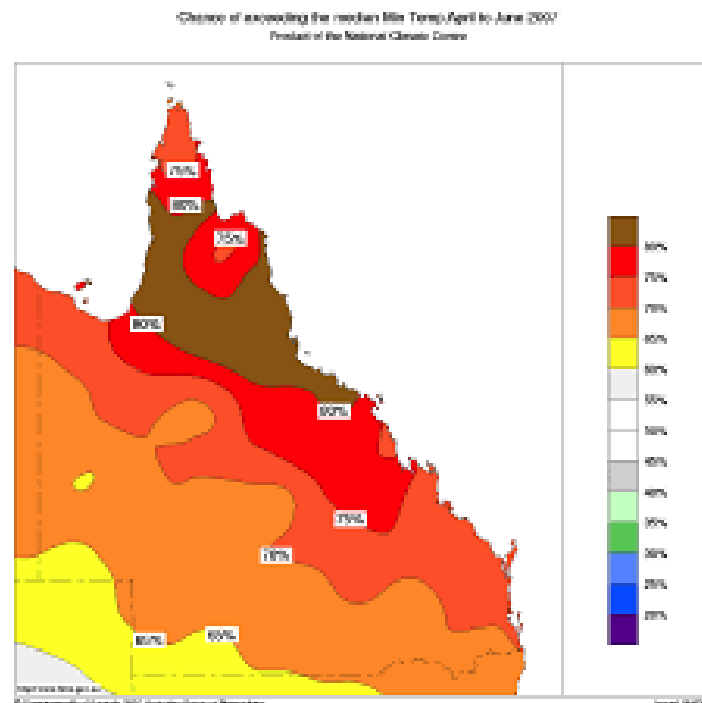
- ❖ located in the northeast of Australia
- ❖ area of 1,852,642 square kilometres (715,309 sq mi)
- ❖ world's sixth-largest sub-national entity, and is larger than all but 15 countries
- ❖ administratively divided into 74 local government areas and 423 postcodes.
- ❖ population 5.26 million people, heavily concentrated in SE and coastal cities/towns



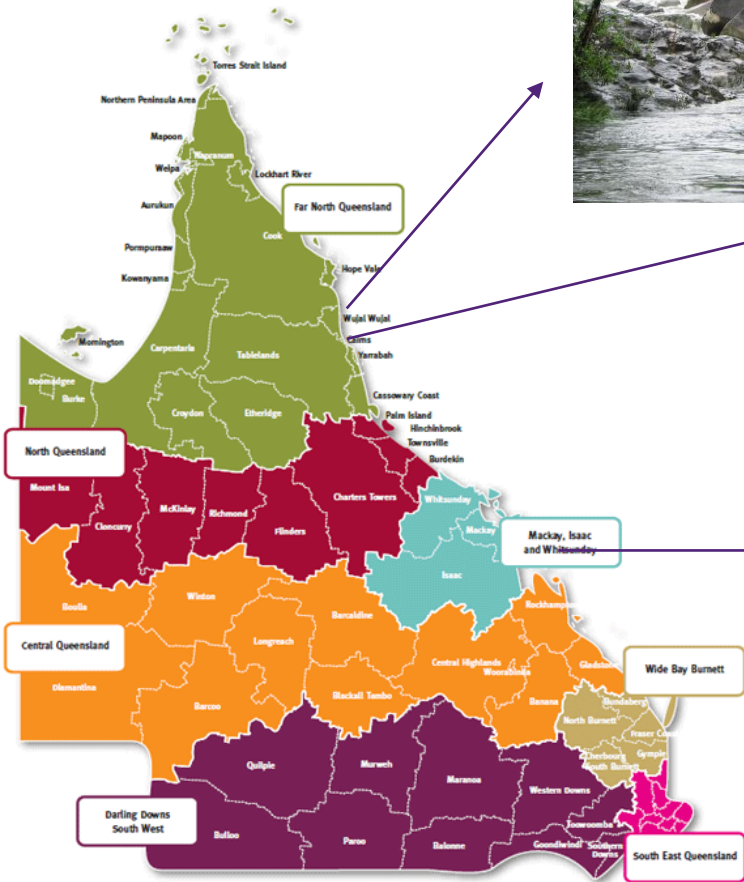
Climate

Due to its size, Queensland's geographical features and climates are diverse, including tropical rainforests, rivers, coral reefs, mountain ranges and sandy beaches in its tropical and sub-tropical coastal regions, as well as deserts and savanna in the semi-arid and desert climatic regions of its interior.

- ❖ northern Queensland is tropical and southern Queensland is sub-tropical.
- ❖ Most of the state experiences two distinct weather seasons: a warm summer with higher rainfall and a mild winter with lower rainfall



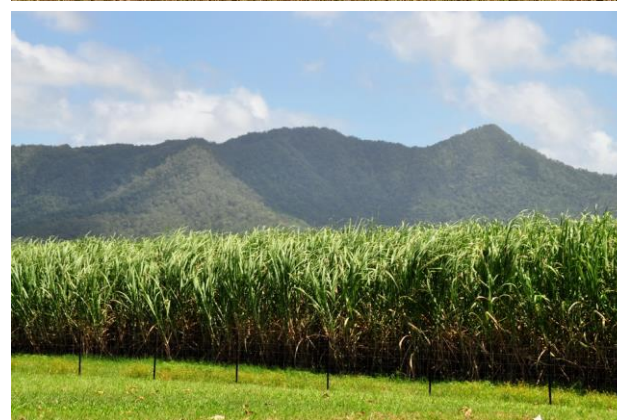
Diverse geographical features and climates



Mossman Gorge

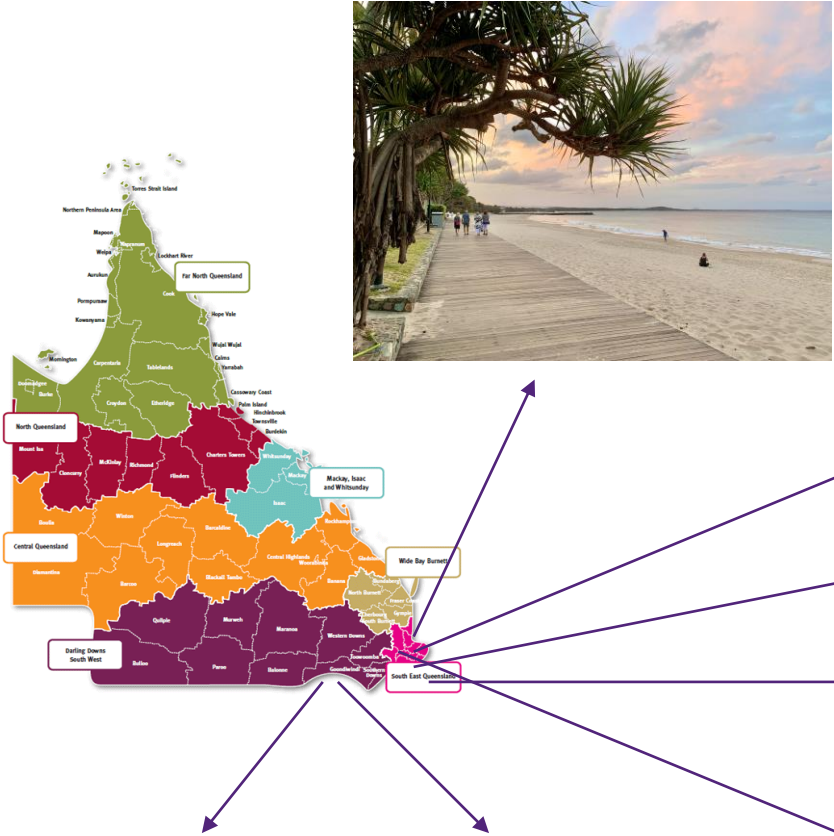


Great Barrier Reef

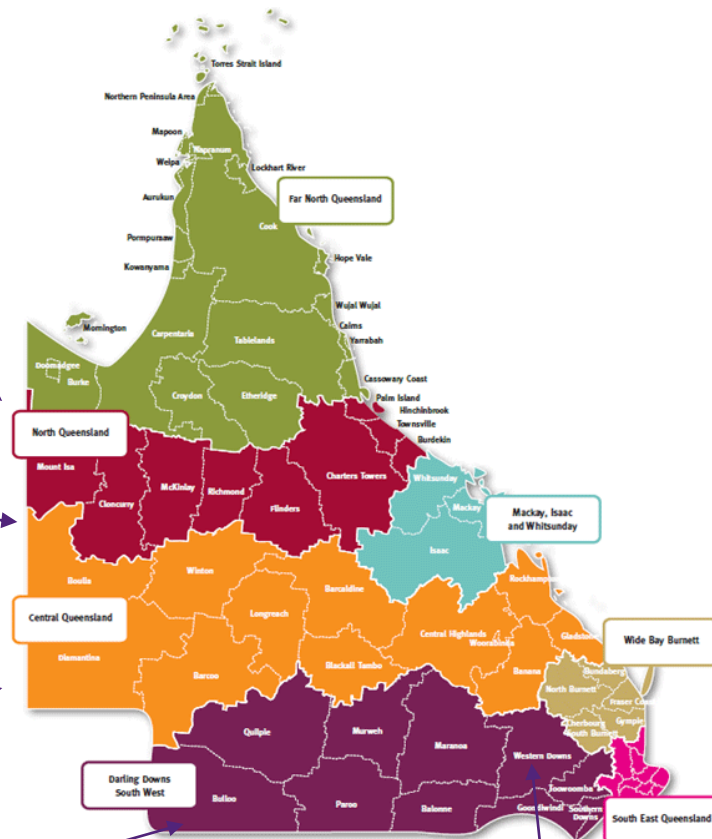


Whitsunday Islands

Brisbane and southeast



Central and West



Changing Epidemiology of Pulmonary Nontuberculous Mycobacteria Infections

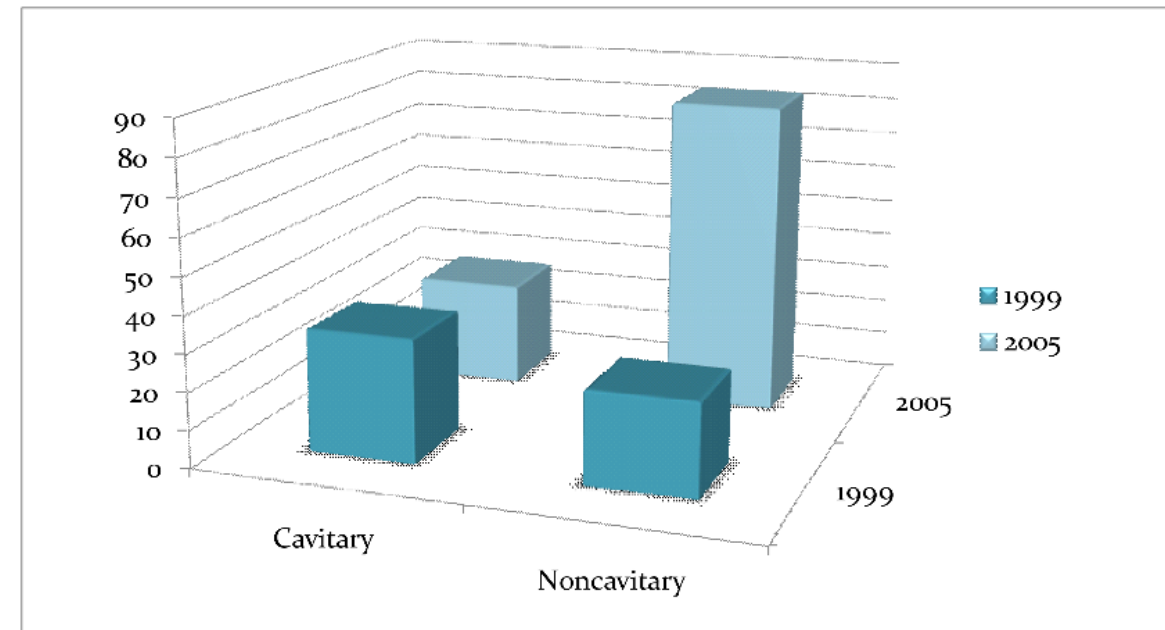
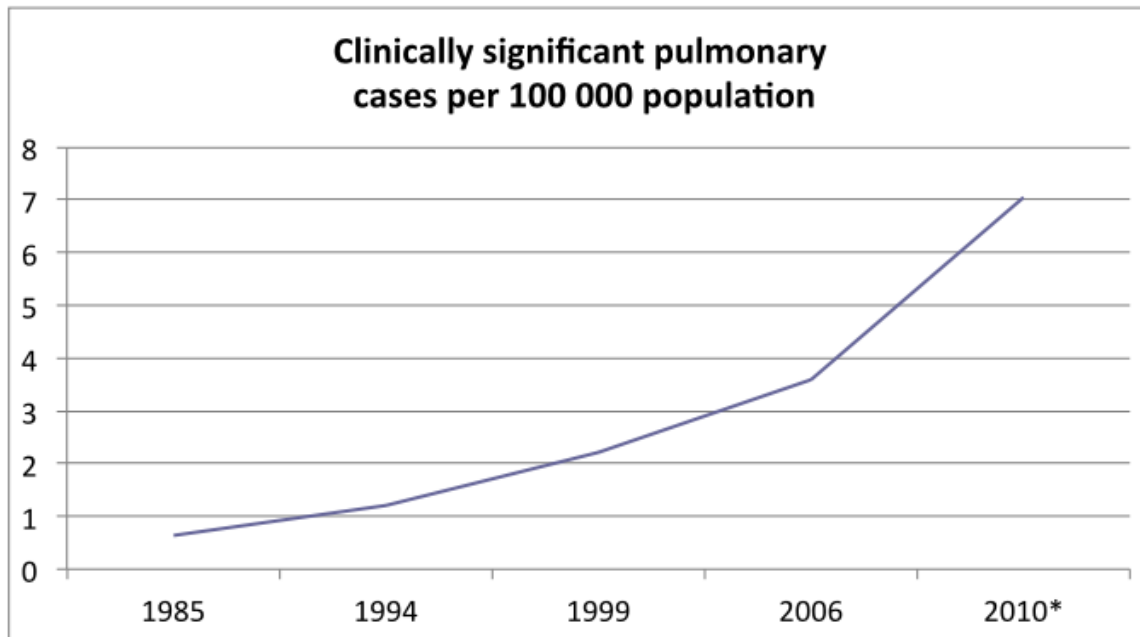
Rachel M. Thomson, on behalf of the NTM working group at the Queensland TB Control Centre and Queensland Mycobacterial Reference Laboratory

Emerging Infectious Diseases • www.cdc.gov/eid • Vol. 16, No. 10, October 2010

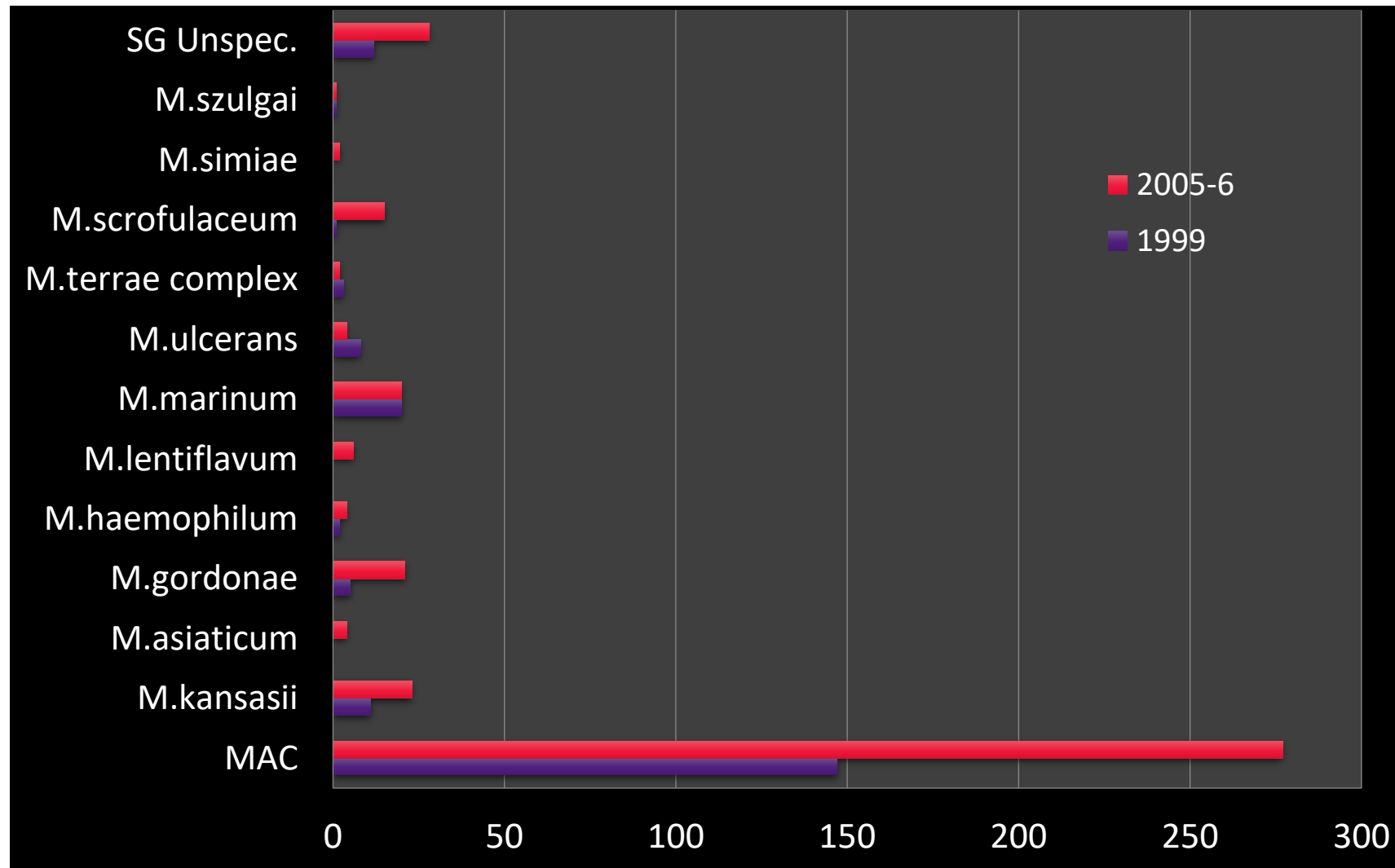
Notifiable conditions database

The state of Queensland in Australia has maintained a mandatory reporting scheme for NTM infections since the introduction of tuberculosis control around 1950.

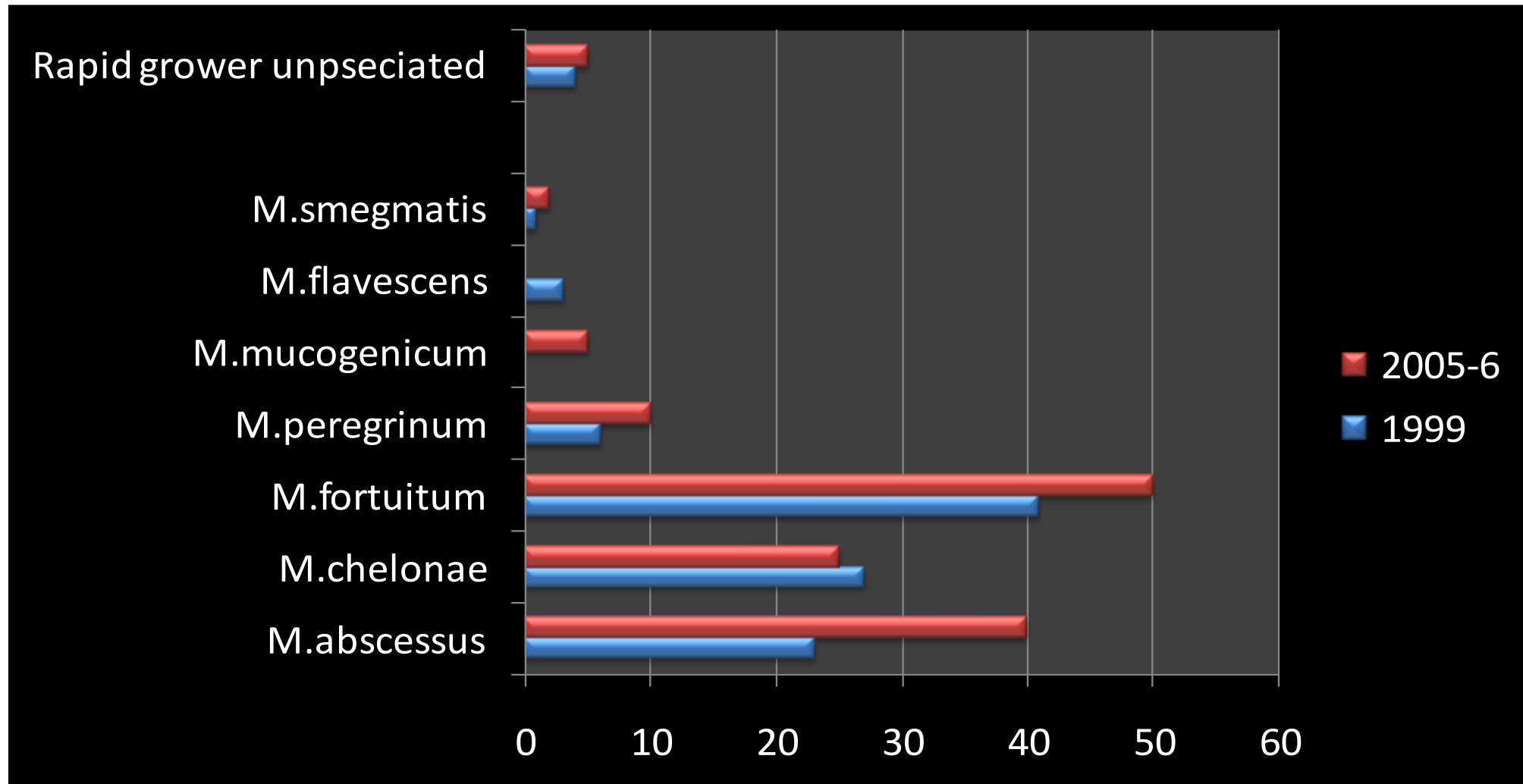
All NTM isolates are recorded in Queensland Health's Notifiable Conditions Database (NoCS)



Species changes – Slow growers



Species changes- rapid growers



RESEARCH ARTICLE

Open Access

A spatial epidemiological analysis of nontuberculous mycobacterial infections in Queensland, Australia

Michael P Chou^{1,4*}, Archie CA Clements¹ and Rachel M Thomson^{2,3}

NTM data QLD Mycobacterial Reference Lab 2001–2011

- Bayesian spatial conditional autoregressive model was constructed at the postcode level
- covariates incl soil variables, max, mean and min rainfall and temperature, income and land use category
- **distinct spatial clusters of *M. kansasii*, *M. intracellulare* and *M. abscessus* infections**
- number of **socio-ecological, economic and environmental factors** associated with NTM infection risk

NTM 2001-2011

Table 1 Descriptive statistics for NTM isolates from 2001-2011

Species	Count			Proportion of all isolates	Mean \pm SD (per postcode)	Range
	Total	Pulmonary	Extra- pulmonary			
<i>M. intracellulare</i>	2,306	2,184	122	34.9%	5.50 \pm 7.76	0–63
<i>M. avium</i>	674	599	75	10.2%	1.50 \pm 2.72	0–16
<i>M. fortuitum</i>	493	195	298	7.5%	1.10 \pm 1.92	0–13
<i>M. abscessus</i>	489	334	155	7.4%	1.16 \pm 2.01	0–17
<i>M. kansasii</i>	188	174	14	2.8%	0.45 \pm 1.17	0–15
<i>M. chelonae</i>	183	64	119	2.8%	0.43 \pm 0.95	0–9
<i>M. goodii</i>	162	146	16	2.5%	0.39 \pm 0.81	0–6
<i>Other</i>	1,357	909	448	20.6%	2.40 \pm 3.61	0–34
<i>Unspecified</i>	747	703	44	11.3%	2.39 \pm 3.59	0–31
<i>Total</i>	6,599	5308	1291	100.0%	2.55 \pm 4.96	0–63

Data sources

Income data: 2010–11 Australian Bureau of Statistics (ABS); based on the classifications ABS Percentage < \$32 000 reflected relative disadvantage and < \$52 000 is related to the average annual income of \$51 923 for Australians in 2010–11.

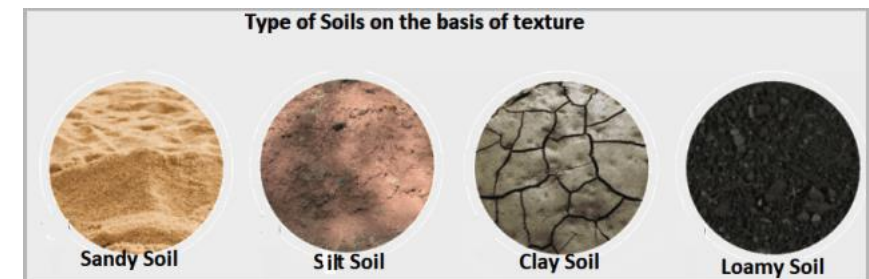
Indigenous and labour data : Office of Economic and Statistical Research

Weather data: Thirty arcsecond resolution raster data for maximum, minimum and mean temperature and rainfall: WorldClim database.

Soil characteristics (permeability, depth, drainage, pH, nitrogen, phosphorus, bulk density, and composition), with a 1 km resolution: Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australian Soil Resource Information System.

Layer A (surface layer, or topsoil) variables were used because this layer interfaces directly with human contact and activity.

Soil composition classification data were refined for categorical analysis into their predominant base **soil types - sand, clay, peat and loam**.



Results

Each species of NTM showed distinct spatial patterns.

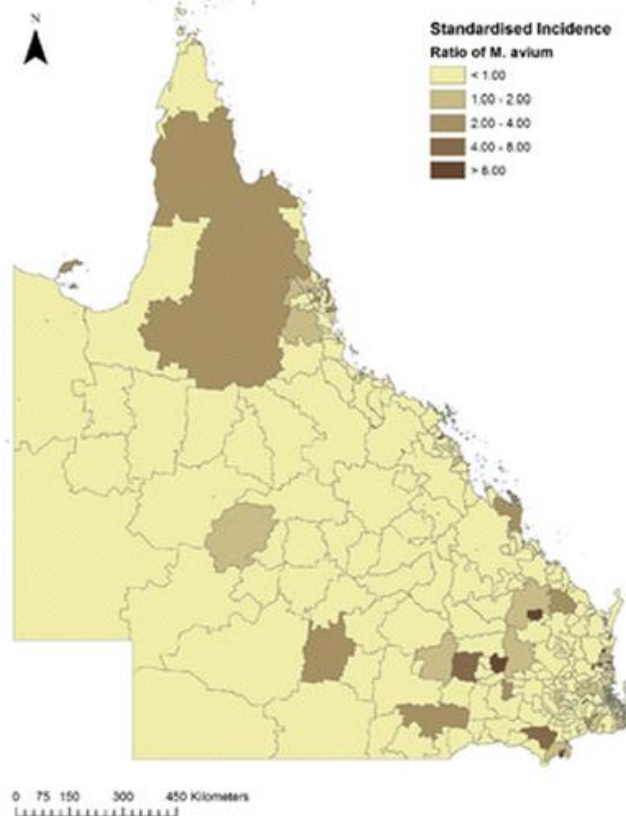
- For four NTM species – *M. abscessus*, *M. avium*, *M. intracellulare* and *M. kansasii* – the models with the best fit included those with a spatially structured component
- **indicated that risk of infection with these four NTM species demonstrated significant spatial heterogeneity** after accounting for the covariates in the models
- number of socio-ecological, economic and environmental factors associated with NTM infection risk
- among the other NTM species where the models did not support evidence of spatial heterogeneity:
 - **soil pH** identified as a significant predictor variable for *M. fortuitum* (RR 21%; 95% CI 1-45%)
 - **soil nitrogen content** found to be a significant predictor variable for *M. chelonae* (RR 24%; 95% CI 3-50%).

M. intracellulare

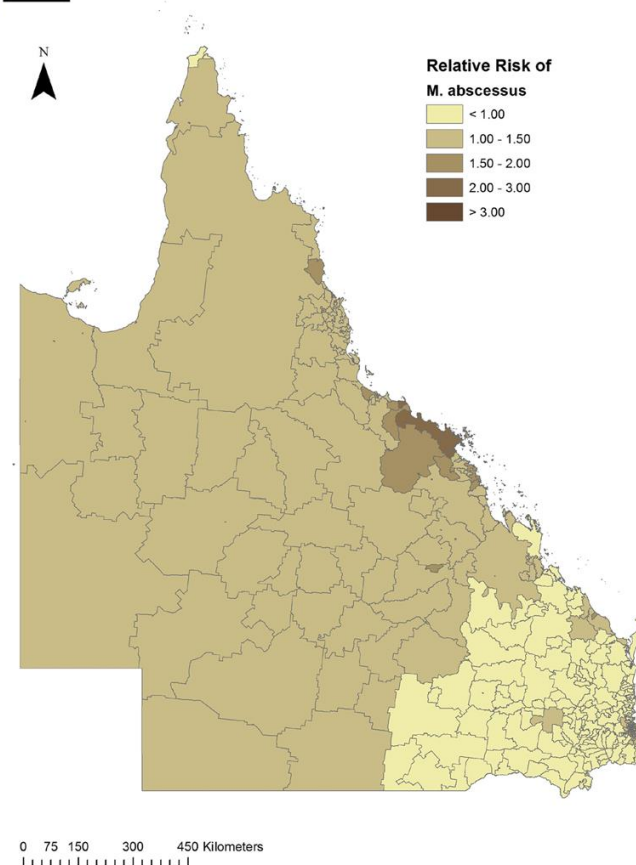
- Risk estimated to increase by 21% per % increase of population earning < \$52,000
- Risk correlated with a shallower soil depth- decreased by 13% for every metre increase of topsoil depth



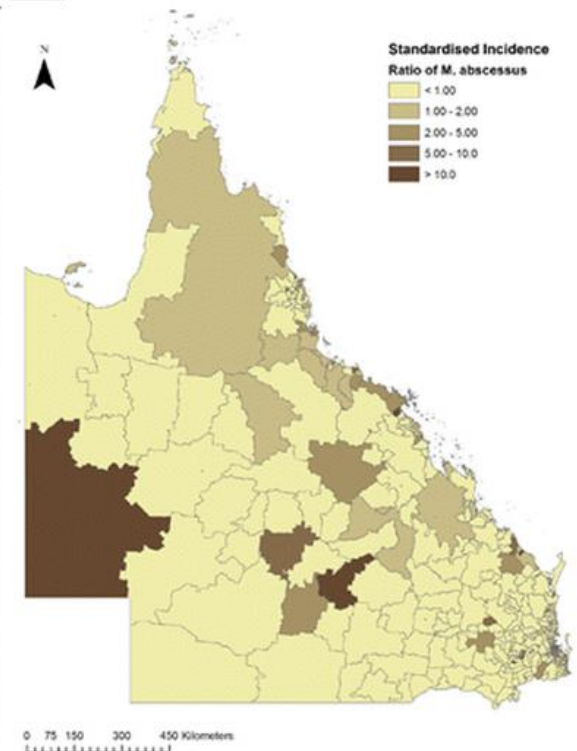
Standardized incidence ratios



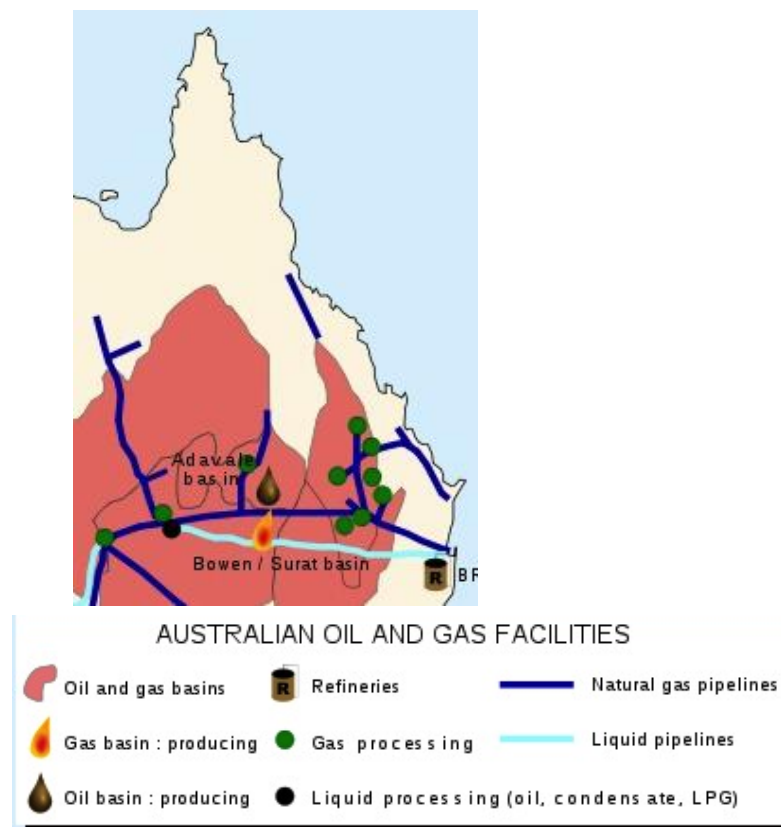
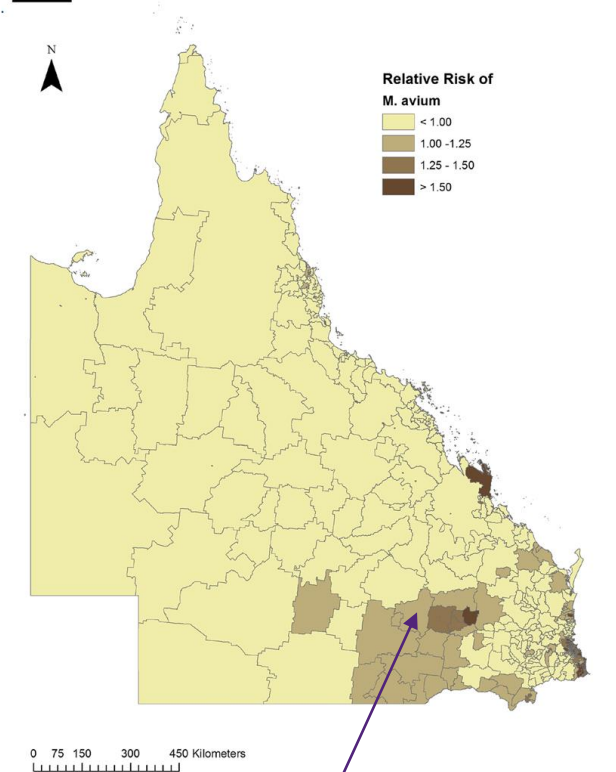
Relative risk attributable to spatial factors



A *M. kansasii*



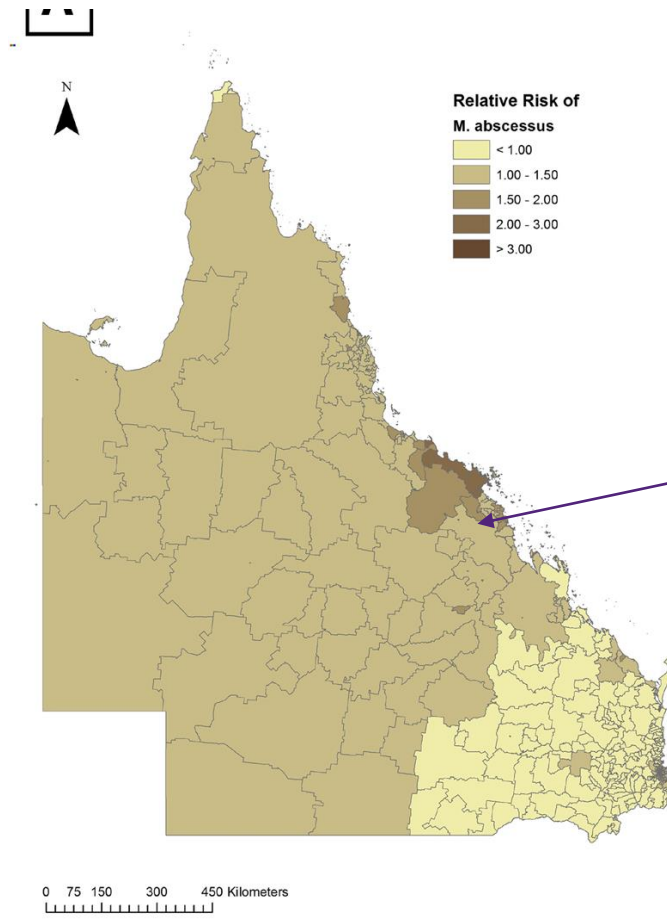
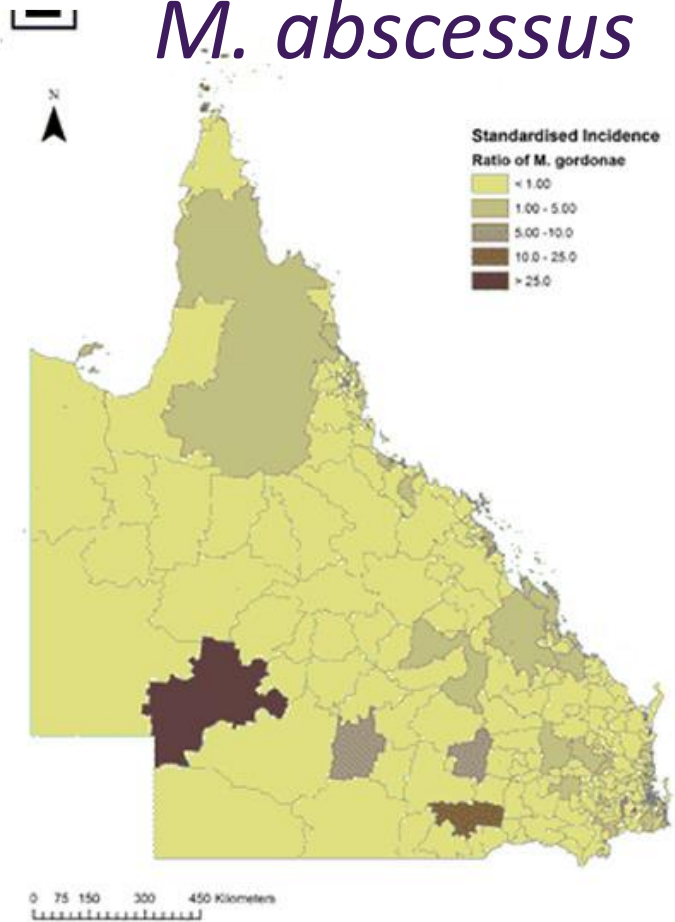
B



- Risk est to ↑ by 79% per mg/m³ increase of soil bulk density; to ↓ by 19% for every % ↑ in pop'n earning < \$32,000.
- RR was 75 X higher than average (p < 0.05) in postcodes containing the towns of Clifford and Yuleba, nearby to Roma.

- Yuleba – major processing facility for silica deposits
- Roma- first site of gas discovery 1906; open cut coal mining
- Oil and gas facilities overlying Surat basin
- Agricultural and mining activities, petroleum and coal seam gas wells
- Water supply- private/communal bores, aquifers, rainwater tanks

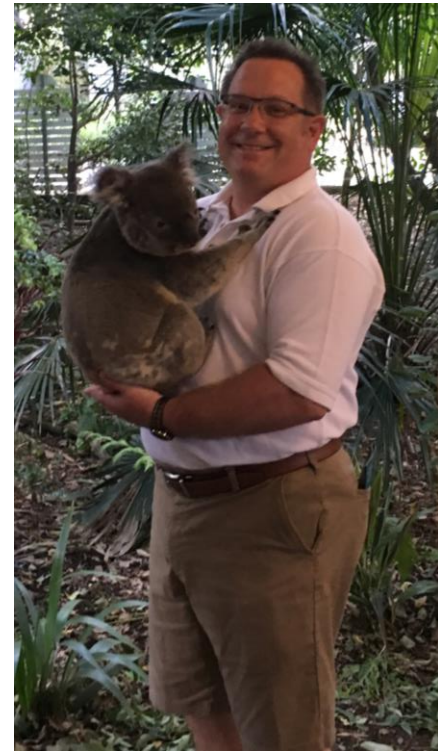
M. abscessus



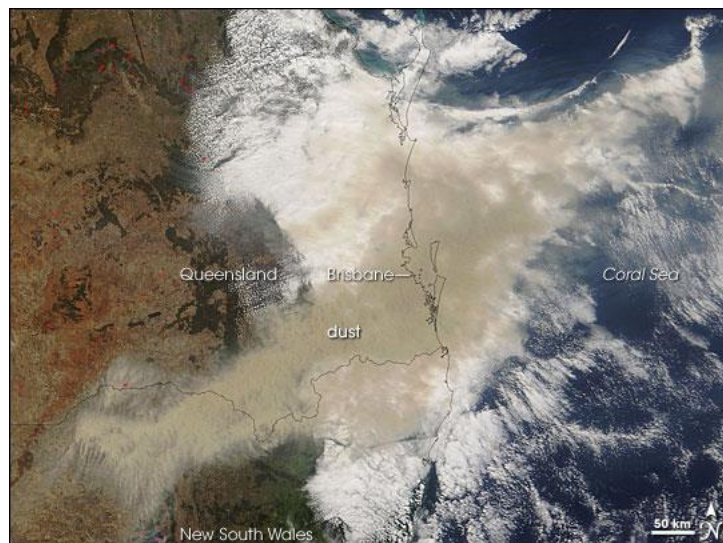
Airlie Beach, Whitsunday Islands



- Jacobs -positive correlations with water temperature, nitrogen and phosphorus content; negative correlations with depth and salinity.
- Soil nitrogen and phosphorus content was not associated with *M. abscessus* in our analysis.



Major weather events and climate?





Influence of climate variables on the rising incidence of nontuberculous mycobacterial (NTM) infections in Queensland, Australia 2001–2016

Rachel M. Thomson ^{a,*}, Luis Furuya-Kanamori ^b, Cushla Coffey ^b, Scott C. Bell ^c, Luke D. Knibbs ^d, Colleen L. Lau ^b

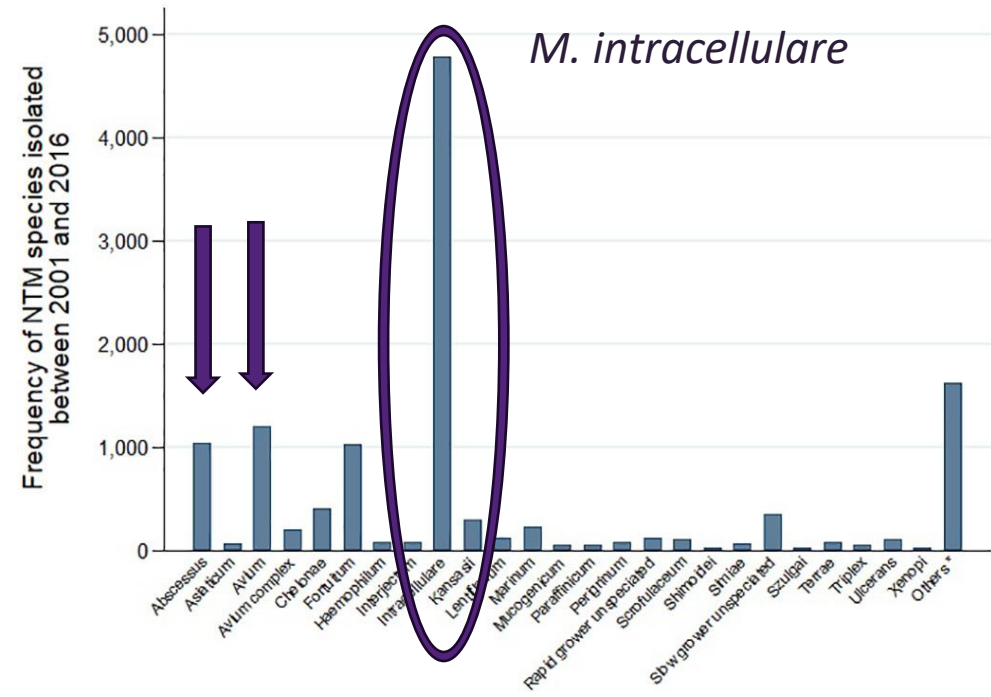
- 16 regional Hospital and Health Services (HHS).
- average rainfall and temperature: national network of weather stations operated by the Australian Bureau of Meteorology
- Monthly rainfall and temperature (maximum and minimum) point data were extracted from the nearest available weather station adjacent to selected urban centres.
- Maximum and minimum temperatures were strongly correlated - only included maximum temperature in the analysis because previous studies suggested that warmer temperatures may be more conducive for environmental survival of NTM
- higher temperature in municipal water pipes may allow greater degradation of disinfectants, leading to enhanced growth of mycobacteria in pipe biofilm
- Point rainfall and temperature data were aggregated per HHS and month for analysis.
- Data on dust was obtained, insufficient resolution for meaningful analysis

Analysis

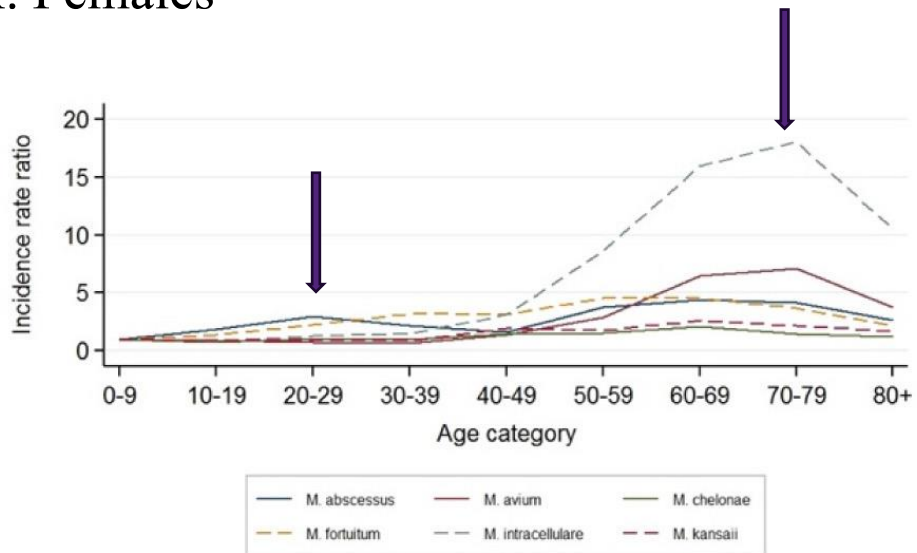
- **Poisson regression models using robust standard errors and the total HHS population as the exposed population at risk were used to estimate the notification rates per 100,000 population and the incidence rate ratios (IRRs) by sex, age, and HHS.**
- **Analyses were conducted for:**
 - 1) **total NTM** notifications,
 - 2) **individual NTM species** (the three most common slow-growing (SGM) [i.e. *M. avium*, *M. intracellulare*, *M. kansasii*] and the three most common rapid-growing (RGM) [i.e. *M. abscessus*, *M. chelonae*, *M. fortuitum*] NTM species), and
 - 3) for **all slow-** and **all rapid-growing NTM species** to examine if there were differences in notifications rates by sex, age, and HHS over time between the NTM species.

Epidemiology 2001-2016

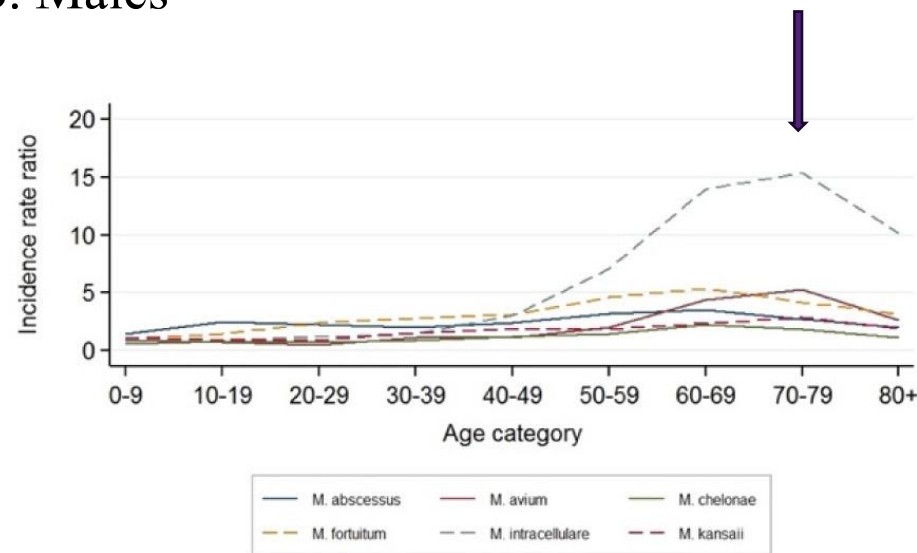
- 12,219 cases of NTM in patients > 18 years 2001-2016.
- median age 66 years (IQ range 53–75 years)
- 49.9% male
- estimated incidence rate increased 2.3-fold from 11.10 per 100,000 in 2001 to **25.88 per 100,000 in 2016**
- IRRs for all NTM species significantly increased with age
- highest IRR observed in those 50-79yrs
- IRR for *M. intracellulare* increased markedly with age compared to other species



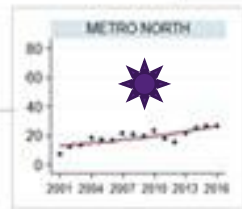
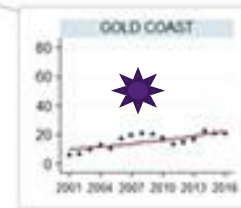
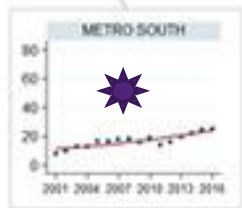
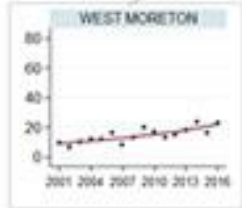
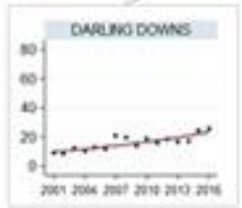
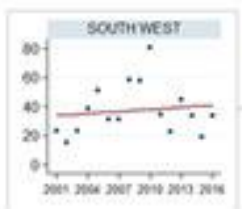
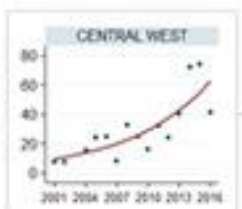
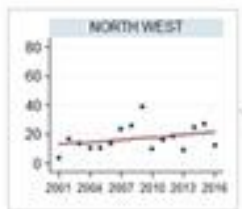
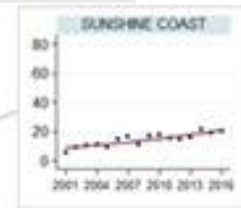
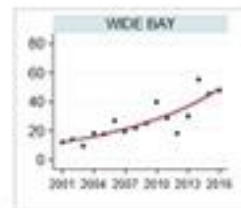
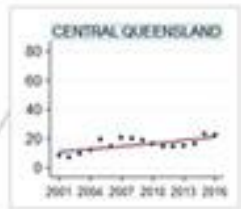
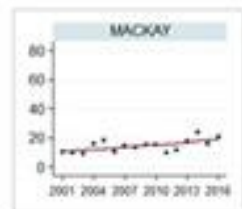
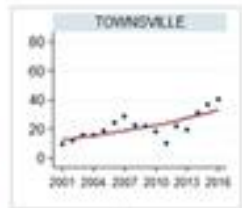
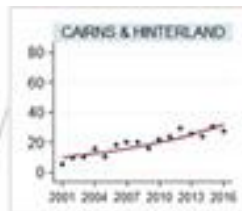
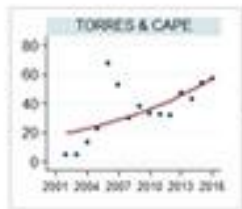
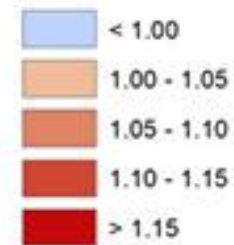
A. Females



B. Males



Incidence rate ratio



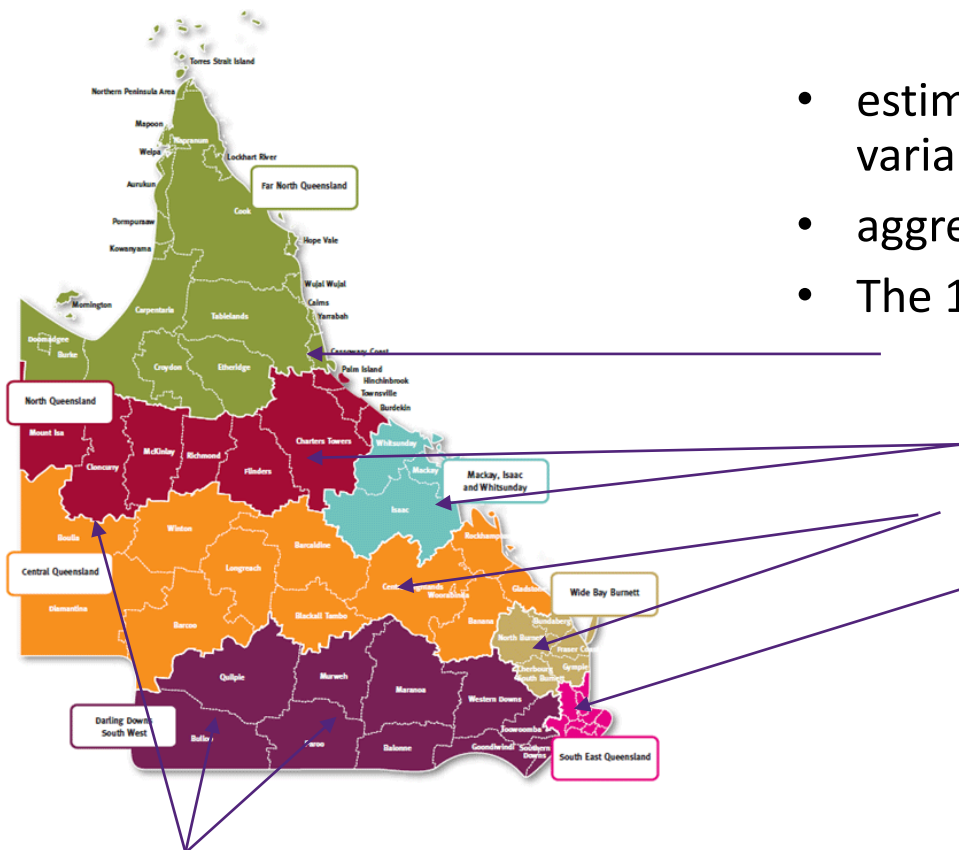
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Cross-correlation coefficients (CCF)

Used to examine the correlation and lag value (in months) between NTM incidence and environmental factors using the temporal trend data.



- estimated using continuous variables (NTM incidence and environmental variables)
- aggregated by month, year, and HHS.
- The 15 HHS were grouped into 5 HHS regions based on climatic similarities.

1) North region (Torres & Cape and Cairns & Hinterland);

2) North East region (Townsville and Mackay)

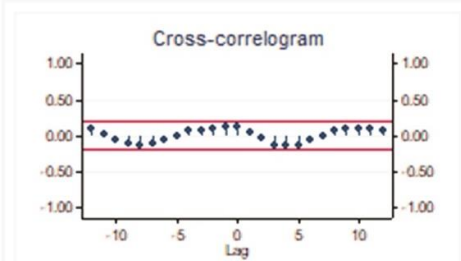
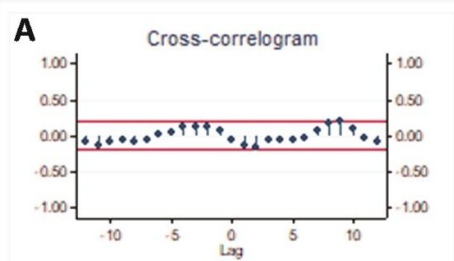
3) East region (Central Queensland, and Wide Bay)

4) South East region (Sunshine Coast, Metro North, Gold Coast, Metro South, and West Moreton)

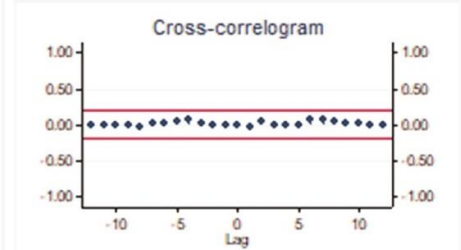
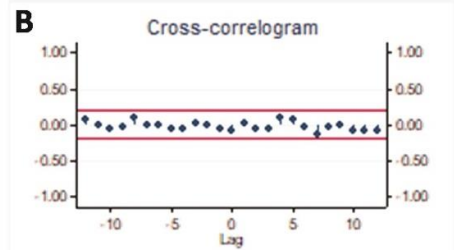
5) **West** region (Darling Downs, South West, Central West, and North West).

Cyclical incidence relative to peaks in Temp and rainfall

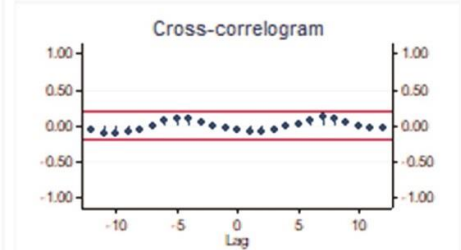
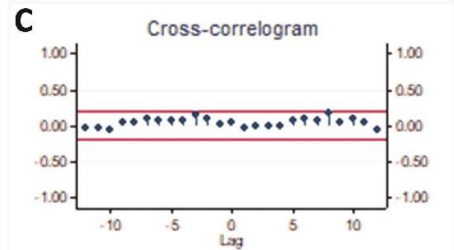
North



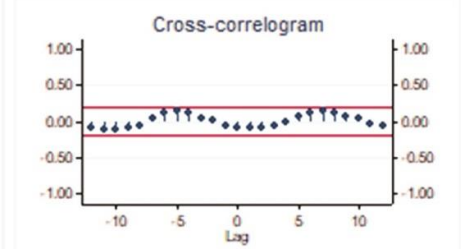
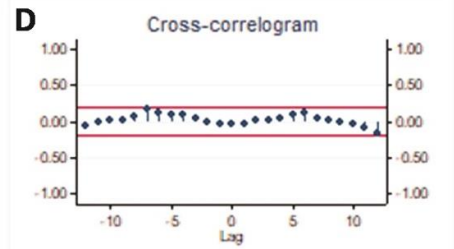
North East



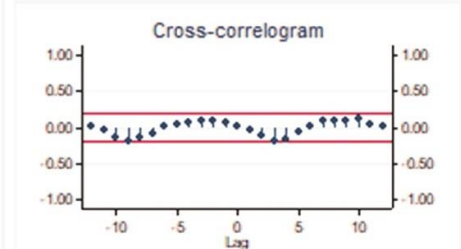
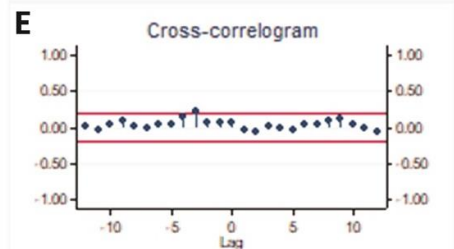
East



South East



West



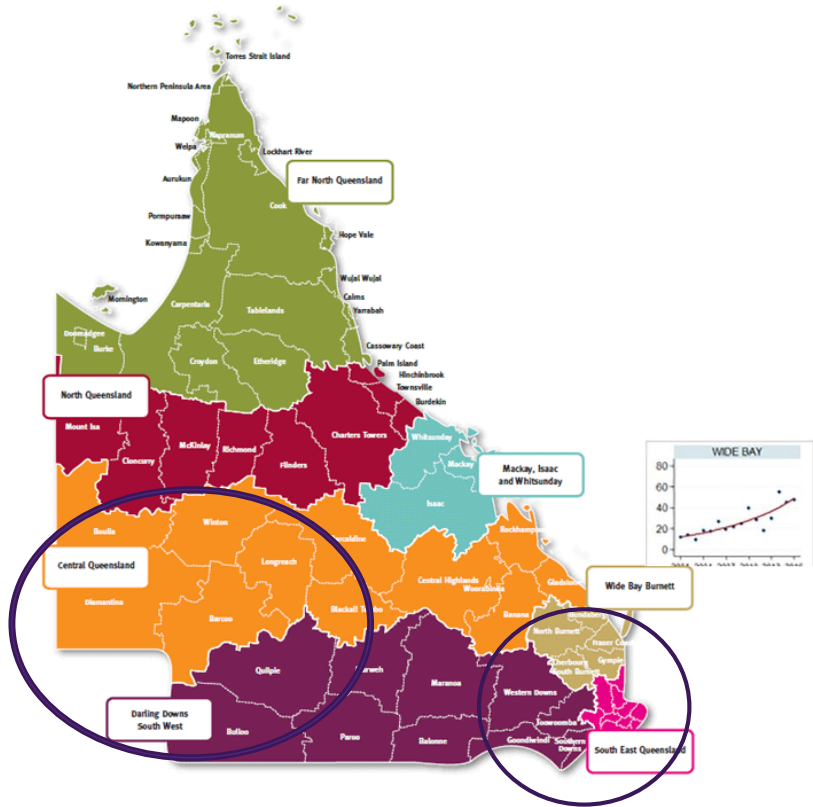
The effects differed between the more tropical regions of the north compared to the more arid regions of the west.

Temperature was not significantly associated with overall NTM incidence; however, there was a trend towards a cyclical incidence in NTM isolation relative to peaks in temperature as noted by the wave forms in the cross correlograms.

The Y-axis represents the cross-correlation coefficient, values above zero indicate a positive or direct correlation, a value of zero indicate no correlation, while values below zero indicate a negative or inverse correlation between the NTM incidence and the environmental variables.

Rainfall

Hypothesis: increases in rainfall would reduce dust/soil associated NTM in the air and lead to a reduction in incidence



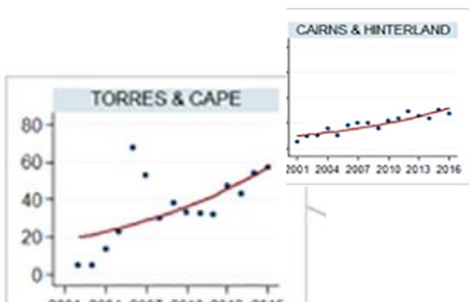
2009 dust storm



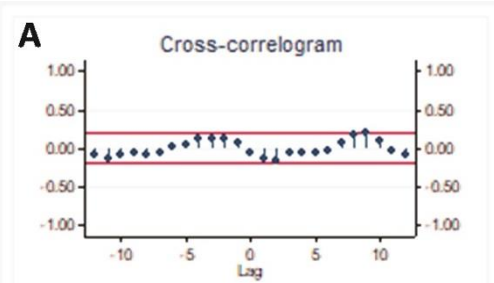
2011 flood

A decrease in overall NTM incidence, particularly *M. avium*, was seen in the more arid West region 4 months after an increase in rainfall.

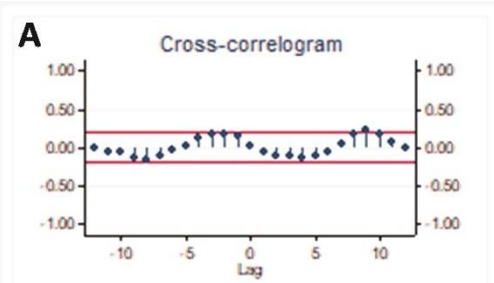
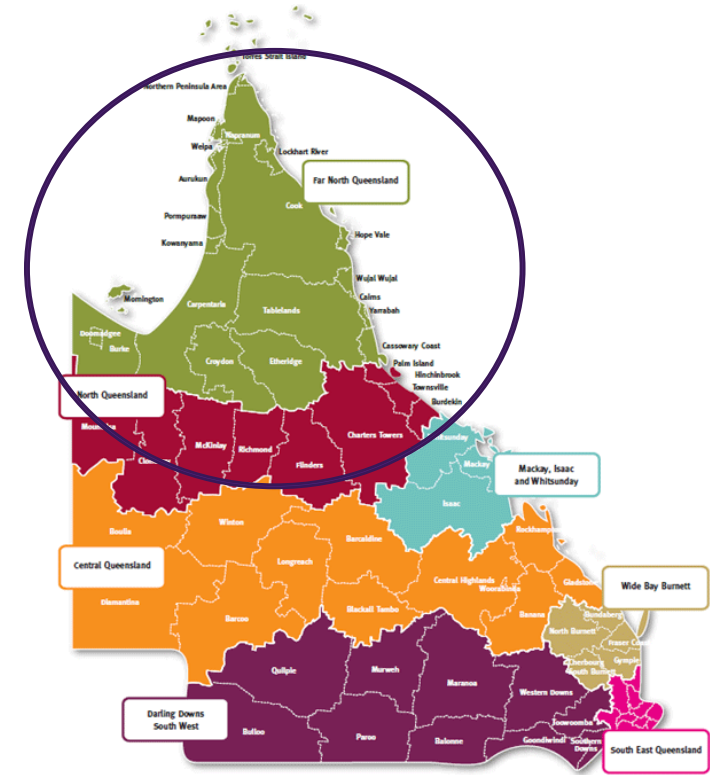
M. abscessus incidence decreased 7 months after an increase in rainfall in the South East



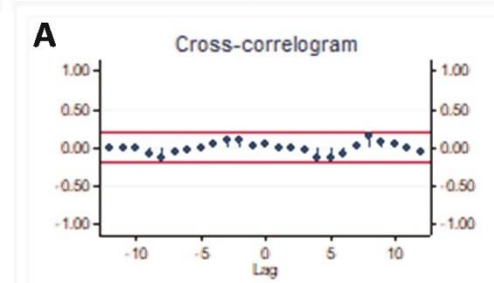
Rainfall



In the northern tropical region, overall NTM incidence was **positively correlated** with rainfall at a lag of 9 months, indicating that **NTM incidence increased 9 months after the rainy season.**

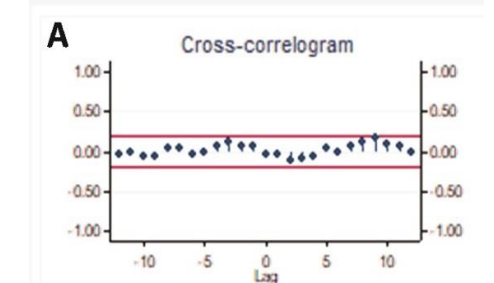


This was largely driven by the change in **slow growing species**, that increased 8-10 months after increased rainfall

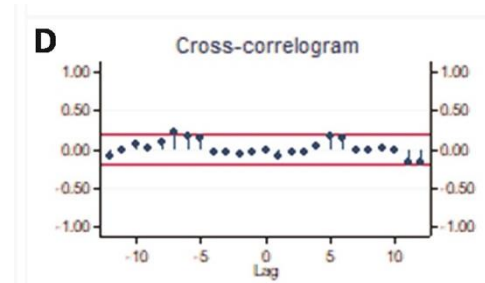


M. intracellulare

The rapid growing species trended towards an increase in the 4–5 months after the rainfall, then dropped significantly at 11–12 months.



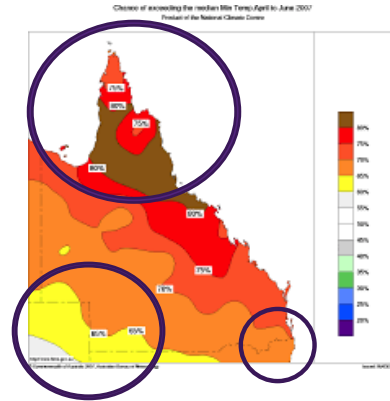
M. avium



Temperature

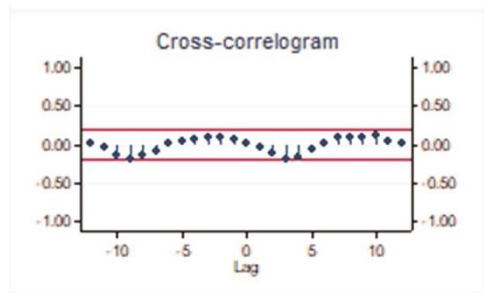
The most clinically relevant observation was in the North regions, where a significant decrease in rapid growing species, in particular *M. abscessus* incidence occurred 6 months after after an increase in temperature.

This trend was also observed in the South East.

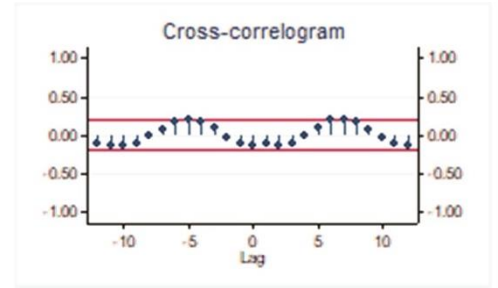


In the West region, the trend was more towards decreased NTM incidence at around 3 months after peak temp for all NTM species

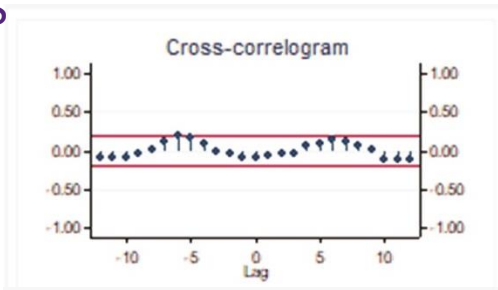
West- all NTM



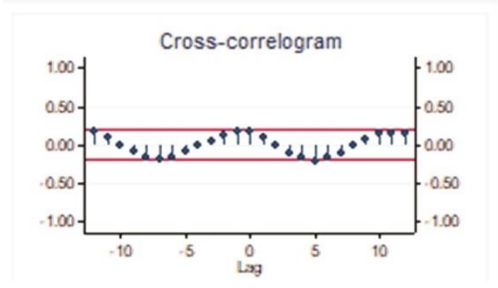
North RGM



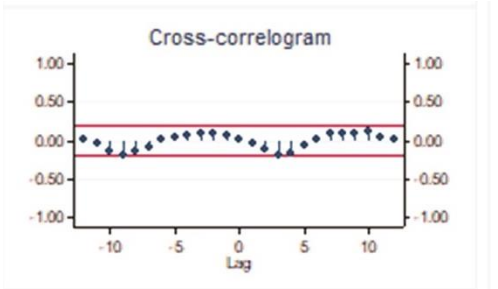
North MABS



North SGM



South East

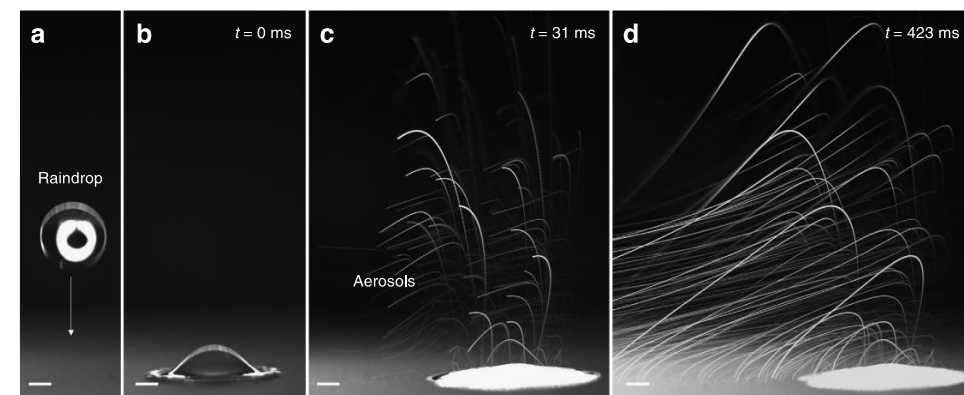
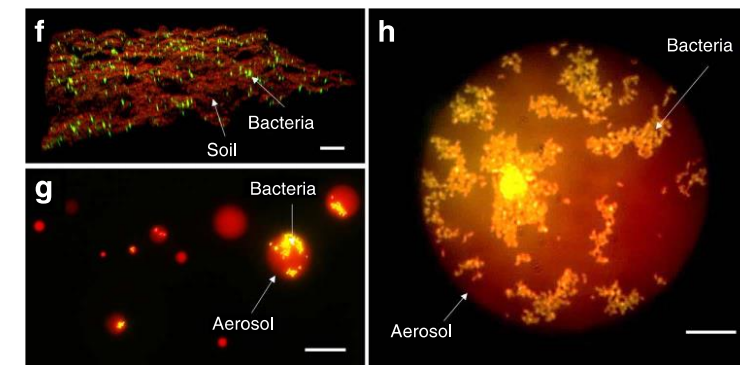


Alternative hypothesis

possible that pathogens in the soil may be disrupted by the physical action of raindrops, potentially leading to a more immediate spike in air contamination.



This region is renowned for cyclones and heavy storms and high humidity - enhanced dispersal and transport of bioaerosols



ARTICLE

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OPEN

Bioaerosol generation by raindrops on soil

Young Soo Joung^{1,2}, Zhifei Ge¹ & Cullen R. Buie¹

Conclusions and limitations

- Ambient temperature, heavy rainfall, flooding and drought are likely to influence the prevalence of environmental organisms.
- lag period between exposure and disease presentation
- It is only in patients where NTM isolation in sputum reflects contamination (rather than chronic invasive disease) that recent exposure could account for a positive test.
- use of aggregated NTM data by HHS may have masked associations between NTM and climatic variables at finer spatial and temporal resolutions. The artificial nature of HHS boundaries may also have affected observed associations and spatial patterns
- Confounding this is human behaviour during weather events – e.g. time spent indoors during rain or extreme heat.
- possible relationship between weather and host susceptibility, e.g seasonality of Vitamin D levels, overall host immunity is thought to be lower in winter months due to reduced UV exposure

Environmental epidemiology informs potential sources of infection

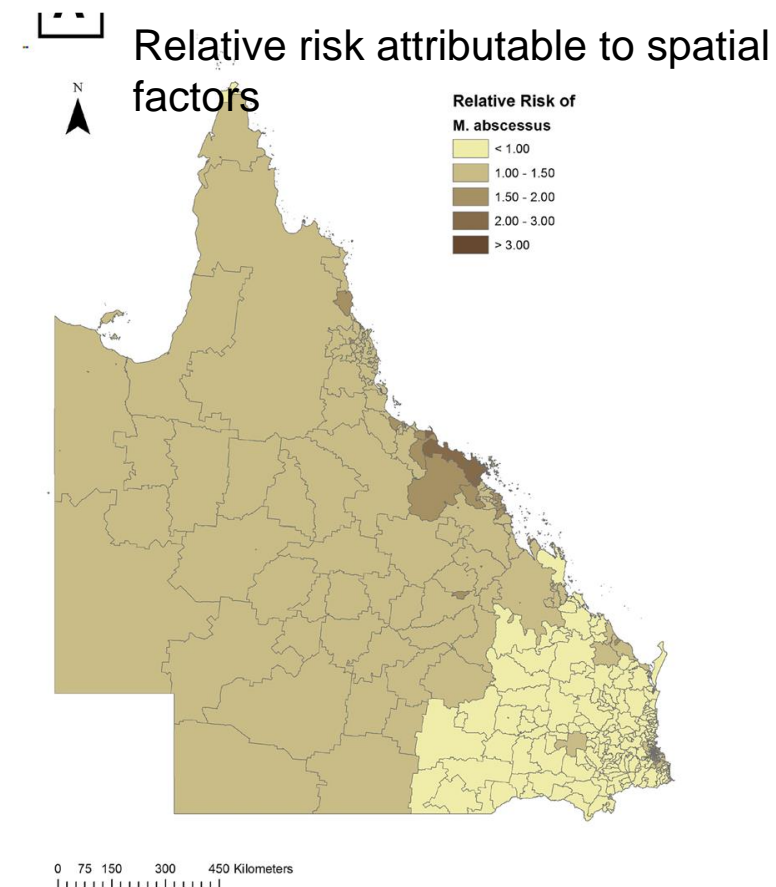
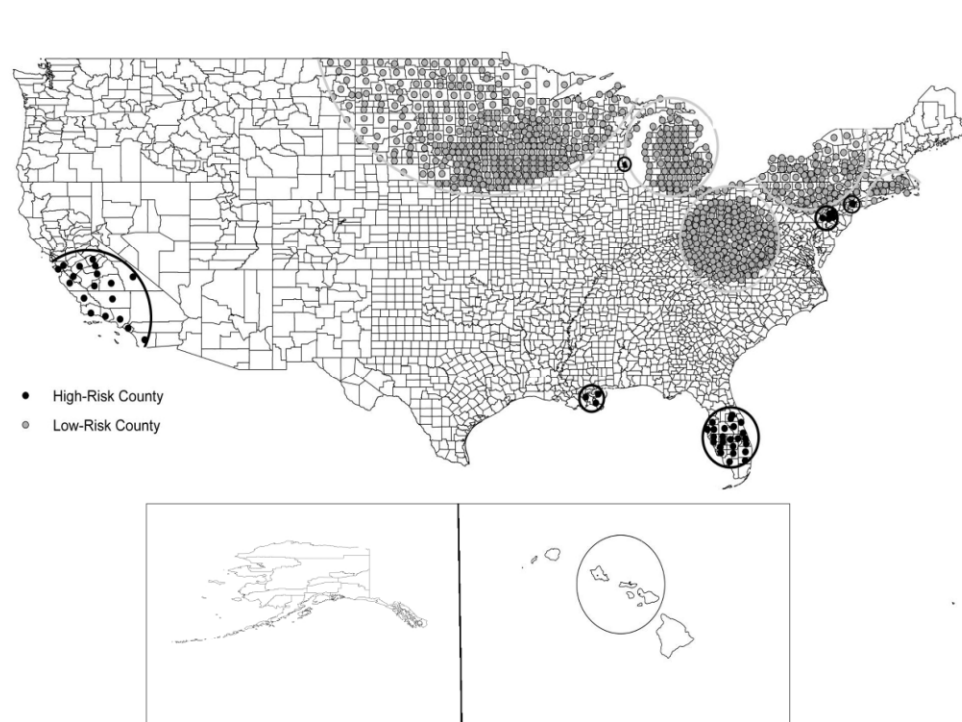


Figure One - Significant clusters of counties identified by SaTScan as being at either high- and low-risk for PNTM disease among U.S. Medicare beneficiaries aged ≥ 65 .

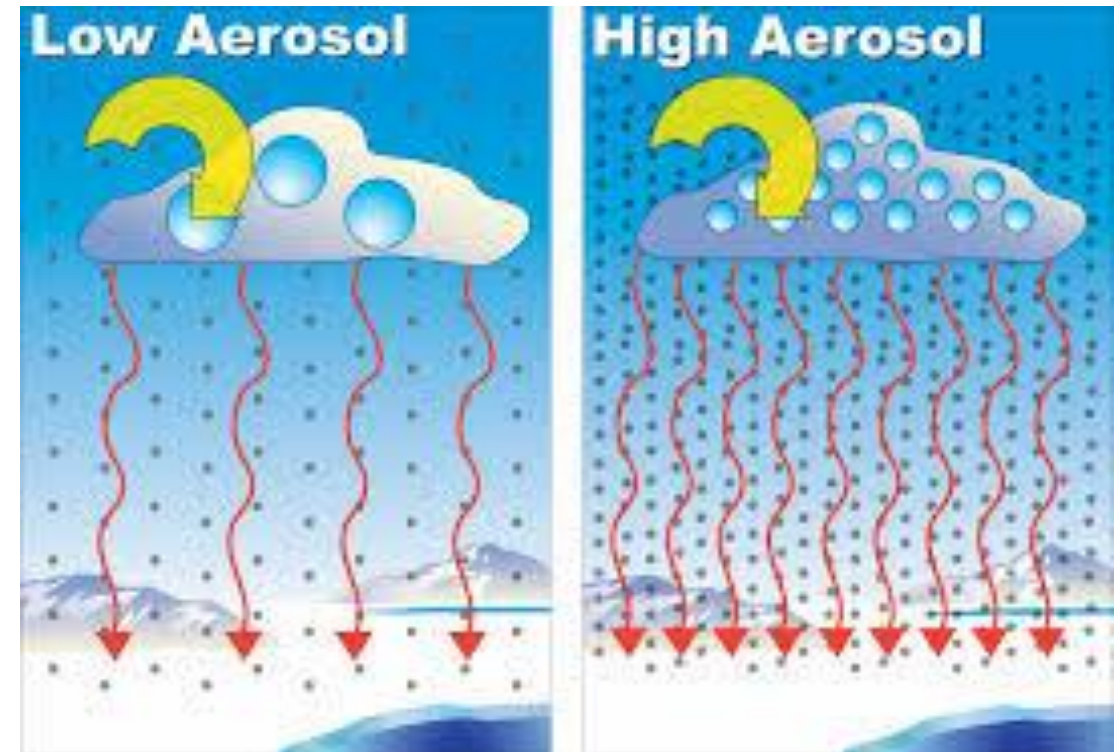
Adjemian J, et al. Spatial Clusters of Nontuberculous Mycobacterial Lung Disease in the United States. *AJRCCM* 2012 Vol 186

Chou M, Clements A, Thomson R. A spatial epidemiological analysis of nontuberculous mycobacterial infections in Queensland, Australia. *BMC Infectious Diseases*. 2014;14:279.

NTM risk

Table 3. Multivariate logistic regression model of environmental and socioeconomic factors significantly associated with high-risk counties for PNTM disease among U.S. Medicare beneficiaries aged ≥ 65 years relative.

Variable	Adjusted Odds Ratio (95% Confidence Interval)	p-value
Population per square mile (per 100 person increase)	1.4 (1.1-1.7)	0.003
Median household income (per \$1,000 increase)	1.4 (1.1-1.8)	0.004
Proportion of area as surface water (per 10% increase)	4.6 (1.5-14.6)	0.009
Mean daily potential evapotranspiration (per 0.1 mm increase)	4.0 (1.6-10.1)	0.004
Copper soil levels (per 1 ppm increase)	1.2 (1.0-1.4)	0.008
Sodium soil levels (per 0.1 ppm increase)	1.9 (1.2-2.9)	0.004
Manganese levels (per 100 ppm increase)	0.7 (0.4-1.0)	0.03



Evapotranspiration- a measure of the atmosphere's ability to remove water from the surface through the processes of evaporation and transpiration and convert it to atmospheric water vapor

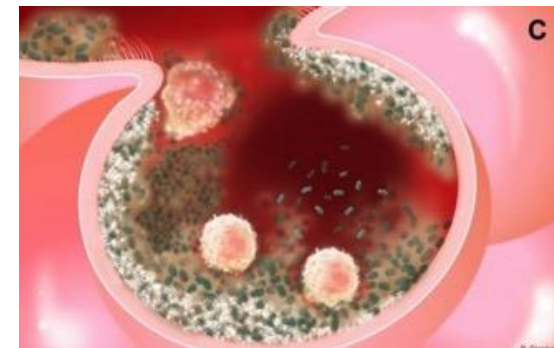
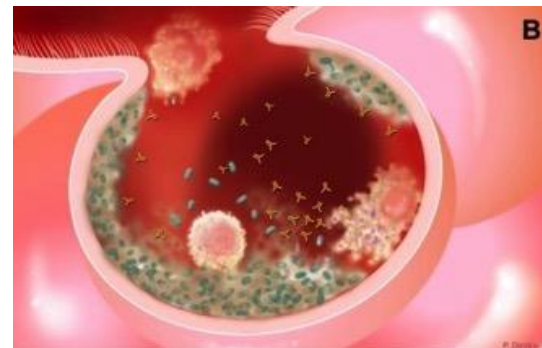
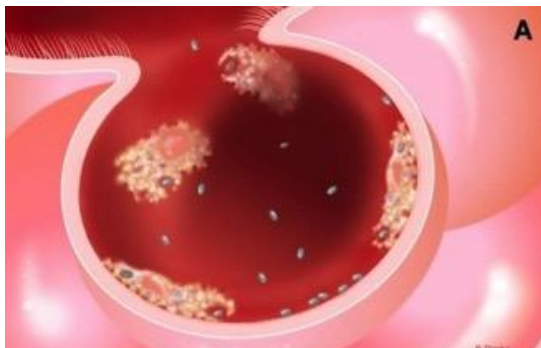
Aerosols



Mycobacteria are naturally hydrophobic and can be aerosolized from natural waters and transferred from seawater to air by natural processes.

Aerosolisation-1000 fold increase in the numbers of viable mycobacterial cells per ml of water

Mycobacteria in natural aerosols found in particles and droplets of a respirable size (ie $<5\mu\text{m}$)



“Hot tub” lung



- Hypersensitivity pneumonitis – use of hot tubs, *M. avium*
- reported in lifeguards and pool attendants, who worked in an indoor swimming pool that featured waterfalls and sprays.
- following disinfection of metalworking fluid *M. immunogenum*

Water

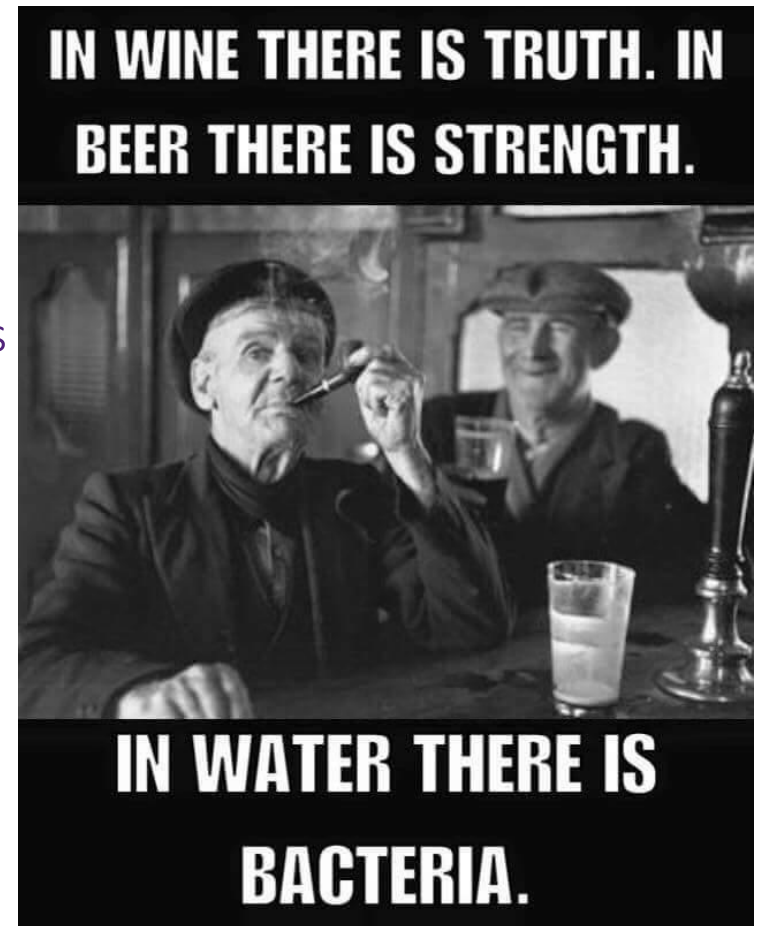
Wide variety of NTM species identified in water samples back to mid 1900s – not all associated with disease

Accurate speciation, and genotyping to match patient with water isolates

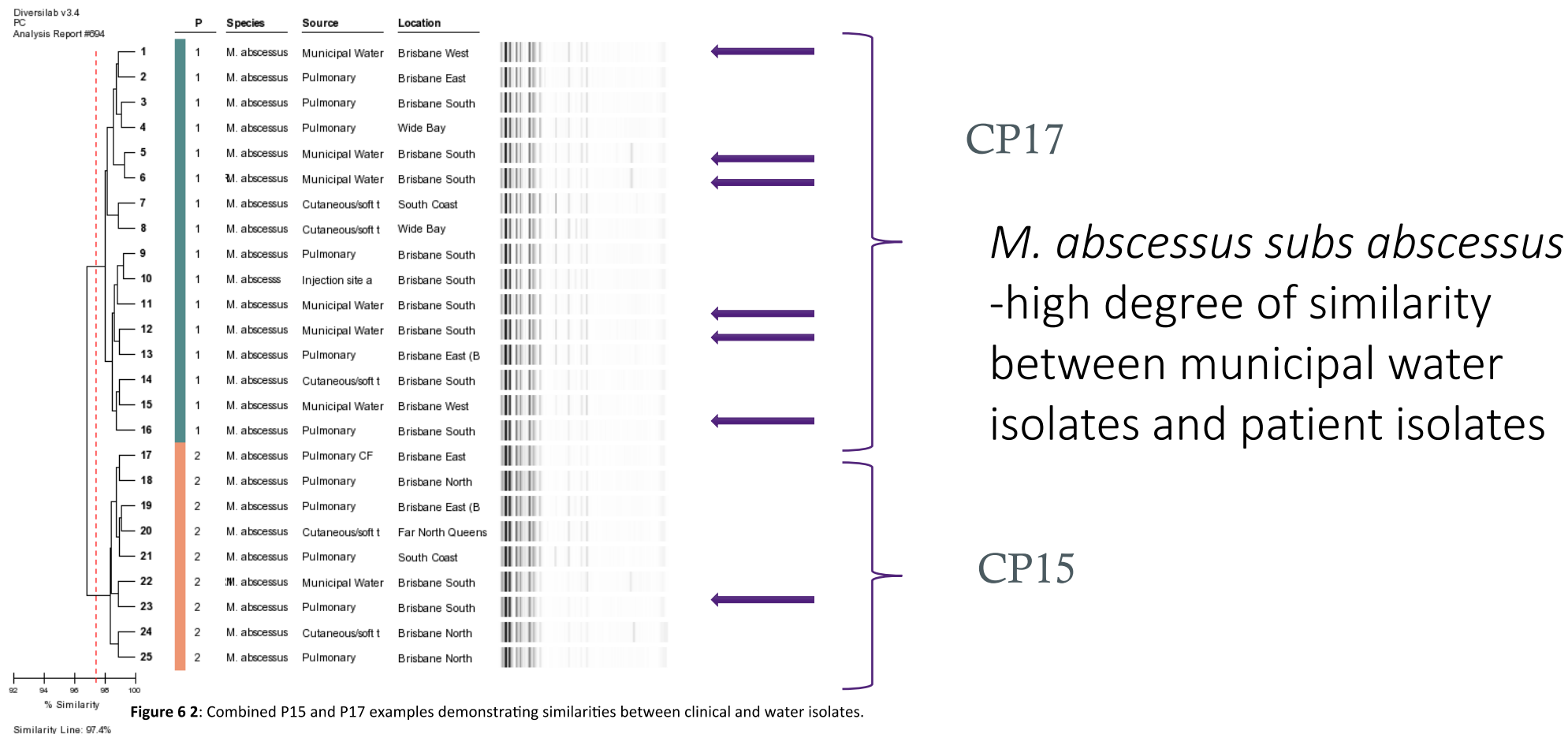
Household/municipal water systems - *M. avium*, *M. abscessus*, *M. kansasii*, *M. lentiflavum*

Hospital water - *M. porcinum*, *M. avium*, *M. abscessus*, *M. fortuitum*, *M. chimaera*

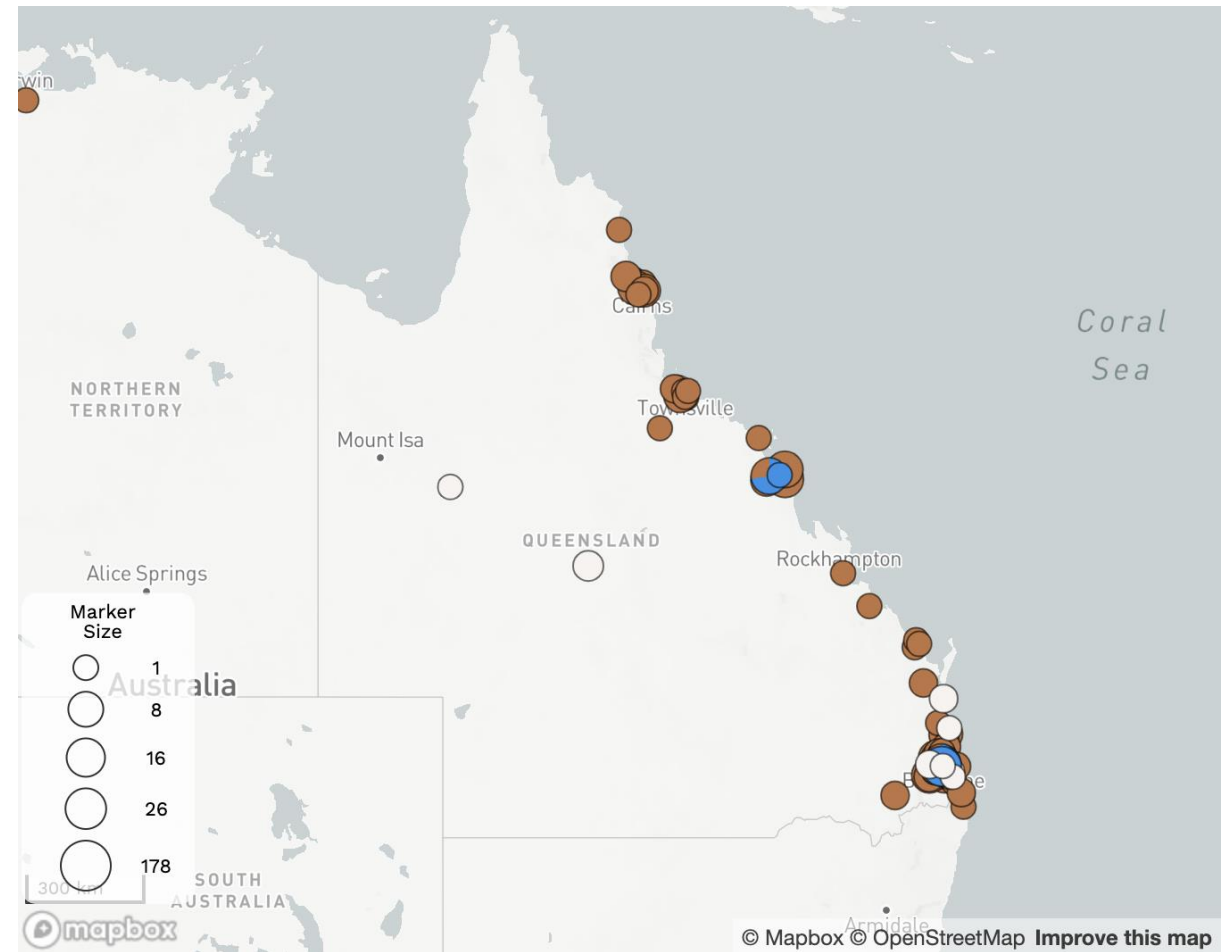
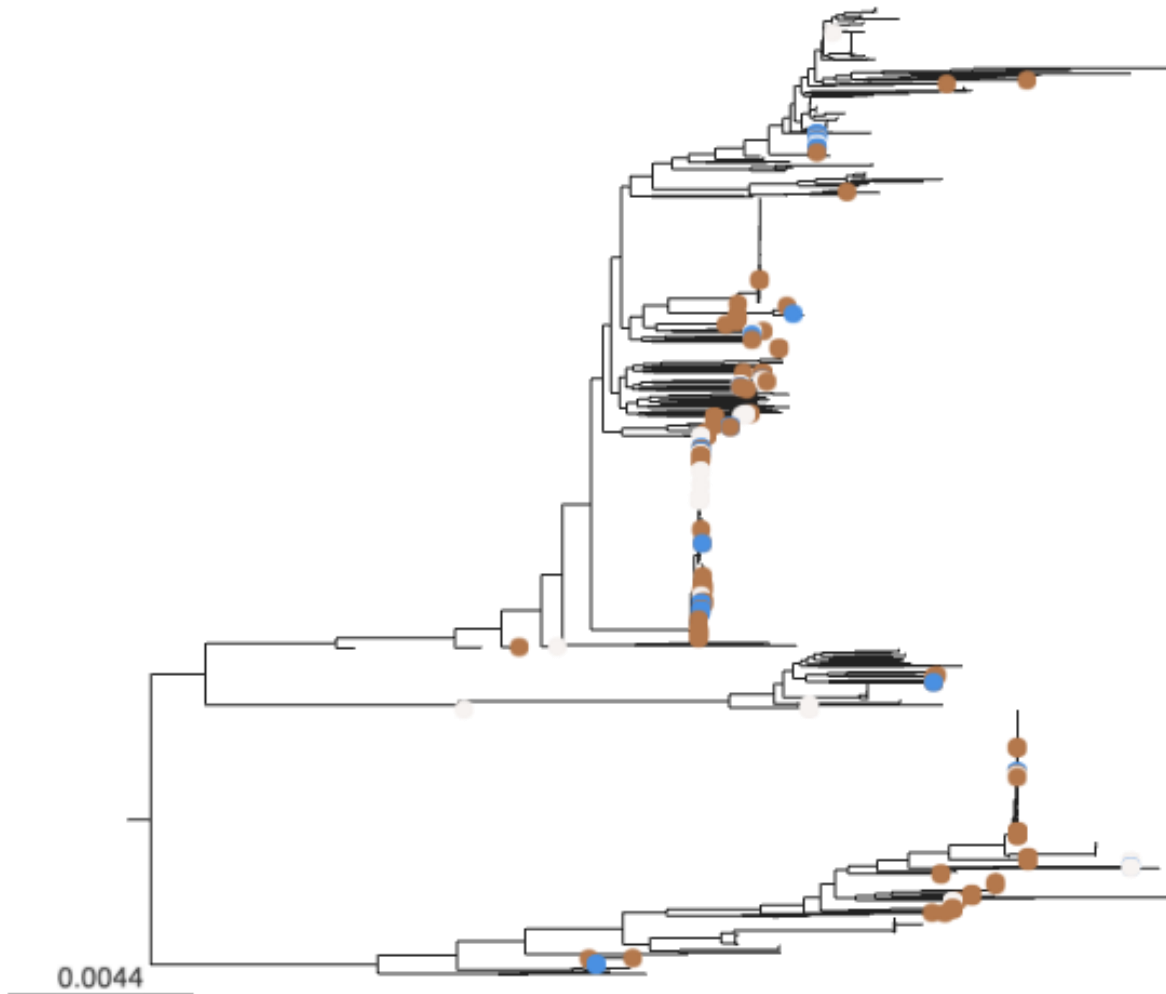
- not *M. intracellulare*



Genotypic matching of clinical and environmental isolates

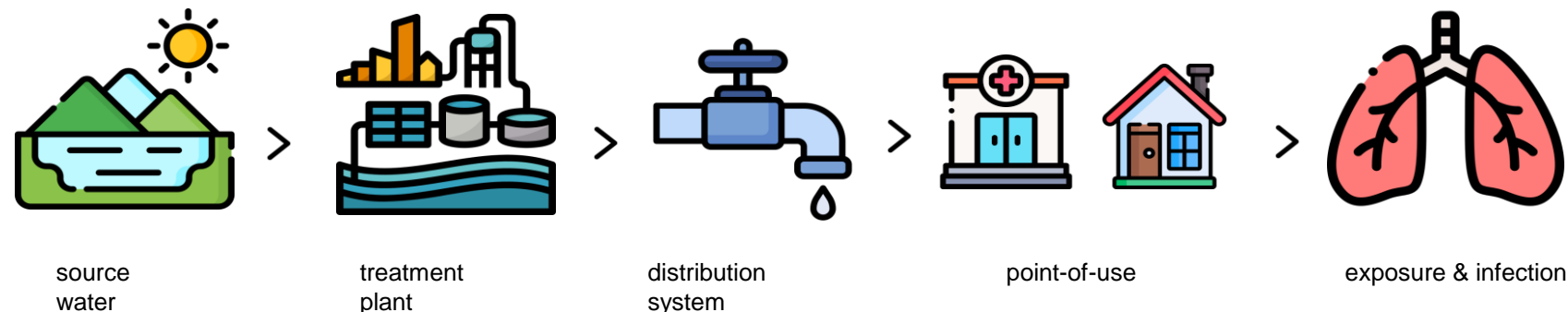
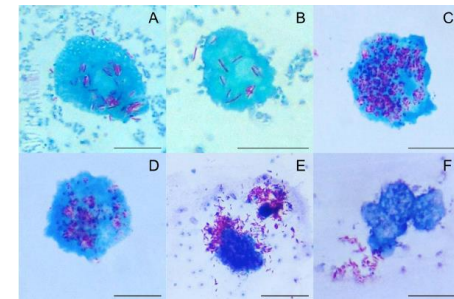


M. abscessus in QLD water and patients

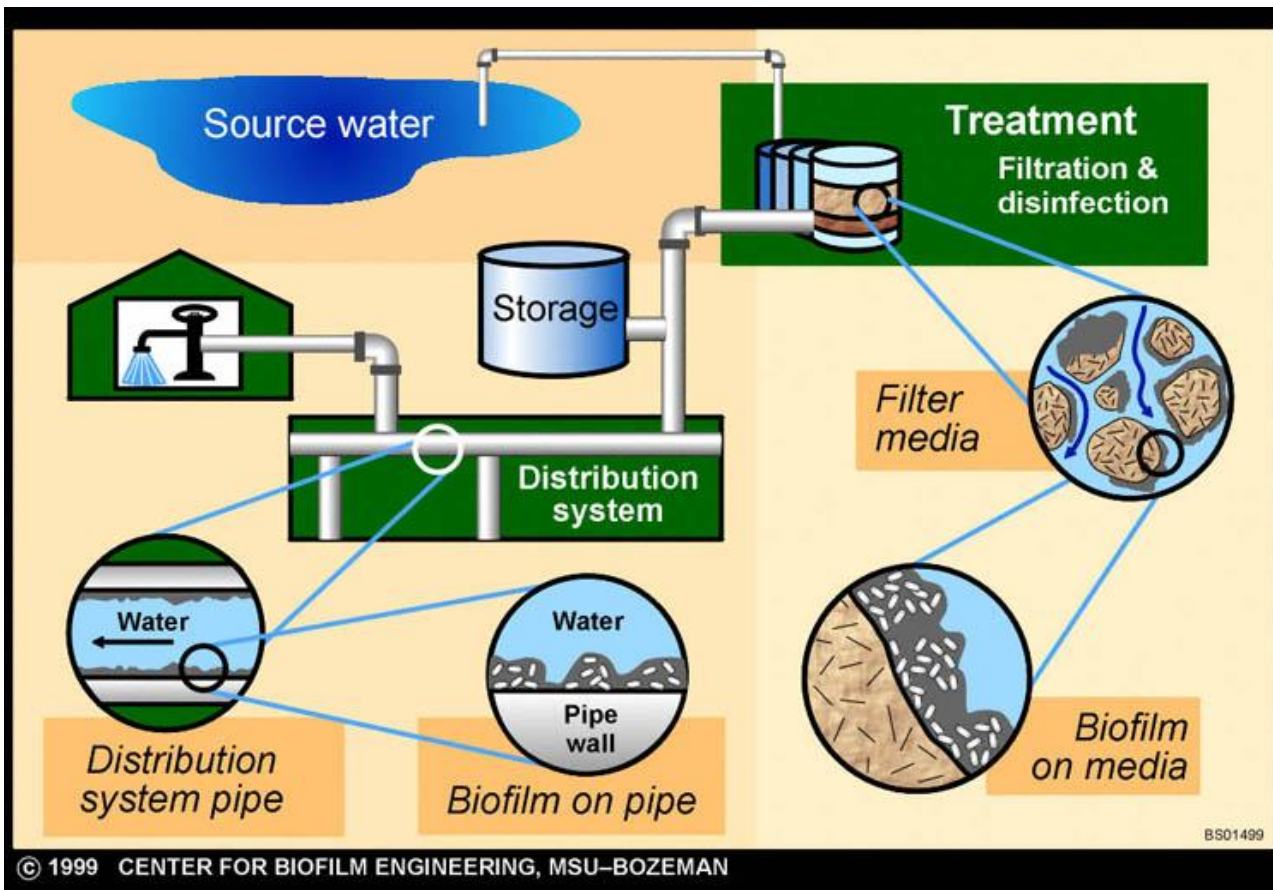


Significant interplays among bacterial species driven by source water and disinfectant

- Surface vs ground water
- Trace metals in surface water (vanadium, molybdenum)
- Chloramine vs chlorine
- Pipe material, diameter and age
- Temperature in the pipes
- Distance from the treatment plant
- Survival within amoebae
 - vehicle for replication and transmission
 - enhanced virulence



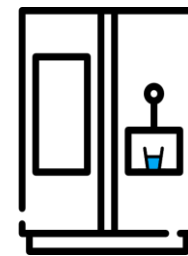
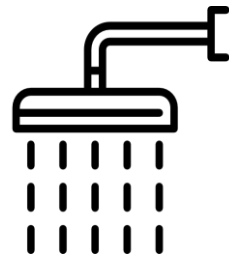
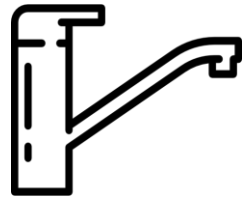
Biofilm



- organisms are many times more resistant to chlorine, chloramine, chlorine dioxide and ozone than other water borne micro-organisms such as *E. coli*.
- disinfection may contribute in part to the persistence of NTM, as competition for nutrients is lacking.
- significantly higher mycobacterial numbers in distribution samples (average 25000 fold) than those collected immediately downstream from treatment plant

Point of Use Connections

POU connections and treatment devices promote biofilm formation and amplify numbers of mycobacteria.



Inhalation

Aspiration

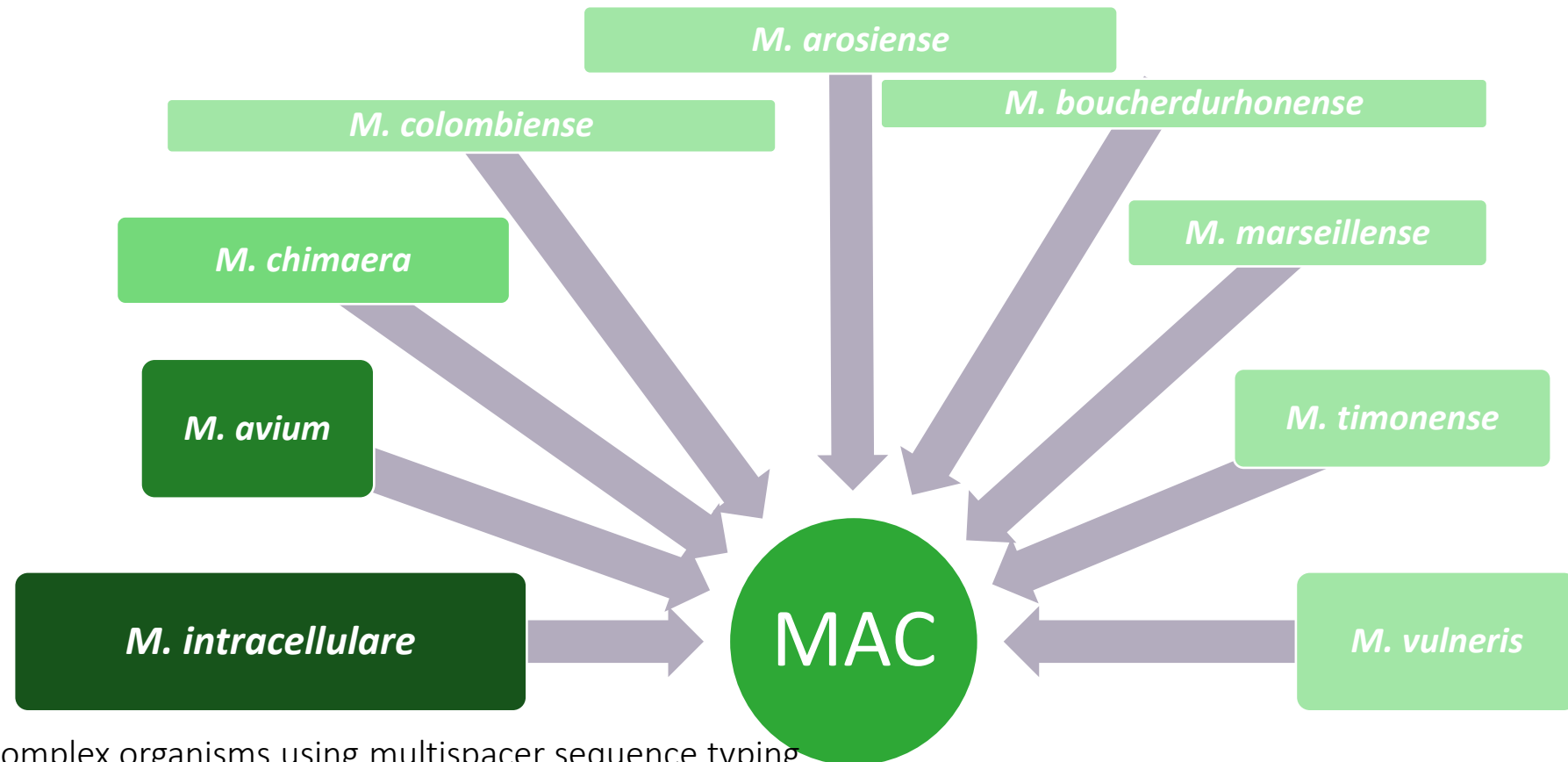
Showerheads

- Culture-independent technology (rRNA gene sequences): Sequences representative of NTM and other opportunistic human pathogens are enriched to high levels in many showerhead biofilms, >100-fold above background water contents. Feazel PNAS 2009, 106, 16393-16399.
- Higher relative abundance of MAC and *M. abscessus* in showerheads correlated with higher NTM disease prevalence
- Pathogen abundance correlated with shower water total chlorine, alkalinity, and pH levels Gebert et al 2018; mbio 9; e01614
- NTM grown from shower aerosols: *M. avium*, *M. abscessus*, *M. kansasii*
Thomson J Clin Micro 2013



Absence of *Mycobacterium intracellulare* and Presence of *Mycobacterium chimaera* in Household Water and Biofilm Samples of Patients in the United States with *Mycobacterium avium* Complex Respiratory Disease

Richard J. Wallace, Jr.,^a Elena Iakhsiaeva,^a Myra D. Williams,^b Barbara A. Brown-Elliott,^a Sruthi Vasireddy,^a Ravikiran Vasireddy,^a Leah Lande,^{c,d} Donald D. Peterson,^{c,d} Janet Sawicki,^d Rebecca Kwait,^c Wellington S. Tichenor,^e Christine Turenne,^f Joseph O. Falkinham III^b



Genotyping of Mycobacterium avium complex organisms using multispacer sequence typing

Caroline Cayrou, Christine Turenne, Marcel A. Behr and Michel Drancourt

Microbiology (2010), 156, 687–694

Soil

TABLE 2.

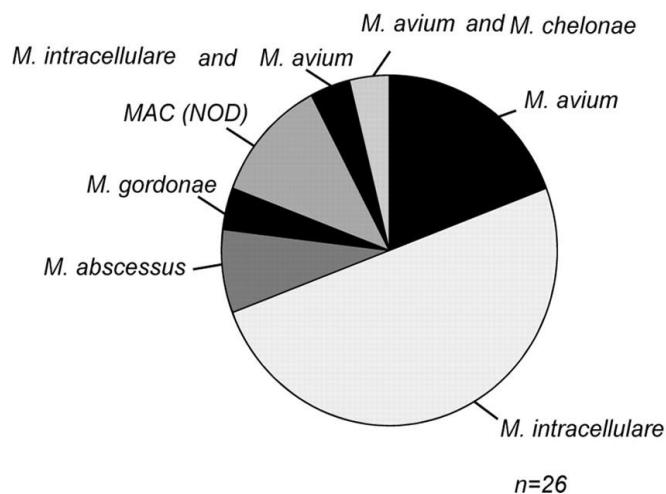
Mycobacterial species isolated from pulmonary MAC patients

Species isolated from soil	<i>M. avium</i> (n = 67)	<i>M. intracellulare</i> (n = 26)	<i>M. avium</i> + <i>M. intracellulare</i> (n = 7)	p value
MAC	36 (53.7) ^a	10 (38.5) ^a	4 (57.1)	0.38
<i>M. avium</i>	23 (34.3)	4 (15.4)	1 (14.3)	0.19
<i>M. intracellulare</i>	17 (25.3)	7 (26.9)	3 (42.9)	0.36

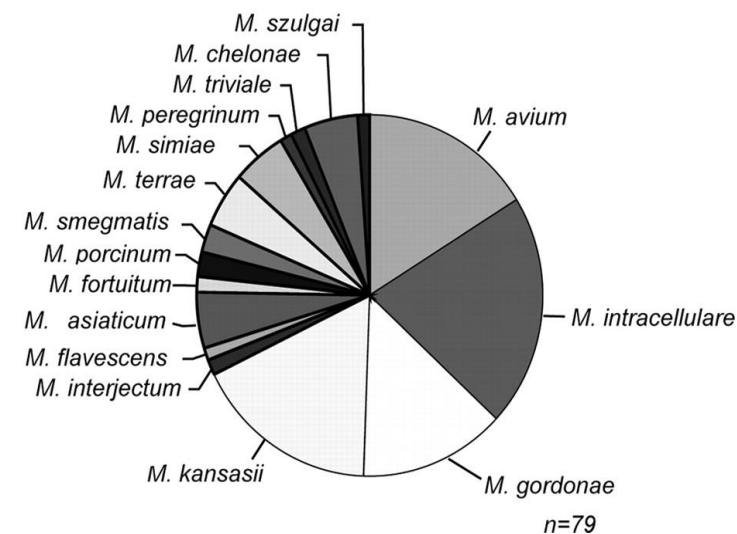
Data show number (%) of samples positive for MAC strains.

^aBoth *M. avium* and *M. intracellulare* were detected in four soil samples from the residences of patients infected with *M. avium* and in one soil sample from the residence of a patient infected with *M. intracellulare*.

A. Patient isolates



B. Soil isolates





NTM grown from aerosols generated by pouring of potting mix and soil samples from patient homes (not speciated)

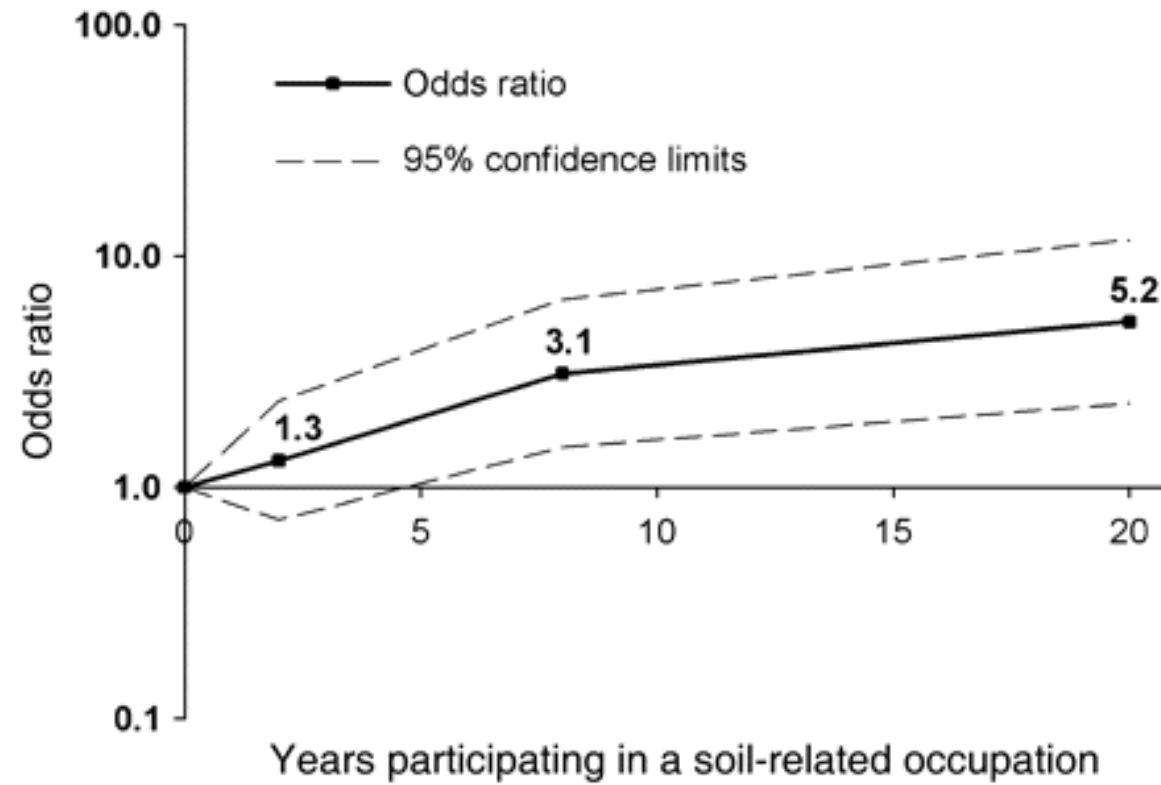
At least 3 studies that have correlated soil exposure with NTM risk

Environmental Risk Factors for Infection with *M. avium* complex

Soil exposure						
Soil occupation, any	94/147	83/186	53.1	2.2	1.4, 3.4	<0.01
None	53/147	103/186	34.0	1.0		
Farm planting, ever‡	55/146	41/185	57.3	2.6	1.5, 4.4	<0.01
Farm truck driver, ever†,‡	33/139	25/172	56.9	2.6	1.4, 4.8	<0.01
Lawn/landscape service, ever‡	34/146	28/186	54.8	2.4	1.3, 4.3	<0.01
Other soil occupations, ever‡	33/145	26/185	55.9	2.5	1.3, 4.5	<0.01

Water exposures						
Shower/bath >once/day	59/147	63/186	48.4	1.3	0.8, 2.0	0.24
Does dishes by hand >once/day	42/123	56/145	42.9	0.8	0.5, 1.4	0.45
Drinks bottled water >once/day	28/136	38/163	42.4	0.9	0.5, 1.5	0.57
Ever swims, any	107/147	145/186	42.5	0.8	0.5, 1.6	0.28
Ever, pool	73/141	109/183	40.1	0.7	0.5, 1.1	0.16
Ever, lake	31/138	48/179	39.2	0.8	0.5, 1.6	0.37
Ever, ocean	91/144	119/181	43.3	0.9	0.6, 1.4	0.63

Soil exposure is a risk factor for NTM



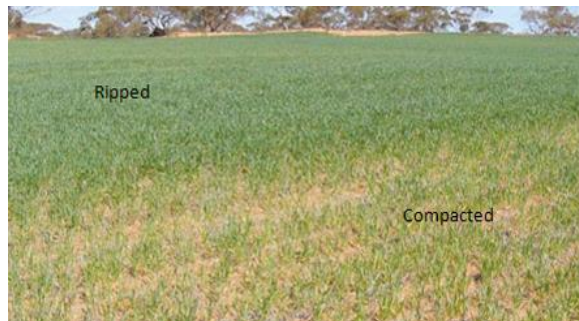
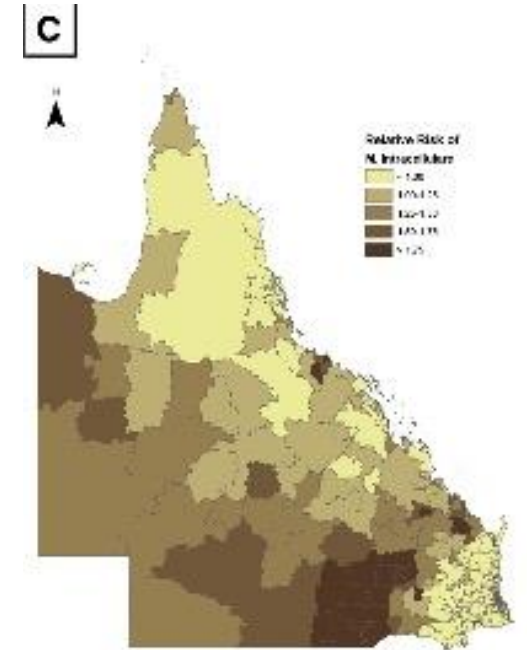
M. intracellulare

Risk correlated with a shallower soil depth

Poor rooting of vegetation in shallow soil, decreased uptake of soil nutrients, leaving a nutrient rich topsoil environment in which mycobacteria may thrive

A shallow soil depth = low Plant Available Water Capacity (PAWC) and low crop yields --- “deep ripping” to improve yields

This activity may aerosolize soil particles.

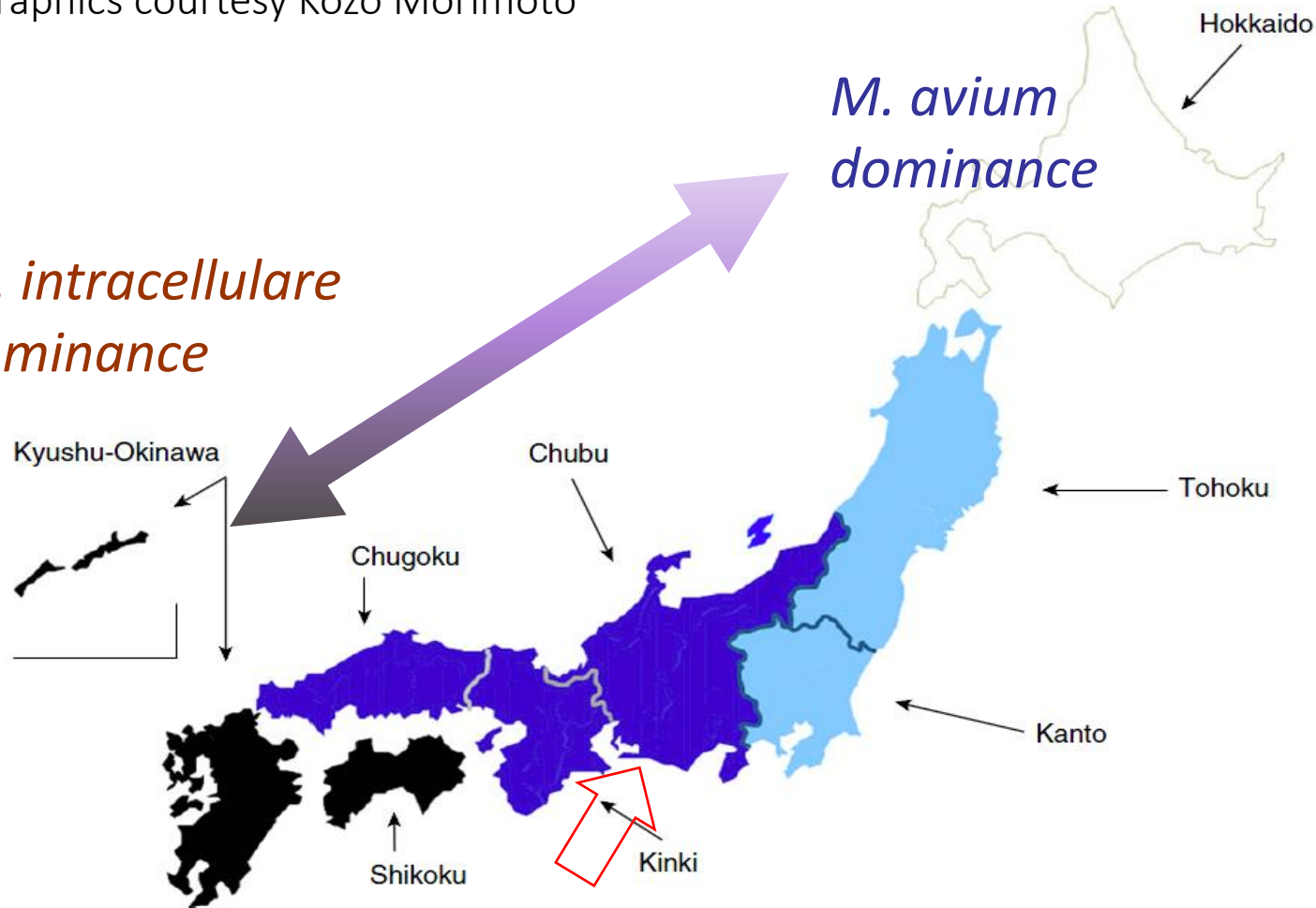


Chou M, Clements A, Thomson R. A spatial epidemiological analysis of nontuberculous mycobacterial infections in Queensland, Australia. BMC Infectious Diseases 2014, 14, 279.

Yellow sand dust haze

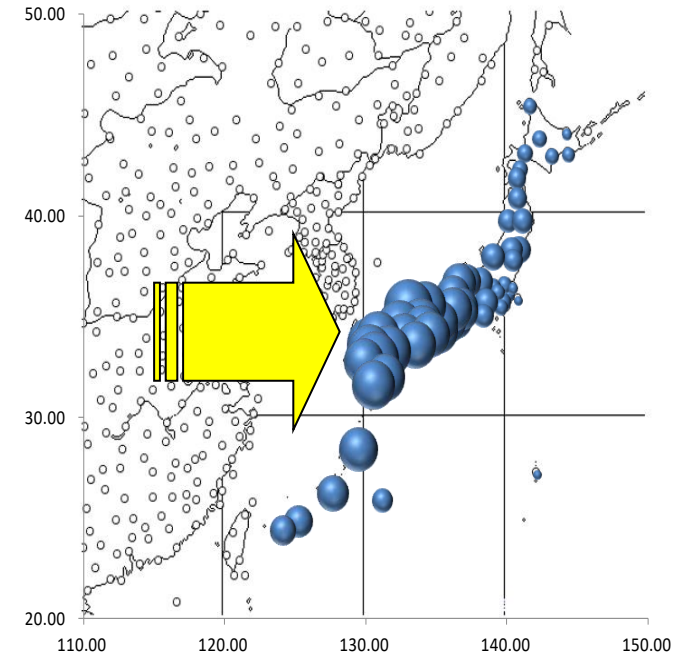
Graphics courtesy Kozo Morimoto

M. intracellulare dominance



M. abscessus

Asian dust (**KOSA**, meaning "**yellow sand**") is observed in various districts of Western Japan. This yellow sand is blown up from the Asian Continent by a frontal wind with low atmospheric pressure and is brought to Western Japan by the prevailing westerlies there.



Total number of the days that observed the **Kosa (yellow sand)** from 2000 to 2013

Long-range transport of airborne bacteria over East Asia: Asian dust events carry potentially nontuberculous Mycobacterium populations T. Maki et al Environ Int 2022

House-Dust

Dust particles are commonly suspended in the air

120 strains NTM isolated from vacuum cleaner dust collected in Queensland

50 strains of *M. intracellulare* – 44% belonged to serotypes that were recognized as disease associated strains

Dawson MJA 1971



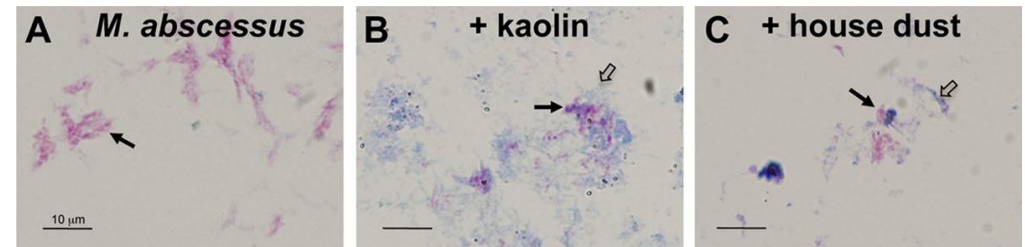
NTM in house dust



Mycobacterial species isolated from the dust samples. Combined data of the GLC and 16 S rDNA sequence analyses.

Species or groups	N	%
<i>M. terrae</i> complex (<i>M. nonchromogenicum</i> or <i>M. arupense</i> , <i>M. kumamotonense</i> , and <i>M. terrae</i>)	43	31
<i>M. avium. intracellulare, scrofulaceum</i> complex (<i>M. colombiense</i> , <i>M. intracellulare</i> , <i>M. avium</i> , and <i>M. scrofulaceum</i>)	38	27
<i>M. gordonae</i>	22	16
<i>M. lentiflavum</i>	7	5
<i>M. triviale</i>	5	4
<i>M. asiaticum</i>	3	2
<i>M. "aquaeductus"</i>	3	2
<i>M. bohemicum</i>	2	1
<i>M. interjectum</i>	2	1
<i>M. malmoense</i>	2	1
<i>M. palustre</i>	1	1
<i>M. "savoniense"</i>	1	1
<i>M. tusciae</i>	1	1
Non-identifiable	10	7

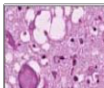
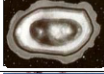
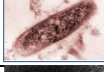
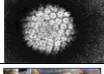



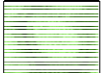
Survival of NTM on surfaces



M. abscessus :

- displays fitness for fomite transmission
- physically associated with particulates
- growth enhanced in the presence of both kaolin and house dust
- survived desiccation for 2 weeks

Malcolm et al Appl env micro 2017

Levels of Disinfection Difficulty	
Extremely Hard to kill	
Harder to Kill	Prions  Transmissible Spongiform Encephalopathy (TSE); Creutzfeldt-Jakob disease (CJD); Mad cow disease; Scrapies
	Bacterial Spores  Spores of: <i>C. difficile</i> ; <i>C. tetanus</i> ; <i>C. botulinum</i> ; <i>C. perfringens</i> ; Anthrax
	Mycobacteria  <i>M. tuberculosis</i> ; <i>M. avium</i>
	Viruses without envelopes  Norovirus; Rotavirus; Rhinovirus; Poliovirus; Papillomavirus (HPV); Coxsackie; Adenovirus
	Fungi includes fungal spores  <i>Aspergillus fumigatus</i> , <i>A. flavus</i> ; <i>A. niger</i> ; <i>Candida albicans</i>
	Gram negative bacteria  <i>Pseudomonas</i> , <i>Acinetobacter</i> , <i>Klebsiella</i> , <i>E. coli</i> ; Enterobacteriaceae, <i>Legionella</i>
	Gram positive bacteria  <i>Staphylococcus</i> ; <i>Enterococcus</i> ; <i>Streptococcus</i> ; <i>Clostridia</i> vegetative rods
	Viruses with lipid envelopes  Influenza; HBV; HCV; HIV; RSV; Coronavirus; CMV; HSV; Measles, Mumps; Rubella; VZV (Varicella-Zoster) Shingles/ Chickenpox
Easy to kill	

What role does the environment play in the observed increases in disease incidence and prevalence?

Human interaction with the environment
– more exposure

Human activity that affects the environment- water disinfection, soil disruption, mining and industry

Climate change, natural disasters

Evolution of the pathogen?



Evolution of the pathogen

Nontuberculous Mycobacteria Infection Risk and Trace Metals in Surface Water

A Population-based Ecologic Epidemiologic Study in Oregon

Ettie M. Lipner^{1,2}, Joshua P. French³, Joseph O. Falkinham III⁴, James L. Crooks^{2,5}, Rachel A. Mercaldo⁶, Emily Henkle⁷, and D. Rebecca Prevots⁸

Environmental Science and Pollution Research (2021) 28:12178–12189
<https://doi.org/10.1007/s11356-020-12171-3>

REVIEW ARTICLE

Enrichment of antibiotic resistance genes (ARGs) in polyaromatic hydrocarbon–contaminated soils: a major challenge for environmental health

Anand Prakash Maurya¹ · Jina Rajkumari¹ · Piyush Pandey¹

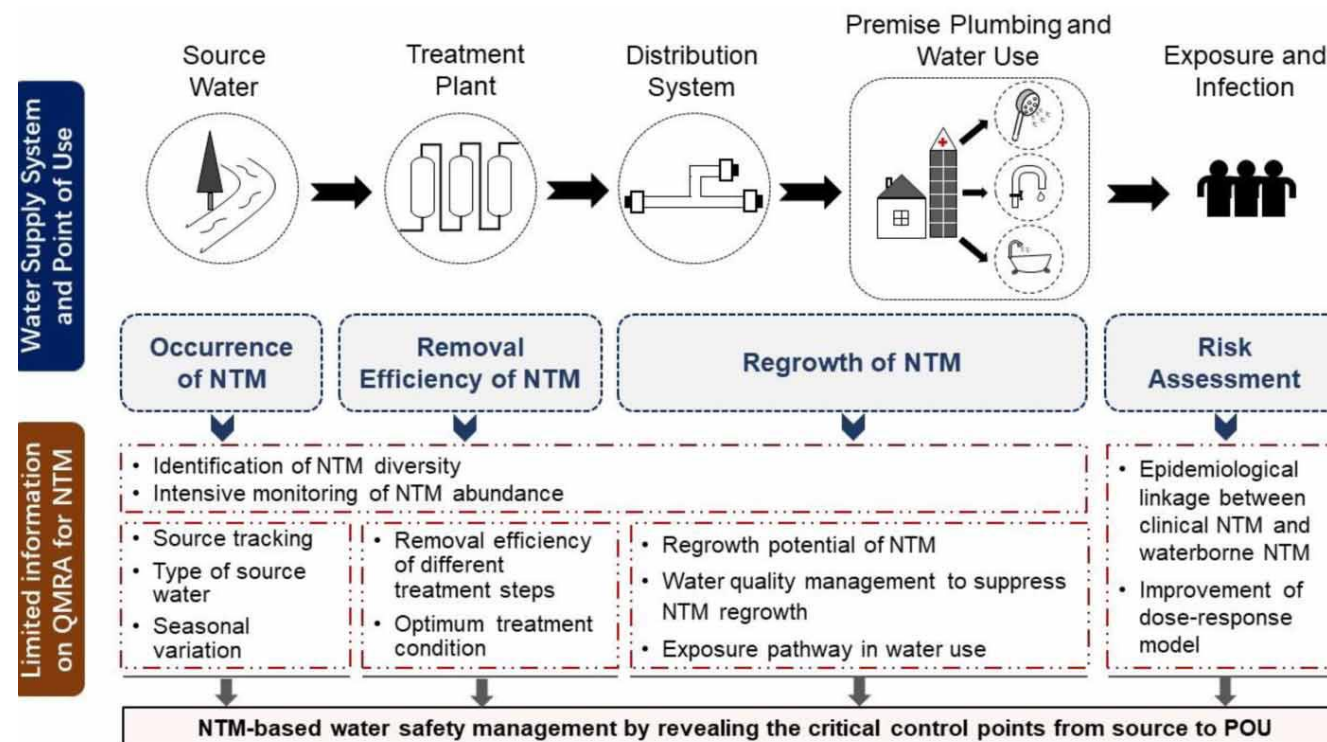
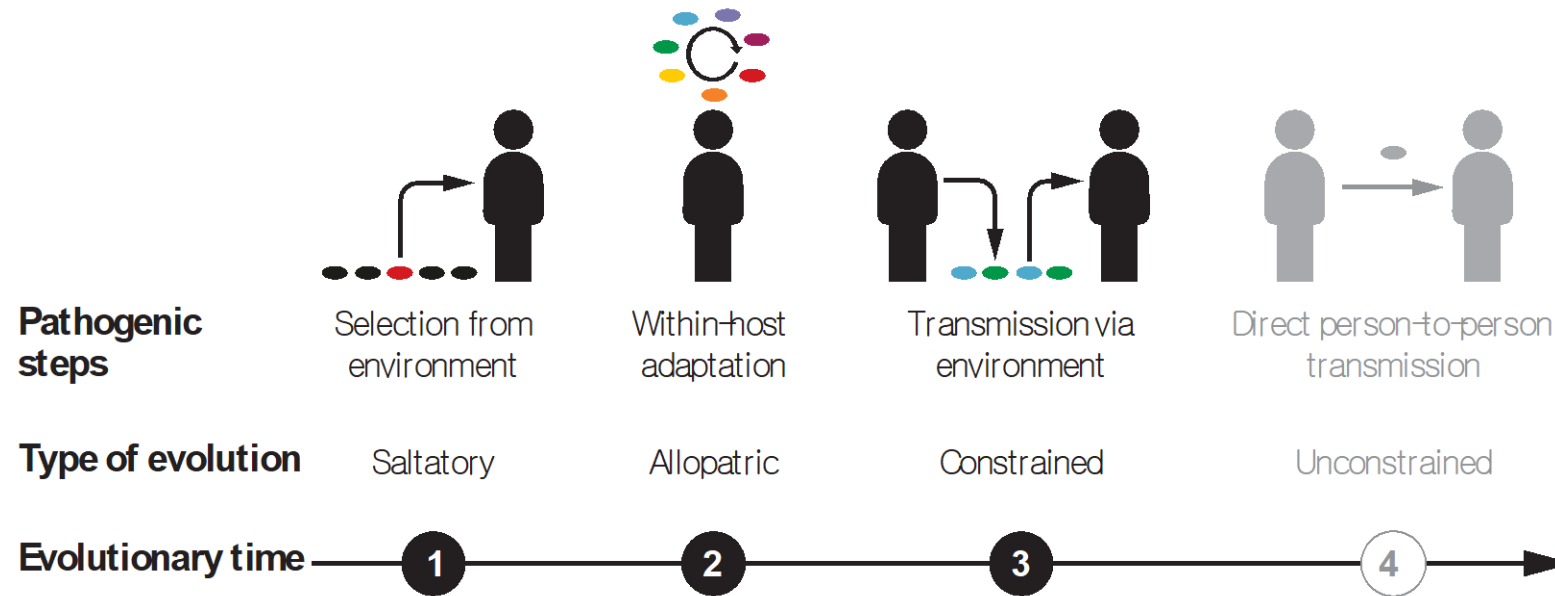


Figure 2 | Application of comprehensive QMRA to NTM in water supply and water use.

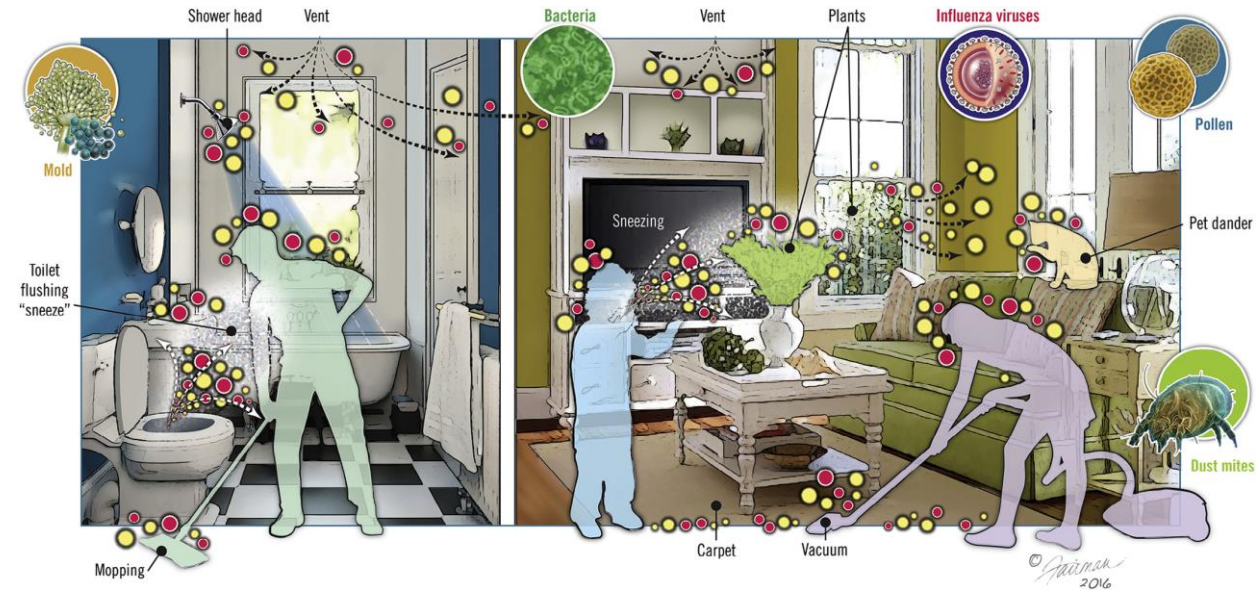
Pathogenic evolution of *M. abscessus*



Transition from smooth to rough morphotype - less surface glycolipid, more hydrophobic and therefore capable of aerosolization

Recently emerged dominant circulation clones (DCCs) of *M. abscessus* causing disease in multiple countries
M. abscessus grown from cough aerosols

Summary



- NTM causing human infections can be found in a wide variety of environmental sources, but ecological niche likely to be species specific – eg *M. avium* vs *M. intracellulare*
- Geographic variation in species distribution in both patients and the environment
- Human activities may influence the numbers of mycobacteria in the environment (e.g agriculture, water disinfection practices) and increase exposure (e.g hot tub use, soil related activities, house dust)
- Pathogenic evolution may enhance environment – person and person-person transmission
- Surveillance systems necessary to track changes in epidemiology and to link these changes with environmental changes (natural or man-made) or outbreaks due to patient-patient transmission

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- Flavia Huygens

QMRL

- Chris Coulter