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Senate Inquiry into the: Growing evidence of an emerging tick-borne disease that causes a Lyme-like illness for many Australian patients

SUBMISSION FROM: **LYME AUSTRALIA RECOGNITION & AWARENESS**
GLOBAL LYME & INVISIBLE ILLNESS ORGANISATION INC

LYME AUSTRALIA RECOGNITION AND AWARENESS (LARA)

LARA was founded by independent researcher, Karen Smith, B Psych (Hons). As well as her research work, Karen provides support and advocacy to patients and families living with Lyme disease through patient support forums and raising awareness of Lyme disease through organising and participating in awareness and protest events, both in the national and international arena. The majority of Karen's' research and advocacy was performed under the banner of Lyme Australia Recognition and Awareness (LARA), before co-founding GLiIO with American friend and Advocate Lisa Hilton.

Aims of LARA

To highlight the need for the recognition and awareness of Lyme in Australia;
To provide scientific information to the Australian Health Departments about the urgent necessity for adequate research into the existence of the borrelia species responsible for Lyme disease/borreliosis in Australia
To provide basic, "easy to understand" information on Lyme disease, how it is transmitted and how it can be associated to so many various health problems
To Provide Lyme Patients a place for a "Voice" : to tell their stories, to share their artistic talents and provide access to treatment and research forums ; to be a voice for those no longer with us with the 'Forever Remembered' memorial section sharing memories of those lives lost to Lyme & Co.

GLOBAL LYME & INVISIBLE ILLNESS ORGANISATION INC (GLIIO)

GLiIO is an incorporated association and is currently undertaking paperwork to file for Charity status. The association was founded by Karen Smith (Australian) and Lisa Hilton (American), two friends that met due to raising awareness of Lyme & Co. Lisa and Karen have worked closely together since late 2012, when they joined forces to work on the Inaugural Worldwide Lyme Protests (WWLP) held on May 10th & 11th 2013. Karen and Lisa signed up (were the International representatives) their respective countries for participation, as well as helped to keep track of all the various events in the other 20+ countries around the world, including via keeping an international blog. Through-out their time working together on the WWLP, it became more and more obvious to Karen and Lisa that many people around the world were unaware of where to access information and support in their own countries. In order to correct and help with this situation, and to have one location where people could go to find information on where they could get support anywhere in the world, the Global Lyme & Invisible Illness Organisation was founded.

Aims of GLiIO

Connecting support groups for Lyme & other Invisible Illness' around the World;
Uniting Worldwide Awareness in May - International Lyme Awareness Month ;
International Red Shoe Day: A Day of Remembrance ; Theda's Foundation ;
Holiday Seasons Events: Support those housebound so they don't have to be alone at Christmas

Thank you for the opportunity to present the following information on behalf of all those living with Lyme and other vector borne diseases. Your attention to the plight of all those suffering, not only from illness but from the fight necessary for medical treatment and understanding is very much needed.

On behalf of Lyme Australia Recognition and Awareness: Research information addressing the Terms of Reference for the Inquiry, as well as papers written previously by Karen Smith on this topic are provided. (Further information on previous papers / attachments provided on page 4)

On behalf of Global Lyme & Invisible Illness Organisation: International Red Shoe Day – A Day of Remembrance Division the 'Time to Recognise Lyme' Clock, is presented. This clock project aims to show the human side of this disease and the devastation its denial and lack of treatment and medical care is causing.

Contents

Attachments Included with this submission

Attachment One:

Lyme Disease: A Counter Argument to the Australian Government's Denial" K. Smith 2012

This Counter-Argument examines the research from the Department of Medical Entomology (DME), Westmead Hospital, NSW that underlies the denial in Australia, the majority of which was published in a paper by Russell et al., (1994) *Lyme disease: search for a causative agent in ticks in south-eastern Australia.* As the research paper is also the basis of the information regarding Lyme disease on the DME website, information from this site is also briefly explored. The aim of this document is to highlight that the research methodology has a number of flaws. There will always be problems encountered within research; it is in learning from these difficulties that science and knowledge can progress. While most studies address the problems that arise and offer possible alternative viewpoints or conclusions, the disturbing factor in the DME's investigations is that, despite being new to the field of Lyme research, the team at the DME assessed their own investigations as "expert" and ignored all other contradictory research that revealed there is a high probability that Lyme *is* in Australia.

Information in Attachment One was published on the LARA website in July 2012 and produced in PDF format in 2013. The counter-argument was included in response to the Department of Health Scoping Study in 2014 and in February 2016 it (along with Scott and Ruby's story) it was handed to the Prime Minister of Australia, Malcolm Turnbull.

Attachment Two:

Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia'.
K Smith 2012

The overview was prepared as a complimentary report to the counterargument. While the counter-argument focused more exclusively on examining the problems with methods used and conclusions drawn with regards to the research underlying the denial of Lyme in Australia, the aim of this current review is to provide a brief outline of Lyme borreliosis. What it is and the clinical picture and symptoms associated with the disease as well as detailed information on how it is transmitted and maintained in the environment. By outlining the basics and providing background information, it is hoped that the 'mystery' surrounding Lyme is lifted and that it can be very plainly seen that the likelihood that the bacteria responsible for Lyme is in Australia is quite high, and that there is an urgent need for further investigation and thorough research in this field.

Information in Attachment Two was published on the LARA website in July 2012. In November 2012 the segments 'Lyme Disease Transmission and Maintenance within the environment' and 'Tick Vectors and Reservoir Hosts of Lyme / Borrelia in Australia' was handed to Dr Jeannette Young, Chief Health Officer for Queensland. In 2014 the same sections that had been provided to Dr Young were included in response to the Department of Health Scoping Study. The research was produced in PDF format in 2014 and updated in 2016 to include further information in the Babesia section and add an executive summary.

Attachment Three:

Migratory Marine Bird (sea and shorebird) sites around Australia's coastline. *K Smith 2012*

This document is by no means a comprehensive list of all the bird sites, rather it has been prepared as basic information to outline how closely marine birds interact with humans (and other mammals/birds) around the coastlines and islands of Australia (A number of these species of birds can also be found inland on lakes and rivers within Australia, however the range is simply too large an area to cover). Numerous, though certainly not all, sites for birds have been listed for Queensland, New South Wales and Victoria. Information for Tasmania, South Australia, Western Australia and Northern Territory is still in note form and yet to be completed.

Information in Attachment Three was published on the LARA website in July 2012. In November 2012 the Queensland information segment (as well as those mentioned from Attachment Two above) was handed to Dr Jeannette Young, Chief Health Officer for Queensland. It was produced in PDF format in 2014 and included as an attachment in response to the Department of Health Scoping Study.

- The utilisation of this symbol throughout the document indicates that information from one of the attachments above has been copied over in order to address a specific Term of Reference.
  It is utilised for those that may not have the time to read all of the provided attachments.

A. The prevalence and geographic distribution of Lyme-like illness in Australia

Since the 1980's in Australia, there have been over one thousand patients tested each year for suspected Lyme disease. Despite the enormous number of clinically suspected cases, the current position of the Australian Health Department continues to be that there is no evidence that Lyme disease is a threat to public health. This position means that even when hundreds of people are testing positive, they results are termed a 'false positive' as Lyme is deemed to be 'not endemic to Australia'. It is a vicious roundabout and one that needs to be addressed with up to date research.

This 'No Lyme in Australia' stance is based on one study by Russell et al. (1994) **"***Lyme disease: search for a causative agent in ticks in south-eastern Australia***"** (1) and ignores all other previous research and studies undertaken during the same time period, in which the conclusions were highly suggestive of the fact that the *Borrelia* bacteria which underlies Lyme disease does exist in Australia (eg: 2-12).

The findings and issues with the conclusions drawn and methods used in the 1994 study are addressed in detail in Attachment One of this submission: '*Lyme Disease: A Counter Argument to the Australian Government's Denial'.* (NB: some segments of the counter-argument are also reproduced in this submission in the appropriate Terms of Reference sections)

Prevalence: A Clear cut definition first required

In order to track the prevalence of Lyme disease, or a Lyme-like illness, there first needs to be a clear cut definition of what is being referred. Is it just the infection due to the *Borrelia burgdorferi sensu lato species* (Lyme disease/ Borreliosis), or is it referring to a broader clinical patient picture that encompasses those that are suffering from multiple vector borne infections – which most people living with Lyme tend to have.

In the United States: Lyme disease or Lyme Borreliosis has been used interchangeably in the literature by Centre for Diseases Control (CDC) and Infectious Diseases Society America (IDSA) authors since the Lyme was first 'discovered' in the 80's. For example, in 1994, Steere (who first 'recognised' Lyme disease) described "Lyme disease or Lyme borreliosis as the result of an infection from *B. burgdorferi* ss, *B. afzelii* or *B. garinii*" (13). Since then there have been numerous other Borrelia species in the burgdorferi sensu lato complex discovered (see table on page 7 of this document).

In Australia, there appears to be various terms used, which confuse the situation, and need to be clarified. For example:

The New South Wales Department of Health website (last updated 6th of January 2016) notes: Lyme disease is a tick-borne infection caused by the bacterium Borrelia burgdorferi s.l.

Lyme disease – testing advice for NSW clinicians "Lyme disease (Lyme borreliosis) is a multisystem tick-borne zoonosis caused by spirochaetes of the Borrelia burgdorferi genospecies complex. Ticks with Borrelia burgdorferi infection are found in temperate forested areas of northern Asia and Europe and North America".

Reading these two pages – it appears the NSW Department of Health also uses the traditional terminology – ie: Infection caused by *Borrelia burgdorferi sl* . (Even though they do only test for a very small number of the species within that class– a topic covered more in TOR C: Page 13 of this document).

The Institute of Clinical Pathology and Medical Research (ICPMR), Centre for Infectious Diseases and Microbiology Laboratory Services, Westmead, Fact Sheet on Lyme disease states "At least five specific IgG immunoblot bands are required to confirm **true Lyme disease** after the first few weeks of infection."

What exactly does the ICPMR classify as "true Lyme disease" ?

Dr Lum, Head of the Office of Health Protection in the DoH, told the standing committee on Health in September 2015 : that "The department recognises that **classical Lyme disease** exists endemically in parts of the USA , Europe—including the UK—and Asia" .

Dr Lums statement adds yet another term to the literature in Australia regarding Lyme, and again begs the question - What exactly is being referred to when speaking of "classical Lyme disease" ?

Borrelia responsible for Lyme disease/borreliosis in humans, is traditionally delineated (14) by genetic and vector (different tick species) differences. These genetic and vector differences distinguish it from *Borrelia* responsible for Relapsing fever in humans, Spirochetosis in birds and Bovine borreliosis.

A definition that is based on the genomic typing of the *Borrelia*, rather than the time or location in the world (or undefined explanations of ‘true or classical’) that the species of *Borrelia* was originally discovered needs to be made clear / defined so everyone is able to be on the same page.

Once a definition is clarified, whether it is called - Lyme disease / Lyme borreliosis or; Lyme Like Illness or ; Relapsing fever or ; ‘whatever’ - cases of the infection/ spectrum of illness can then be made notifiable, which would ultimately allow the incidence of the disease / suspected incidences to be monitored and potentially further understood. The one sure thing is that up-to-date research urgently needs to be undertaken with regard to identifying the pathogen(s) underlying Lyme / vector borne illness in Australia.

In order to explain a little more re the various species / terminology - Background information with regards to a brief history of Lyme and Borrelia Species is provided below.

- Lyme Disease History, Borrelia Species and Table a section from Attachment Two of this submission: *Lyme Disease / Borreliosis: An Overview of Lyme and Direction for further Research required in Australia (Pgs 9-10)*

Lyme Disease History and Borrelia Species

Brief History

Investigations first began into Lyme disease (LD) in the USA in 1975 after two concerned mothers, Polly Murray and Judith Mensch from Old Lyme in Connecticut contacted the health department about their sick children and what they felt was an abnormally high number of children with “juvenile rheumatoid arthritis” in their area. One of the scientists involved in the research of the cluster of patients in Connecticut, Willy Burgdorferi, identified the bacteria responsible for Lyme disease as a spirochete belonging to the *Borrelia* genre in 1981 (Two dates 1981/1982 seem to be used interchangeably in various literature: 1981 is the year the ‘discovery’ was made, whilst 1982 is the publishing date of the journal article in which the finding is described). As such this first species was named *Borrelia burgdorferi*, and being the first species identified, it is typically known *as B. burgdorferi sensu stricto* (in the strictest sense).

Due to the original beginnings/investigation, LD was initially presumed to be a primarily arthritic condition, however it was soon found to have dermatological and neurological manifestations. In Europe, clinical aspects of LD have been written about in medical journals since the 1800’s. A skin condition which is now associated with chronic LD, acrodermatitis chronic atrophicans (ACA), was noted in patients of a German doctor, Alfred Buchwald in 1883, whilst the rash that some LD patients observe, known as erythema migrans (EM) was originally described in 1910 by a Swedish dermatologist, Arvid Afzelius as erythema chronicum migrans (ECM). In 1922, French physicians, Garin and Bujadoux, described neurological (Meningopolyneuritis) symptoms which occurred in a patient after an Ixodes hexagonus tick bite.

In the thirty years since the original investigations began, numerous other species of *Borrelia* have been identified and along with *B. burgdorferi sensu stricto*, are collectively classified as belonging to the *Borrelia burgdorferi sensu lato complex*. Whilst all the species in the sensu lato complex may be classified as belonging to the Lyme borreliosis group (1, 2), another group of *Borrelia*, *B. miyamotoi*, has recently been reported to cause relapsing fever and Lyme disease-like symptoms in humans (2,3). *B. miyamotoi* was first described in Japan in 1995 as a new species of *Borrelia* (4) that resemble relapsing fever species in some ways and Lyme borreliosis species in others” (5: Pg 1129) . Spirochetes that were found to be closely related to *B. miyamotoi* (*B. miyamotoi sensu lato*) have been reported in a number of studies in the United States from 2001 (eg: 6-8) and Europe since 2002 (9). Genetic sequencing of *B. miyamotoi* has revealed that it is closely related to the *B. lonestari* species of *Borrelia* (1). *B. lonestari* is associated with a “Lyme-like” disease known as, Southern Tick Associated Rash Illness (STARI), or Masters disease, which is reportable to the Centre for Disease Control (CDC) as Lyme disease (10).

Borrelia Species

Worldwide there has been over 20 *Borrelia* species identified as being associated to Lyme, or Lyme-like disease in humans. Species that have been identified in various continents are detailed in Table 1 on the following page (page 10). To avoid some confusion that may come about when reading literature with regards to *Borrelia* species and infections, it is worthwhile to point out that spirochetes of the *Borrelia* family are also responsible for other known diseases in humans and animals. Some of these include:

Relapsing Fever in humans: eg: *B. duttonii, B. hermsii, B. turicatae and B. recurrentis* (*B. recurrentis*, is transmitted by the human body louse, and is the only species acknowledged as being transmitted via an insect rather than a tick)

Spirochetosis in birds: eg: *B. anserina* (*Borrelia* species such as *B. garinii* and *B. valaisiania* responsible for Lyme disease in humans are also carried in birds)

Bovine borreliosis: eg: *B. theilerii and B. coriaceae* (As well as being able to cause disease in humans, both the *B. burgdorferi ss* and *B. garinii* species have also been found associated with borreliosis in cattle)

Borrelia responsible for the above diseases are differentiated from the *Borrelia* species that are responsible for Lyme disease/borreliosis in humans, by genetic and vector (different tick species) differences. Although it should be noted that differentiating via tick species that transmit the disease is starting to become more ambiguous with species such as *B. miyamotoi*, in which the vectors differ from the typical pattern. Typically, spirochetes responsible for Lyme disease are transmitted via hard ticks, whist relapsing fever is transmitted via soft ticks, however with the *Miyamotoi* species, both hard and soft ticks have been found capable of transmitting the disease, and also unlike other *Borrelia* species responsible for Lyme disease, the bacteria is passed from the female tick to the egg/larvae (eg 1, 5, 6).

Table 1: *Borrelia* Species Associated with Lyme Borreliosis

Continent/ Country	***Borrelia* Species**
North America:	*B. burgdorferi ss*, B. americana, B. andersonii, B. bissettii*, B. californiensis, B. carolinensis, B. garinii*, B. kurtenbachii. B. miyamotoi sl*** and *B. lonestari****
Canada:	B. *burgdorferi ss*, B. bissettii*,* BC genotypes (3 distinct though as yet unnamed species)
Europe:	*B. burgdorferi ss*; B. afzelii*, B. bavariensis** (previously known as *B. garinii OspA serotype 4*), *B. bissettii*, B. garinii*, B. finlandensis, B. lusitaniae*, B. spielmanii*, B. valaisiania* and B. miyamotoi sl***
Asia:	*B. afzelii*, B. garinii*, B. lusitaniae*, B. sinica, B. valaisiania* , B. yangtze* and *B. miyamotoi*** (The first isolation of *B. burgdorferi ss** in Southern China (11) was from a hare in 2011)
Japan	*B. garinii*, B. japonica, B. tanukii, B. turdi, B. valaisiania** and *B. miyamotoi*** (Whilst Japan is a part of the Asian continent; the studies examining LD differentiate as Japan is a "stand-alone" island)
Australia	*B. queenslandica* (*Borrelia* species found and cultured from rats in Richmond, Nth Queensland in 1962)

* Known to be pathogenic to humans **Relapsing Fever/ Lyme-like disease ***Lyme-like illness

See references 12-16 for sensu lato species and pathogenicity

Prevalence from a patient / advocate perspective:

From a perspective of someone who has been researching advocating and raising awareness of Lyme & Co., since 2010 one outstanding factor that I can attest to is Lyme patient numbers are increasing at a rapid rate. The pain and suffering of hundreds of people being ignored is something I would never have thought possible in Australia. The prevalence rate is increasing – or perhaps that would be better explained as ; the awareness of Lyme and vector borne illness is increasing – and people are becoming aware of the fact that their illness may in fact due to Lyme & other Co-infections/ vector borne diseases.

To expand on this a little below is an excerpt from a speech written with regards to the 'Changing patient experience in Australia': which was based on the raising level of Lyme awareness and patient numbers due to awareness and media events from 2010 through to 2013.

Karen Smith's Speech / Notes – Worldwide Lyme Protest: Sydney Event: May 10th 2013

Today, to highlight how each and every-one of us has made a difference and how far we have come, I am going to give a brief background of the changing patient experience in Australia, as I have experienced it, over the last few years. I will then hand over to Janice who will cover the political side of where we are currently at regarding the government's acknowledgement of Lyme in Australia. Janice will also cover, what we, as Lyme patients – not only in Australia, but in 27 other countries - are asking for with the actions of the Worldwide Lyme Protest.

For my part, I became involved a number of years ago with Lyme disease awareness, and thankfully, I can say in this time - much has changed regarding the patient situation and awareness in Australia.

I first heard the words Lyme disease in July 2010. At this stage I had been sick for just over a year and after an endocrinologist's appointment, in which the doctor mentioned the possibility of an underlying autoimmune disorder – I began searching the internet looking for a reason as to why my health had been deteriorating so badly. Very quickly I came across something that fit all my symptoms - Lyme disease!!

I continued to look on the internet the next day and all the information I first encountered stated that Lyme disease was not in Australia. I was so confused – as I was so sure that I finally had my answer with regards to my health problems. Finally I came across one website, that of Dr Peter Mayne, who explained that Lyme disease was in fact in Australia. At this time, Dr Mayne's site was the only alternative information to the NSW Health Website which stated that Lyme wasn't here.

This situation, the number of websites about Lyme in Australia was to change quite quickly, and by the end of 2010, both the Lyme Disease Association of Australia (late November 2010) and the Karl McManus Foundation (early December 2010) had websites published that gave the public further ways to access information about Lyme in Australia.

By January 2011 I had spoke to the ladies running these two organisations – Mualla McManus had lost her husband Karl in July 2010 and founded the Karl McManus Foundation, and Nikki Coleman, whose whole family was affected by Lyme, and had herself been very sick and in a wheelchair for a number of years had stepped into the role of the first president of the Lyme Disease Association of Australia early in 2010...

In 2010 – 2011 there was not a lot of patient awareness/ advocacy in the public arena. There were the two Yahoo groups started in 2009 by Rosemary (Lyme Oz) and Dona (Aussie Lyme). Though they provided a great way for patients to connect, there was not a lot of socialisation / advocacy within these groups – rather they were for helping with questions about treatment and testing by those who had already discovered that Lyme was indeed in Australia.

In April 2011, I joined facebook to make some noise and raise awareness about Lyme. Back then there were only a handful of Australian Lyme patients on facebook, and I was the only Queenslander at this time. On the days I was able to get out of bed, I connected with a lot of Lyme patients in America and Europe – mainly observing and learning as much as I could – whilst raising awareness about Lyme being in Australia on my personal facebook page.

.... By the end 2011 there were still only around a dozen Australian Lyme patients - that I was aware of - on facebook. This all changed in February 2012: This is when awareness and the number of Lyme aware patients in Australia began to grow - and hasn't stop since. Patients also started becoming more "connected" through facebook and support networks.

The change was brought about by a series of Today Tonight Shows – Which began on the 13th of February 2012. The night before the first of the series aired Belinda Baker (who was interviewed) started the first Australian Facebook support group "Aussie Lyme". It was great timing in that it allowed people searching for further information due to the awareness that the shows brought about to connect with others looking for extra information.

As well as a number of other Australian Lyme patients, I was also interviewed by Today Tonight, with my segment being aired in the second episode, on the 14th February. Considering my research into the denial of Lyme, I found it somewhat ironic that the person being interviewed just before me was Dr Jeremy McAnulty; NSW Director of Health Protection, denying the presence of "locally acquired Lyme disease".

In July 2012, I published the information accumulated from over 1,000 hours of research that I had done throughout 2010 and 2011 on my website: Lyme Australia Recognition and Awareness (LARA). It was the 4th Australian website providing information and a landing base for those looking for answers about Lyme in Australia. LARA was different to the other websites already existent in Australia, in that it was designed to provide, what as a researcher I went looking for: Answers as to how Lyme disease could underlay so many health problems, as well as how it was transmitted and survived within the environment and why the Australian government denies its presence. LARA answers these questions, and provides just under 1000 journal article references.

Since late 2012, early 2013, the number of websites and blogs with various information about / on living with Lyme disease in Australia has steadily increased. With the numbers in the Lyme community growing, the number of facebook support groups began growing throughout 2012 also. Separate state groups started in Western Australia and Queensland, and Lyme Australia & Friends (currently the largest in Australia was started on July 17th 2012). Now in 2013, there is over a dozen Australia wide, State, Local area orientated Lyme Support groups.

These increases in Lyme patient numbers / awareness have been brought about by protests and awareness events such as todays. The first of these was organised by Danielle Ryan and Dayna Parkinson. They rallied the Lyme community and organised the first ever Australian Lyme patient Protest outside of New South Wales (NSW) Health department in Sydney on September 14th 2012. Whilst the event was extremely successful, when the New South Wales (NSW) health department updated their website the following month, they only made minor updates to their online Lyme disease resources. The minor changes did not reflect the spirit of the discussion held.

Due to this, a second protest in Australia was organised by Rachel Robins and myself outside Queensland Health Department on November 23rd, 2012. Queensland health representative Dr Jeanette Young agreed to a meeting with representatives of the Lyme community though was not really open to discussions and would not commit to any action on behalf of the Queensland health department, simply deferring to the Communicable Diseases Network Australia (CDNA) review being conducted.

While preparing for the Queensland Protest, the notifications calling for interest from advocates around to world to start a Worldwide Protest event started appearing. My brain told me it was madness for my health to undertake such an endeavour, but I truly felt that this would be something the Lyme community around the world could get some much need attention by doing. So, on the 3rd November 2012, I signed up as Australia's International Representative and started the Worldwide Lyme Protest (WWLP) – Australia facebook page [now Global Lyme Project – Australia] and the Worldwide Lyme Protest Australia Discussion group [now Lyme Action Australia – Events Planning group] to connect Australian advocates holding State events. Janice Foster came on board almost immediately as Joint National Co-ordinator, and by February 2013 we had many volunteers joining us, and over a dozen events planned in Australia for May 2013. When we approached the Lyme Disease Association of Australia to sponsor the posters for the WWLP, their committee agreed and we are thankful that Sharon Whiteman / LDAA came on board to help with our project in March 2013.

Which brings us to the here and now: On behalf of Janice and myself – we send out a huge thanks to all of the State event co-ordinators, and to everyone that has helped with the events, and to those who will be attending the events around Australia this week-end. Together we can win this fight for Lyme recognition.

The Inaugural Worldwide Lyme Protest in May 2013 (for which the speech / notes were prepared for above) was very successful in terms of media and awareness around the world. It also brought a huge amount of awareness about Lyme disease Australia-wide. Some of this awareness was evidenced by the large influx of numbers into Australian Lyme patient support groups and patient queries to the LDAA.

From May 2013 the awareness and education continued, with the Karl McManus Foundation having the first Tick-borne Conference in Sydney that year, as well as their awareness events in September, followed by the Lyme Disease Association having their annual awareness month in October. From 2014 through to now, while the awareness and education events have been evolving and growing, over the years they have the one constant feature of continuing to increase awareness in Australia The number of associations / patient groups in Australia has also increased from 2012-13, with Chrysalis , Sarcoidosis and Lyme, Global Lyme & Invisible Illness Organisation, Multiple Systemic Infectious Disease Syndrome (MSIDS), WA ME/ CFS Lyme Association, Ruby Red Trust all forming over the years with the same cause – to raise awareness of Lyme and other vector borne illness'.

As the above outlines, we have gone from a relatively small community in 2010, to one that in 2016 has numbers in the thousands. Each year – the individual advocacy, associations, foundations, awareness events and media have served to continually get the word about Lyme and Co., in Australia out to the general public. The numbers have increased exponentially, not necessarily due to current infections, but because people are becoming aware of the disease being in Australia – and many people who have been sick for years, after seeing a media event, or coming across an awareness event, or simply talking to someone educating about Lyme, start to see the pieces of their health puzzle fall into place.

One very heartening aspect of all the awareness is that some people are joining the support groups on tick bite / acute infection – because they had read about Lyme, seen a media story etc., they were aware of potential problems that tick bites can bring and were able to seek immediate advice and help. A number of people have only required short term treatment due to awareness and immediate treatment.

Geographic Distribution

H. longicornis (Bush/Scrub Tick) Map and Recorded Tick Bite/ Lyme Cases LDAA

The *H. longicornis* tick as a vector of Lyme borreliosis in China. This tick species is in Australia and one that there is ample research provided below (Page 20) to indicate that it should be investigated as a vector of Lyme Borreliosis in Australia.

An interesting map comparison with regards to this is below: Maps show the H. longicornis Tick locations beside a map from the Lyme Disease Association of Australia who has been surveying patients with regards to a Lyme Borreliosis since 2012.

Distribution of *H. longicornis* : Bush / Scrub Tick

Recorded Tick Bite Map from LDAA Website.
http://www.lymedisease.org.au/stats/

Migratory Marine Pathways.

A study in 1995 (15) revealed "a significant role for seabirds in a global transmission cycle by demonstrating the presence of Lyme disease *Borrelia* spirochetes in *Ixodes uriae* ticks from several seabird colonies in both the Southern and Northern Hemispheres." It was noted that: "Of particular interest is the finding of suspected cases of Lyme disease in Australia and South Africa, although no Lyme disease-causing spirochete has been isolated from these regions yet. Most of the findings in Australia are based on serological data and clinical cases with symptoms typical of Lyme disease. Our finding of *Borrelia* DNA in I. uriae ticks obtained from the Crozet Islands and Campbell Island [New Zealand coast] suggests that Lyme disease enzootic foci are present in that part of the world" (15: Pg 3272-3).

Reports such as that above are being discarded as not problematic for Australia as the 'seabirds don't come close enough to the mainland'.

Attachment Three (*Migratory Marine Bird (sea and shorebird) sites around Australia's coastline)* shows that this is simply not the case and there is plenty of interaction with seabirds, all along the coastlines of Australia.

Mention of Seabirds was also made by John S Mackenzie (2013) in the Department of Health Scoping Study to develop a research project(s) to investigate the presence or absence of Lyme disease in Australia. John S Mackenzie September (The Scoping Study was commissioned by the Clinical Advisory Committee on Lyme disease established by Chief Medical Officer, Professor Chris Baggoley in 2013)

John Mackenzie: Page 9, Par 3: It is therefore plausible that certain *B. burgdorferi* s.l. strains could be brought to the Southern Hemisphere and enter local Australian ecosystems through intermingling between seabirds and land-based avian species, but most bird ticks do not bite humans, and if they did, would rapidly drop off before the opportunity to transmit the spirochaete. If cases of human infection were to result, they would be very occasional and localised.

A few notes/ queries with regards to the sentence above:

Tick species such as *H. longicornis* are mainly associated with mammals, though in early life stages (ie; nymph/larvae) are also associated with birds, including migrating seabirds. *I. Uriae* has also been associated with biting humans in Faroe Islands.

Foxes and dogs decimated seabird populations on Middle Island in Victoria between 2000-2005. They were able to access the island (Which has numerous seabird colonies) and come back to mainland at low tide. In some *Borrelia* species (relapsing fever) it has been shown that "rats and dogs can be infected through the consumption of infected rat brains or organs". Studies are required on other *Borrelia* species to ascertain this possibility also. Denying the possibility of human infection in the Australian environment due to the notion that "most bird ticks do not bite humans", seems quite illogical. It assumes that birds and the ticks on them are maintained in a closed ecological environment.

If the occasional and localised cases of human infection were to result – where do we propose that people get treatment, or who are the cases reported to, as they are told 'there is no Lyme in Australia'.

B. Methods to reduce the stigma associated with Lyme-like illness for patients, doctors and researchers

The stigma associated with Lyme borreliosis in Australia stems from those parties that are intent on holding on to the "status quo" that there is no Lyme disease here. Some patients that attend hospitals, or go to see a doctor are ridiculed, just for bringing up the suggestion that their symptoms, illness might be related to Lyme.

It is astounding that in other areas of medicine, it is acknowledged that there are constant changes to be kept up to date with. But apparently logical and educated minds are quite prepared to keep quoting that there is 'No Lyme in Australia' based upon research that dates back to 1994. Surely doctors, specialists, and all medical personal are interested in more up to date research when people's health and lives are put into their hands?

A part of the stigma no doubt stems from a lack of education about Lyme Borreliosis. It is such a broad field to learn about; one that even after years of research, there is new information coming out. It would be extremely difficult for someone to ever really understand everything there is to about Lyme. Ie: The various species that cause different clinical pictures, the different treatment modalities depending on length of time of illness and other co-infections, the modes of transmission, the vectors associated. It is a huge topic, and one where, with so many unknown / unexplained facts, that when many in the medical field go to a website – they are quick to read the information on the NSW Department of Health that says – Lyme is not in Australia. They then believe this information without question.

The deference to the 'perceived authority' of Westmead information on Lyme is, in my mind, only happening as those reading the website really do not fully understand what Lyme, or other vector borne disease are / how they are transmitted and maintained in the environment.

For example: The Department of Medical Entomology website page states: *None of the mammal species identified as reservoir hosts in the northern hemisphere are present in Australia".*

This is simply not correct. Mammals that have been identified as reservoir hosts in the northern hemisphere include, rats, mice, hares, rabbits, foxes, cats, dogs, cattle and horses. Ask people if they know what a reservoir host is, or the difference between that and a tick host – and you may get blank stares. The very real and sad truth is that Vector Borne disease information is just not being taught in medical schools or to the general public to be aware that ticks can carry serious infections.

Education is necessary! Medical professionals need to be provided with up to date information and learn about Lyme (and other Vector borne diseases) as a possible differential diagnosis in illness. General public awareness is also imperative. Awareness can lead to early treatment of an acute infection, saving people from years of illness, and then years of treatment/ trying to repair the damage done from long term/ misdiagnosed infections.

C. The process for diagnosis of patients with a Lyme-like illness, with a specific focus on the laboratory testing procedures and associated quality assurance processes, including recognition of accredited international laboratory testing

The problems with Clinical and Serological Issues were examined in detail in Attachment One: *Lyme Disease: A Counter Argument to the Australian Government's Denial (Pages 7-9)*

There has been various updates to the testing procedures in Australia since the Counter-argument was written in 2012, though much of the information is still relevant. I have not familiarised myself with the latest literature and updates with regards to Australian testing to comment to what degree, if any, the various laboratories testing for Lyme have changed their procedures.

One thing that is obvious however is that any test result that is reported as a positive, without travel to an 'endemic' country, is then reported as a false positive test as 'Lyme is not in Australia'. It seems we are caught in a vicious circle of around and around and until research is invested and a causative agent is discovered in Australia this cycle will continue.

Research is needed, and I would defer again to the notion that that Lyme disease is primarily a clinical diagnosis as testing for the *Borrelia* bacteria is limited in so many ways, especially due to the number of species and strain variations within the species:

- Pathogenicity and species diversity information is from Attachment Two of this submission: *Lyme Disease / Borreliosis: An Overview of Lyme and Direction for further Research required in Australia (Pge 10)*

Pathogenicity and species diversity issues underlying identification of Borrelia

The pathogenicity of bacteria (or any organism able to cause illness) refers to its ability to bring about disease in a host. *Borrelia* species vary in their ability to cause illness in different animal species, including humans. While all the species listed in Table One above have been isolated and identified from ticks and animals, and therefore can potentially cause disease, it is not until a species has been isolated from human tissue, that it is acknowledged as pathogenic to humans.

The ability to understand the pathogenicity of each species and the development of adequate diagnostic/ testing procedures to ascertain human infection status is made that much more difficult by the fact that within the above mentioned species there are 100's of strain variations (eg:17-24) involved. For example, until recently *B. bavariensis* was known *as B. garinii OspA serotype 4*. Sequence analysis and testing revealed that this strain (serotype 4) was specific to rodent hosts (and unable to survive bird serum), with the opposite being shown for *B. garinii* serotypes 3,5,6 and 7, which are bird associated strains, and unable to survive in rodent serum. Due to the sequence analysis and host differences, *B. garinii OspA serotype 4* was therefore classified as a separate species, *B. bavariensis* (17). Another brief example is that vector differences, as well as sequence analysis, reveals that the *B. garinii* and *B. valaisiania* strains from Europe differ from the *B. garinii* and *B. valaisiania*-related strains from Asia (18,19).

These above brief examples outline why it is "important to develop alternative identification tools which are able to distinguish *Borrelia* strains not only at the specific level but also at the intraspecific level" (25: Pg 509). Understanding that there is such an enormous number of strain diversities, even within species of *Borrelia*, allows for a better appreciation as to why Lyme disease is primarily a clinical diagnosis. When testing for *Borrelia* infection, it is imperative that there is an understanding that the accuracy of the tests are limited by various factors, one of which is the species diversity, and that for more accurate testing and diagnosis, "the choice of a *B. burgdorferi sensu lato* strain for an antigen in serological testing is important" (26: Pg 52).

D. Evidence of investments in contemporary research into Australian pathogens specifically acquired through the bite of a tick and including other potential vectors

Current research into Australian pathogens is being undertaken by Murdoch University in Western Australia (via a Bayer funded grant) and the Sydney University Tick Borne Diseases Unit (Karl McManus Foundation / Charity funded).

Government based research ceased after the publication of 1994 study by Russel and others. As previously mentioned, the problems and inconsistencies with the study's conclusions and methods are examined in Attachment One: *Lyme Disease: A Counter Argument to the Australian Government's Denial" K. Smith 2012*

Funding, rather than a concern for human health also appear to play a big role in a lack of government funded research into vector borne illness since the 1990's in Australia. While the abstract of Playford and Whitby (1996) directly below shows that it was apparent that there were problems associated to tick bites in Australia, a paper by Richard Russel *(Vectors vs Humans in Australia – Who is on Top Down Under? An Update on Vector- Borne Disease and Research on Vectors in Australia. Journal of Vector Ecology),* not only shows there were concerns, but that the funding was not there to follow them up.

From: Playford G and Whitby M (1996) Tick-borne diseases in Australia ; 25(12):1841-5.

Abstract: "**Tick bites are a common problem in Australia and an important cause of morbidity in medical and veterinary practice.** Complications include local inflammation and infection, paralysis and transmission of various pathogens. Over the past three decades, several new tick-borne diseases have been recognised both in Australia and overseas. The importance of these diseases has also increased, in part due to greater recreational activities occurring in tick infested areas. **However, our understanding of the microbiology and epidemiology of many of these diseases is incomplete".**

Richard C Russel: Vectors vs Humans in Australia – Who is on Top Down Under? An Update on Vector-Borne Disease and Research on Vectors in Australia. Journal of Vector Ecology: 1998 Jun;23(1):1-46
Proceedings : Second International Congress of Vector Ecology, Orlando, Florida, 19-24 October 1997

Page 3:

Australia continues to have problems with vector-borne diseases; however, apart from the mosquito-borne arboviruses, there is relatively little activity in research, prevention or control, and there is much left to be desired with respect to the mosquito/arbovirus situations. A more detailed examination of the current state of the various situations will be presented below. Overall, there is not a lot of optimism; both academic involvement and funding for vector-related research are diminishing; taxonomists and other researchers in government institutions are disappearing; interest by public health authorities is gravitating towards epidemiological number crunching and more sophisticated reporting, with less public health action.

Richard C Russel: Vectors vs Humans in Australia – Who is on Top Down Under? An Update on Vector-Borne Disease and Research on Vectors in Australia. Journal of Vector Ecology: 1998 Jun;23(1):1-46

Conclusion: Page 31:

CONCLUSIONS

With respect to future activities in vector ecology and vector-borne disease research in Australia other than that associated with mosquitoes, there appears to be little that could be foreseen at this time. There is virtually no prospect of ongoing research activity with the flea- or mite-borne diseases mentioned above; they are too sporadic by nature and little interest can be instigated or sustained unless there is an increasing incidence of one of the currently known pathogens, e.g. scrub typhus, in a politically sensitive area such as an important tourist locality, or perhaps a number of outbreaks of murine typhus in various states. However, these are unlikely, given the ecology of the vector/host/pathogen cycles, and effective drug treatment provides a ready answer to the occasional instances of pathogen activity—provided there is accurate and early diagnosis.

Despite the greater incidence of tick-related problems, there is also little to be optimistic about with prospective tick research. The groups working with tick-problems, investigating the toxin and allergens in *Ix. holocyclus* saliva, the rickettsial infections, the (?)spirochaetal infections, and the viruses, have all been disbanded as funding has disappeared, and retirements and redundancies have taken their toll. Notwithstanding, the discovery of a new infectious organism (e.g. a spirochaete that can be shown to be responsible for the so-called Lyme disease syndrome in southeastern Australia) may bring a renewal of interest and funding.

That leaves the mosquito-borne pathogens; and if there is any real optimism for future research activity, it lies therewith. The appearance of JE virus in Australia, increases in activity of Barmah Forest virus, and recent activity of RR virus in the capital cities has excited some overdue interest in government circles. A number of the issues are seen to be of national significance and there have been recent proposals, supported by the Commonwealth Department of Health, to increase interstate collaboration through State Health Departments, and university and research institute interests, particularly with regard to increasing the opportunities for early detection of MVE virus activity. There is strong support for a national arbovirus strategy, particularly for a standardized system for national surveillance and for the coordination of strategic applied research.

....

Hopefully, Australia is moving forward in this area at least. In recent years, Western Australia has been the state with the greatest interest and activity in promoting arbovirus disease research, and Queensland has been the focus of improvements in mosquito control efforts. New South Wales and Victoria have managed to sustain arbovirus surveillance programs, and the latter supports some mosquito control efforts. Recently in New South Wales, there has been an initiative by the Minister for Health for the development of a 'Green Paper' for the NSW Cabinet, proposing a whole of government approach to mosquito control and mosquito-borne disease for the state, and if this is initiated it may signal a new era in Australia with respect to vector-borne disease surveillance and control—something that is seemingly demanded, as indicated by the high incidence of disease affecting our communities. Time will tell.

Acknowledgments

A draft of the manuscript was read by Annette Broom, Stephen Doggett, Brian Kay, Michael Lindsay, and Peter Whelan; I am grateful for their comments and support.

E. Potential investment into research to discover unique local causative agents causing a growing number of Australians debilitating illness

Thorough and up to date investigations are required in order to identify the various *Borrelia* species within the animals in Australia, and to ascertain what species they are and whether they are pathogenic to humans. Research should also include examination of potential tick vectors and reservoir hosts to ascertain what bacteria, viruses and protozoa they carry.

Research spanning decades indicates that there is *Borrelia* in the blood of animals in Australia. With the past and ongoing introduction / importation of animals, their interaction with other mammals and birds within the Australian environment the spread of pathogens is inevitable. Migrating seabirds, the ticks they carry and their interaction in the Australian environment also means that new pathogens are able to be introduced into the environment at any given time. This fact was highlighted with the death of the New South Wales male in 2011 due to a *Babesia microti* infection. *Babesia microti* is not endemic to Australia; rather it is an American species of *Babesia.* Research on how these protozoa came to be in the Australian environment, and how someone contracted it, and subsequently died, still does not appear to have garnered research or public education with regards to *Babesia* in Australia.

It must be acknowledged that a number of areas regarding the presence and the transmission of Lyme disease in Australia have been completed ignored for many years. The absence of adequate research makes the rebuttal of the existence of Lyme in Australia premature and arguably naive. Up to date research is necessary in order to better understand, diagnose and treat not only Lyme, but other vector borne diseases that may be undiagnosed in thousands of Australians.

Richard C Russel: Vectors vs Humans in Australia – Who is on Top Down Under? An Update on Vector-Borne Disease and Research on Vectors in Australia. Journal of Vector Ecology: 1998 Jun;23(1):1-46

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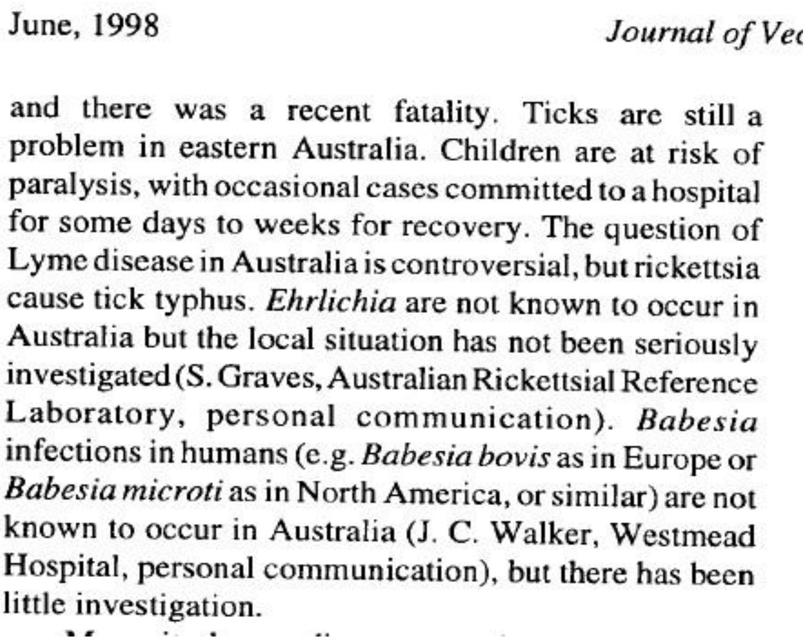
Russell on lack of investigation with regards to Babesia – In 1998!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and there was a recent fatality. Ticks are still a problem in eastern Australia. Children are at risk of paralysis, with occasional cases committed to a hospital for some days to weeks for recovery. The question of Lyme disease in Australia is controversial, but rickettsia cause tick typhus. *Ehrlichia* are not known to occur in Australia but the local situation has not been seriously investigated (S. Graves, Australian Rickettsial Reference Laboratory, personal communication). *Babesia* infections in humans (e.g. *Babesia bovis* as in Europe or *Babesia microti* as in North America, or similar) are not known to occur in Australia (J. C. Walker, Westmead Hospital, personal communication), but there has been little investigation.

- This information is a section from Attachment Two of this submission: *Lyme Disease / Borreliosis: An Overview of Lyme and Direction for further Research required in Australia (Pgs 15-23) It is produced in full below for those that may not have the opportunity to read the entire attachment.*

Tick Vectors and Reservoir Hosts of Lyme / Borrelia in Australia

Initial investigations into Lyme disease in the Northern Hemisphere revealed that four Ixodes species (*scapularis, pacificus, ricinus, persulcatus),* from the Ixodidae family of ticks underlay the transmission of Lyme disease/ borreliosis. As Table Two (Tick Vectors or Lyme Disease / Borreliosis) demonstrates, since the early research into Lyme, numerous other species of ticks have been found to be implicated in the Lyme transmission cycle.

The discussion in this segment examines four tick species from the Ixodidae family that are listed on Table Two that have been recorded as being in Australia. The ticks are also explored in relation to their respective animal hosts, with the presence of both the bird and mammal hosts in Australia being discussed. A number of other Ixodidae tick species that have been implicated as being involved in the *Borrelia* cycle are also examined.

In order to fully appreciate why the information presented in this section is relevant to understanding the extremely high possibility that the *Borrelia* bacteria underlying Lyme is in the Australian environment, an outline of this segments discussion is as follows:

- *Examination of Ixode Ticks and Bird species involved in the Borrelia cycle in Australia:* Ixodes ticks that are listed in Table Two as capable tick vectors of Lyme and that have been recorded in Australia include the *I. Uriae* and *I. Auritulus* species*.* As these are both bird ticks, their role in the *Borrelia* cycle is discussed in conjunction with bird hosts that have been shown to be either simply hosts/carriers of the tick, or those that are also reservoir hosts of the *Borrelia* bacteria. Also discussed are various birds that have been introduced into Australia, and are known reservoir hosts in the Northern Hemisphere.

- *Examination of* Haemaphysalis *Ticks and Mammals involved in the Borrelia cycle in Australia:* Haemaphysalis ticks that are listed in Table Two as capable tick vectors of Lyme and that have been recorded in Australia are the *H. bispinosa* and *H. longicornis* species. While the immature (larvae, nymph) tick may feed on birds, these ticks are associated more so with their mammal hosts. These two ticks are discussed in conjunction with mammal hosts that have been shown to be either hosts/carriers of the tick, or those that are also reservoir hosts of the *Borrelia* bacteria.

  In order to explain a little the importance of animal introduction and importation, the way in which Lyme can present as a clinical illness and contact transmission in animals is briefly outlined. The introduction and importation of various mammal species into Australia that have been shown to have varying reservoir host competence of *Borrelia* underlying Lyme is also discussed.

- *Rhipicephalus Ticks: R. sanguineus* and *R. Microplus.* These tick species are found in Australia. They are not listed in the above tick vector table, however they have also been implicated in the *Borrelia* cycle, in that they have been found to carry the *Borrelia* spirochete and are therefore possible vectors of *Borrelia*.

- *Dermacentor Ticks*: Although this family of ticks is not in Australia, this species is also briefly mentioned in order to demonstrate that when looking at the vector competence of a particular species of ticks that findings on competence may be altered when ticks are examined in co-feeding studies (numerous tick species feeding together - which would emulate the natural environment), as opposed to ‘traditional laboratory’ studies where only one tick species is commonly examined.

- *Various Ixodidae Genera:* In 1994 research reported by Russel et al., spirochete like objects were cultured from a number of tick species. These included the *Ixodes holocyclus*, *Haemaphysalis bancrofti* and the *Amblyomma Morelia.* These findings are looked at very briefly.

Examination of Ixode Ticks and Bird species involved in the Borrelia cycle in Australia

The role of the seabird (*I. uriae) and bird (I. auritulus)* ticks is maintaining/spreading the *Borrelia* bacteria to the animal hosts within their environment. However, unlike nest dwelling ticks whose ecosystem is limited, the fact that birds are the hosts has widespread ramifications. Birds can be both biological carriers (reservoir hosts) of many different pathogens including *Borrelia* (1), as well as parasitic carriers of blood sucking insects such as ticks. Anderson and Magnarelli first reported the importance of birds as reservoir hosts and their role in transmitting the *Borrelia* bacteria and ticks into new geographic areas in 1984 (2). In combination this means that not only can birds drop infected ticks into new environments (3-8), but as reservoir hosts, immature ticks that feed on them may become infected and spread the disease to other birds and mammals during their next feed.

Land birds can spread *Borrelia* across continents, whilst migrating seabirds can spread the disease across the Northern and Southern hemispheres (9-16). It must also be noted that while the primary role of *I. uriae* appears to be the widespread dispersal of *Borrelia*, these ticks are known to bite humans (17-18) and are the suggested vector for human disease on the Faroe Islands (18).

Seabird Tick Ixodes uriae and Associated Bird Vector & Reservoir Hosts

The *I. uriae* species is found Australia-wide, including offshore islands (19). It is prevalent in both the Northern and Southern hemispheres and is “closely associated with many species of colony-nesting marine birds” (20). In 1993 Olsen and others (20) extended on the finding that land-birds as well as mammals could be infected by *Borrelia*, with their research revealing that even in the absence of mammals, *Borrelia* was maintained by seabirds within the environment. A further study in 1995 (21) revealed “a significant role for seabirds in a global transmission cycle by demonstrating the presence of Lyme disease *Borrelia* spirochetes in *Ixodes uriae* ticks from several seabird colonies in both the Southern and Northern Hemispheres.” It was noted that: “Of particular interest is the finding of suspected cases of Lyme disease in Australia and South Africa, although no Lyme disease-causing spirochete has been isolated from these regions yet. Most of the findings in Australia are based on serological data and clinical cases with symptoms typical of Lyme disease. Our finding of *Borrelia* DNA in I. uriae ticks obtained from the Crozet Islands and Campbell Island [New Zealand coast] suggests that Lyme disease enzootic foci are present in that part of the world” (21: Pg 3272-3).

There are numerous species of marine birds that migrate between the Northern and Southern Hemispheres to Australia, as well as birds that migrate between New Zealand and Australia each year. In fact, of the 359 species of marine birds worldwide, 78 different species breed on Australian islands and shores. In comparison to other countries, Australia is second only to New Zealand who, with 84 species has the greatest diversity of marine birds anywhere in the world (22). These marine birds are generally broken down into either seabird or shorebird/wader families (23-25). The seabirds consist of around 20 species and are those that are most commonly found on, over or near the ocean, including shearwaters (more commonly known as mutton birds), albatrosses, penguins, frigatebirds, gulls, cormorants and terns. Some seabirds (such as cormorants) may also be found in other areas surrounding water, such as lakes and wetlands, and can become common in urban areas. Shorebirds/ waders are those which are commonly found on coastal shores, including beaches, rocky shores, mudflats, tidal wetlands and lagoons. These include many species of plovers, sandpipers, stilts, curlews and snipes.

In Australia (and many other countries) seabirds and shorebirds are not restricted to separate areas and share many locations with each other as well as land birds and mammals, including humans: “Some seabird colonies are very accessible to large numbers of people. This is especially true of small islands in mainland estuaries or islands that are linked to the mainland in some way or are close to big cities (26: Pg 74)”. The shorebirds from the East Asian-Australasian Flyways alone have 118 internationally important sites that encompass the coastline as well numerous inland areas of Australia (27: Fig 20; pg 210), whilst seabirds nest in many areas on the mainland, as well as on numerous islands off almost every state in Australia. (See Attachment A – Seabird areas for more specific locations, including those on mainland Australia)

Seabirds such as the Sooty and Short-tailed Shearwaters, Common and Little Tern, Gulls, and shorebirds such as; Bar tailed Godwits, Red Knots, Sandpipers, Curlews and Snipes migrate to Australia from California, Europe, Asia (including Russia) and Japan (26-34). Lyme disease is endemic in all of these regions. With over 20 million migrating seabirds and 3 million plus shore-birds breeding on Australian Islands and shores each year, it is inconceivable that the health departments of Australia continue to ignore the long established knowledge that “Migrating birds contribute to the spread of B. burgdorferi sl and of infected tick vectors along migration routes” (35).

Along with the seabird tick (*I. uriae*), a number of different ticks have been associated with *Borrelia* and different bird hosts (eg: *I. auritulus, I. dentatus, I. frontalis, H. flava, H. leporispalustris*). Of interest for Australia is the finding that the *I. auritulus* tick is a vector of *Borrelia* (36-38).

Bird Tick Ixodes auritulus and Associated Bird & Reservoir Hosts

The *I. auritulus* is a native tick species of Tasmania (39-41). Birds continually spread the known distribution range of ticks (eg: 37-38) and as numerous species of birds, such as the Silvereye (Zosterops lateralis: passerine), migrate from Tasmania and disperse into regions of Victoria, New South Wales and south-eastern Queensland there certainly is the possibility this tick has been spread throughout mainland Australia. The common blackbird (passeriforme) is also abundant in Tasmania (and other areas of Australia), and is a bird that has been regularly identified as a reservoir host of *Borrelia*.

Birds of the Passeriforme order, or passerine birds, are more commonly known as perching or song birds (42), and include over 5000 species grouped into approximately 110 families that may be partially (travelling long distances within the same continent) or fully (travelling across continents) migratory. Numerous passerine species have been identified as reservoir hosts of *Borrelia* and include; Robins, Thrushes, Redstarts (formerly thrush family), Sparrows and Tits (eg:2, 9-11,38-40). Thrushes (Turdiae family) appear to be extremely competent reservoir hosts: *Borrelia* is thought to have been introduced into Japan from two species of thrush (Turdus cardis and pallidus) that migrate from Asia (43-45), whilst Song thrushes (Turdus philomelos) and the Eurasian/Common Blackbirds (Turdus merula) are consistently found to be competent reservoir hosts of *Borrelia* in Europe (46-49).

Both Song thrushes (Turdus philomelos) and the Eurasian/Common Blackbirds (Turdus merula) have been introduced into Australia: Song thrushes are established in Melbourne after being introduced in the 1850's. The Eurasian/Common blackbirds were introduced into Melbourne and South Australia in the 1860's and 1870s and are now widespread. They range throughout coastal and lower inland regions of South Australia, the whole of Victoria and New South Wales and spread into Queensland in 1986, breeding in regions around Toowoomba and the Highfields (50-52). They are also "abundant in Tasmania and have successfully colonised offshore islands such as Lord Howe Island, Norfolk Island, Kangaroo Island and Flinders Island" (50: pg 8).

It appears that at least one government department in Australia is aware that Blackbirds can carry *Borrelia*. A risk assessment report from the Queensland State Government (Biosecurity Queensland), examining the potential spread of Blackbirds into Queensland, makes this note with regards to the diseases associated with Blackbirds: "Blackbirds are often infected with intestinal and haematozoan parasites, as well as external parasites such as ticks, which can then infect other blackbirds with illnesses such as Lyme disease" (50: pg 7). Unfortunately, they do not seem to understand the full impact of that statement, which is, that the ticks which feed on both bird and mammal hosts can also spread Lyme disease to other animals within the environment, including humans.

There is the possibility that the *Borrelia* bacteria was brought to Australia with the introduction of blackbirds. However, the presence of the Blackbirds in Tasmania, mainland coastal areas and offshore islands of Australia would no doubt mean that the largest threat of the Blackbirds (and the other reservoir hosts) acquiring and spreading *Borrelia* to other animals and birds would come from sharing the environment with the millions of marine birds that migrate to Australia each year.

In addition to the song thrushes and common blackbirds (Passeriformes), other species of birds that have been introduced into Australia, and are competent reservoir hosts of *Borrelia*, include birds from the order of *Galliformes*: wild turkeys (53), pheasants (54-55), quails (56) and *Anseriformes*: Mallard ducks (57).

Examination of Haemaphysalis Ticks and Mammals involved in the Borrelia cycle in Australia

The *Haemaphysalis* tick species, *bispinosa* and *longicornis* have both been recorded in Australia and have been found to be involved in maintaining and transmitting *Borrelia*. Whilst the immature (larvae, nymph) tick may feed on birds, these tick species also have a close association with mammal hosts. Bearing in mind this association, these ticks are discussed in conjunction with the mammal hosts that have been shown to be either simply hosts of the tick or those that are also reservoir hosts of the *Borrelia* bacteria. In order to further outline the role that mammals play in the maintenance and spread of *Borrelia* within the environment, the following section also briefly examines clinical illness in animals. This not only serves to give a practical example of which animals are reservoir hosts and can carry *Borrelia* (as well as develop a clinical illness); it also helps to reveal the concerns associated with the introduction and importation of numerous mammal species into Australia.

The *H. bispinosa* and *H. longicornis* ticks are very similar, and have the same host preferences. For example, immature ticks feed on birds and hares and hosts of the adult tick include various large domestic and wild mammals such as dogs, sheep, goats, deer, cattle, horses (1-2). Both tick species have been found to be vectors of *Borrelia* in southern China (3-6). *Borrelia* strains isolated from the *H. longicornis* tick include *B.garinii*, *B. afzelii* (5), and *B. valaisiania* (6). Studies also show that as well as a high infection rate of *Borrelia*, *H. longicornis* also carries co-infections such *as Bartonella, Anaplasma*, and *Ehrlichia* (7-8).

Haemaphysalis bispinosa

The H. Bispinosa tick species has been recorded in Australia (9-10). Further research reveals that the ticks recorded were found to be synonymous with *H. longicornis* (11), and Hoogstraal and others (12) reclassified the species of *H. bispinosa* from Australia and New Zealand as *H. longicornis*. Despite the reclassification, this species is mentioned here due to its original listing as being in Australia, its immense similarities with the *H .longicornis,* and that these two ticks are listed as synonymous on many occasions in the literature. It is also worthwhile noting that there have been other tick vectors of *Borrelia* that have been originally thought to be two separate species before it was found they were in fact the same species. These include; *I. scapularis* and *I. dammini*: When it was found that they were in fact the same species of tick, *I. dammini* was re-classified as *I. Scapularis* ; *I. spinipalpis* and *I. neotomae*: Research in 1997 found that *I. neotomae* and *I. spinipalpis* were actually one and the same species, *I. neotomae* was subsequently re-classified as *I. spinipalpis*.

Scrub Tick Haemaphysalis longicornis and Associated Mammal Vector & Reservoir Hosts

The *H .longicornis* is more commonly known as the scrub or bush tick (or cattle tick in New Zealand). It was introduced into Australia on cattle from Northern Japan and was first recognised in 1901 in north eastern New South Wales. It is now established along coastal areas in Queensland, New South Wales, and through north eastern Victoria (esp Murray Valley) and Western Australia (13-14). The bush tick was first recognised at Walpole in Western Australia in 1983, though for how long it had been in the state is unknown. As there have been no reports of the tick in South Australia or the Northern Territory, its presence in Western Australia cannot be attributed to the natural spread of the tick and "The source of introduction to Western Australia has never been traced" (15). Two possible methods of introduction to consider are: Either via cattle transported to the district from states in Australia where the tick is common, or via migrating birds. In a study of New Zealand tick fauna it was noted that "Haemaphysalis spp. could be introduced …by migrating birds from Asia, a major source of members of this genus" (16). Walpole, where the bush tick was first recognised in Western Australia, is adjacent to Nornalup and Walpole Inlet Marine Parks, home to around 150 bird species including migrating shore and sea birds (17-18).

The hosts of the *H. longicornis* tick (19) include numerous animals that have been found to be reservoir hosts for *Borrelia* and have been introduced or imported into Australia from countries that are endemic for Lyme disease. These animals include; smaller reservoir hosts - mice, rats and hares : domestic animals - cats and dogs : medium to large animals - foxes, cattle, horses, sheep and deer (20) that have varying levels of reservoir competence. Importation of animals carrying *Borrelia* can occur as the animal may show no obvious signs of clinical illness.

To examine the very real likelihood of the bacteria underlying Lyme being in Australia, the following extends a little on clinical illness in animals, reservoir competence and the introduction/importation of the aforementioned animals into Australia.
In looking at animals brought into Australia from countries where Lyme disease is endemic, it should be noted that while the first reported cases described as Lyme disease were in the 1970's, DNA studies of

ticks from museums has revealed that the *Borrelia* bacteria underlying Lyme has been in the environment since the 1800's (21-24). A study in Europe concluded, "residents of Europe have been exposed to diverse Lyme disease spirochetes at least since 1884, concurrent with the oldest record of apparent human infection" (21), and a study in America revealed, "These studies suggest that the agent of Lyme disease was present in a suitable reservoir host in the United States before the turn of the century and provide evidence against a hypothesis of recent introduction of this zoonotic agent to North America" (23).

Clinical Illness in Animals

In addition to humans, the only animals that may develop a clinical illness due to a *Borrelia* infection appear to be dogs, cats, horses and cattle (25). The primary symptom in all these animals is arthritic in nature, where inflammation of joints and limbs may lead to lameness.

Dogs are competent reservoir hosts (26) and seem to be the most susceptible to developing a clinical illness (25, 27). As they are generally in close contact with humans, rates of *Borrelia* infection/exposure in dogs has also been studied in order to try and ascertain what the degree of risk of *Borrelia* exposure to humans may be within particular areas/environments (28-30). Apart from lameness (shifting leg lameness in particular), other symptoms in dogs may include; anorexia/weight loss, malaise, neurological dysfunction (25), severe polyarthritis (27), renal lesions (31,32), splenomegaly/ lymphadenopathy, intraocular inflammation (33) abnormal gait and convulsions (34). Cats are more prone to asymptomatic infections (33), though as well as lameness they may develop; fever, anorexia, fatigue (35-36), and kidney problems (37).

Asymptomatic infections seem to be the most common in horses and cattle (38-41), although clinical illness can develop with symptoms in both animals including lameness, uveitis and weight loss (38, 41-43). Other signs in cattle include decreased milk production and abortion (42, 44,45), with head tilt, encephalitis (46,47), aborted, reabsorbed foetuses and foal mortality also being reported in clinical disease in horses (48,49).

Contact Transmission in Animals

Borrelia spirochetes have been found in the urine of infected dogs (31, 50) horses (45, 51) and cattle (45), in both symptomatic and asymptomatic animals. Studies on mice found that the spirochetes in urine remained viable for 18-24 hours and concluded that "Urine may provide a method for contact non-tick transmission of B. burgdorferi in natural rodent populations particularly during periods of nesting and/or breeding" (52: pg 40). Evidence for direct contact transmission has been demonstrated in mice (53) and further studies are required in larger animals to ascertain the potential for the *Borrelia* spirochete to be transmitted simply by being in close contact with an infected animal.

Importation of Animals into Australia: Dogs, Foxes, Cattle, Horses, Sheep and Deer and their involvement in the maintenance and transmission of Borrelia

Dogs are currently able to be brought into Australia from numerous countries in Europe, Asia and the United States (54). They are subjected to a 30 day quarantine, with requirements for rabies vaccination and blood tests for various pathogens (ie: *Ehrlichiosis, Brucellosis, Leishmaniosis, Leptospirosis*), though this does not include *Borrelia* infections (55). Red foxes (*Vulpes vulpes*) are competent reservoir hosts (56-57) and may also carry tick vectors into new geographical areas (58). Foxes were introduced into Australia from Europe in the 1870's. Their range spread across southern Australia in the late 1800s and early 1900s and foxes are now widespread across the continent (59). They are considered a pest in all regions of Australia (eg: 59-60), and in NSW they are listed as responsible for the extinction of several species of native fauna including numerous species of ground-nesting birds (59). On Middle Island in Victoria (home to Little Penguin, Short-tailed Shearwater and Black Cormorant colonies), foxes and dogs that crossed to the island at low tide reduced the penguin numbers from 600 to less than a dozen in between 2000-2005 (61).

The foxes and dogs interaction with the birds has the potential to spread *Borrelia* through the exposure to ticks and from consumption of the birds. If ticks attach to the foxes and dogs, not only can the ticks directly pass on any pathogens they carry, the ticks are also relocated into environments that the animals roam. As with contact transmission, a vector (tick) may not need to be involved in spreading the *Borrelia* bacteria, with research examining relapsing fever *Borrelia* species revealing that infection can be passed on through the consumption of *Borrelia* infected brains and organs (62:cited in). Further research to determine whether this mechanism of transmission may also occur in the *B.B sensu lato* or *B. Miyamotoi* Borrelia groups is required.

Cattle and horses are “low level” reservoir competent hosts, dependent on varying strains of *Borrelia* (63), with reservoir competency still to be assessed with a number of different pathogenic strains. Cattle importation to Australia was suspended relatively recently due to outbreaks of Bovine Spongiform Encephalopathy (BSE) in other countries. Until the BSE outbreaks, cattle were imported from the United Kingdom (UK) until 1988 and from other European countries until 1991, with the suspension being extended to include cattle from Japan in 2001, Canada in 2003 and the United States (US) in 2004 (64-65). Lyme disease has been reported from all of these countries since the late 1970’s, and/or early 1980’s. Horses are still able to be imported from many countries, including the US and with regards to Lyme disease they only require vet certification that “After due inquiry, for 60 days immediately before export, the horse has not resided on any premises in the United States where clinical, epidemiological, or other evidence of contagious …. equine piroplasmosis, horse pox, or Lyme disease has occurred during the previous 90 days” (66). With some animals carrying asymptomatic infections, this certification does not rule out that animals imported will be free of *Borrelia* bacteria.

Sheep and deer may develop antibodies to *Borrelia* infections (67-70), though studies regarding their role as reservoir hosts are mixed, with some studies concluding that they are competent reservoir hosts (68-72), and others finding that their role is limited to that of a host animal supplying a blood meal for the tick (73-75, 63). As with many animals, the differences found in reservoir competency with regards to sheep and deer may be due to species diversity of the animals (eg: there are around 44 recognised species of deer within 17 genera) or *Borrelia* species differences (eg: lizards are not a competent reservoir hosts of the *B. burgdorferi ss*, species, however they are for *B. lusitaniae*) and needs further examination (63). Currently sheep are only permitted to be imported into Australia from New Zealand, with importations from other countries ceasing in 1952 (65). Deer have been introduced into Australia from Europe since the late nineteenth and early twentieth century’s. Whilst over a dozen species of deer have been introduced, only six of these species survived the Australian environment (76). These deer (fallow, red, chital, rusa, sambar, and hog deer) have formed wild populations in Australia, with population numbers estimated to be 200 000 in 2004 (77). Commercial farming of four of these species (rusa, red, fallow, and chital) began in 1971, and in order to increase commercial herd numbers, the importation of a fifth species, the North American elk (wapiti), from Canada began in 1985 (78-79).

Apart from varying levels of reservoir competency, the medium to large animals are regarded as maintaining the *Borrelia* bacteria within the environment by providing the tick with a host for a blood meal, with studies finding deer populations correlated with tick density and human incidence of Lyme disease (80-81). The presence of larger host animals may also amplify the *Borrelia* infection within the environment through tick co-feeding (73, 82), with one study concluding that sheep “can transmit localized infections from infected to uninfected ticks co-feeding at the same site on the sheep's body” (73: pg 591).

In addition to the larger animals discussed above, smaller mammals that are competent reservoir hosts of *Borrelia* in the Northern Hemisphere, that have also been introduced into Australia include; the house mouse, the black and brown rats and the European Hare. The introduction of these mammals’ and their role in the *Borrelia* cycle is discussed in greater detail in this overview’s complimentary report, *‘Lyme Disease: A Counter Argument to the Australian Government’s Denial’.*

As well as the possibility that the previous and ongoing importation of animals into Australia has seen the introduction of various *Borrelia* species, it should also be noted that research from the 1950’s revealed *Borrelia* in Australian animals. A study conducted by Mackerras in 1959 reported that *Borrelia* was found in the blood of cattle, kangaroos, bandicoots and rodents (83). The *Borrelia* in cattle was identified as *Borrelia* theleri (agent of bovine borreliosis), transmitted by the cattle tick (*R. microplus*) (83), whilst the *Borrelia* found in rats in north-western Queensland (Richmond area) was determined to be a new species of *Borrelia* and named *B. queenslandica* (84). The vector *of B. queenslandica* was not ascertained (84) and the species of *Borrelia* in kangaroos and rodents not identified (83). Further to the 1950’s research, other reports involving animals in Australia include the findings of positive serology (Immunofluorescence antibody test - IFAT) for *Borrelia burgdorferi* on a cattle property in Camden NSW in 1989 (85), with another study of dogs in NSW revealing that 6 of 239 (2.5%) of the dogs tested in were seropositive for borrelia (86).

Other Ixodidae Tick Species

Rhipicephalus Ticks

Borrelia has been found in ticks of the *Rhipicephalus* genera, though their competence as vectors (rather than just carriers) is an area of contention that requires much further research. Two Rhipicephalus species that are in Australia are discussed briefly below.

Brown Dog Tick: Rhipicephalus sanguineus

R. sanguineus, or the brown dog tick, is located worldwide. In Australia, it is verified as present in every state apart from Tasmania (1: CSRIO info, last updated 2004). It is a tick of "great medical and veterinary significance being the vector and reservoir of many human and animal pathogens" (2: pg 349). Human pathogens include *Bartonella*, several species of *Rickettsia*, and *Coxiella burnetii* (Q fever). Animal pathogens include; *Ehrlichia canis*, several *Babesia* species such as *Canis vogelli* and *gibsoni* and is a suspected vector of *Anaplasma* (2-4). It is also involved in the transmission of *Theileria* (a protozoa that is closely related to *Babesia*) species such as *Theileria parva,* otherwise known as East Coast Fever and *Theileria ovis* (5,6).

Vector competence has not been established with regards to *Borrelia*, although it has been found to harbour *Borrelia* in both America (7) and Europe (8). It is also the suspected vector in Mexico, where a 2008 study in Mexicali, Baja California (a Mexico-US Border City) reported "the existence of B. burgdorferi past/present infection in dogs in an area where the only identified tick is R. sanguineus" (9). This species should be examined both for the *Borrelia* species they may carry and their vector capabilities.

Cattle Tick: Rhipicephalus microplus

R. microplus (previously known as *Boophilus microplus*), otherwise known as the cattle tick, is considered the most important parasite of livestock in the world (10). It was first introduced into Australia (Darwin) in 1872 on cattle from Indonesia. By 1895 it had spread to Western Australia, reaching Queensland in 1891 and New South Wales in 1906 (11). This tick differs from all other ticks mentioned in the *Borrelia* cycle, in that it is a one host (rather than three host) tick, meaning that it spends its entire life (much shorter cycle than other ticks also) on the one host. As the name suggests, the primary hosts of this tick are cattle, though it may also be found on horses, sheep, goats, camels, alpacas, llamas, deer and dogs (10, 12,13). Although not a common occurrence, these ticks may also attach to humans who come into contact with them (10, 12, 14). While it may not come into contact with humans on a regular basis, this tick may serve to keep the *Borrelia* cycle active within the environment.

Borrelia burgdorferi has been isolated from *R. microplus* (14-16), though it ability as a vector of this species of *Borrelia* is unclear. It is however a known vector of *Borrelia Theileri,* the species responsible for bovine borreliosis. "To date, only *B. burgdorferi ss* and *B. garinii* have been described in bovine Lyme disease. However, two other spirochetes, *B. theileri and B. coriaceae* have been described in cattle and considered as the agent of bovine borreliosis and as the putative agent of epizootic bovine abortion, respectively" (17:pg 2). *B. theileri* has been noted in Australian cattle for over 50 years (18).

DNA sequencing reveals that *B. theileri* is in the same clade as *B. lonestari* and *B. miyamotoi*, the species of *Borrelia* that are responsible for relapsing fever/ lyme-like disease in humans (19, 20). Indeed, they are that similar it has been postulated that due to the eradication of the *R. microplus* ticks from America, the lonestari *Borrelia* species that is found in the *A. americanum* tick may have originally been due to the *Borrelia theileri* bacteria relocating from the *R. microplus* tick to the *A. americanum* (14).

With the presence of *B. theileri* in Australia, combined with the possibility of host shifting and adaptation of various *Borrelia* species, along with the importations of cattle from countries where Lyme is endemic, further investigations of *R. Microplus* ticks to ascertain what pathogens they carry and whether they are infectious to humans is certainly warranted.

Dermacentor Species

Borrelia has been found in ticks of the *Dermacentor* genera, though similar to the *Rhipicephalus* genera, their competence as vectors is controversial and requires further investigation. The controversy with regards to the *Dermacentor* species lays in the fact that while ticks of this species may be found to be incompetent vectors when feeding alone, in studies where they are co-fed with other species of ticks, they are found to be competent vectors. Although there are no ticks of the *Dermacentor* genera in Australia, this family of ticks is examined briefly below due to the significance of these findings.

Species from the *Dermecentor genera* include those found in America: *D. variabilis* (American Dog Tick), *D.andersoni* (Rocky Mountain Wood Tick), and Europe/Asia: *D. reticulates* (Marsh tick or Ornate cow tick) and *D. marginatus* (Ornate sheep tick).

Borrelia has been found in both *D. andersoni* (Rocky Mountain Wood Tick) (1) and *D. variabilis* (American Dog Tick) (1- 5). Whilst this indicates their ability to acquire infection from a host animal, whether they maintain that infection through there next molt/life cycle, or are able to pass it on to another host is unknown. Studies on *Dermacentor* ticks are mixed: When the tick is examined in isolation, it is not considered/found to be a competent vector, however, when "they feed in conjunction with Ixodes scapularis ticks, the *Dermacentor* ticks can acquire and transmit *Borrelia* burgdorferi sensu stricto" (6). The combination of different salivary factors of the ticks feeding in close proximity is believed to be the underlying factor in this finding.

Two *Dermacentor* species found in Europe / Asia are the *D. reticulates* (Marsh or Ornate cow tick) and the *D.marginatus* (Ornate sheep tick). Both species may feed on humans, particularly the scalp (7), and both have been found to harbour *Borrelia* (8-10). *D. reticulates* has been suggested to be involved in the transmission cycle of *Borrelia* in Europe (11) and a case of human Lyme disease after the bite of a *D.marginatus* in Bulgaria has been reported (12).

Considering that in the natural environment many different species of ticks may be found on the host animal, further co-feeding studies of various tick species are warranted and urgently required to further understand the co-feeding phenomenon revealed through examination of the Dermecentor genera.

Various Ixodidae Tick Species: *Paralysis Tick (Ixodes holocyclus), Wallaby Tick (Haemaphysalis bancrofti), Snake Tick (Amblyomma Morelia)*

Other species of the *Ixodidae* family in Australia include the *Ixodes holocyclus (*Paralysis Tick), the *Haemaphysalis bancrofti (*Wallaby Tick) and the *Amblyomma Morelia (*Snake Tick). In research reported in 1994 by Russell et al., *Lyme disease: search for a causative agent in ticks in south-eastern Australia* (1), spirochete-like objects (SLO's) were cultured from these three species of ticks, as well as from the *Haemaphysalis longicornis* (Scrub Tick) species.

Further information on these tick species, as well as an in-depth review of the research methods and conclusions about the research findings drawn by Russel et al., can be seen in this papers complimentary report, *'Lyme Disease: A Counter Argument to the Australian Government's Denial'* (2). For an outline of the findings / completeness of discussion in this review paper, below is the summary of the information with regards to these tick species (as well as *H. longicornis*) as shown in the *Counter Arguments* (2) executive summary:

- *I. holocyclus* - As well as SLO's cultured from this species by Russel et al., spirochetes were also cultured from *I. holocyclus* ticks collected from the Hunter Valley and Manning River district of NSW in research by Wills and Barry in 1991
- *H. bancrofti* - In Wills and Barry's research, spirochetes were also cultured from the *Haemaphysalis* species. The *H bancrofti* tick not only attaches to wallabies, its hosts also include kangaroos. In 1959, Mackerras reported the presence of *Borrelia* in Australian animals, including kangaroos
- *H. longicornis* - is a vector of *Borrelia* in China. It is also the tick species infesting a herd of cattle in which positive serology for *Borrelia* was reported in a cow in Camden NSW in 1989
- *A. morelia* - Snakes are capable reservoir hosts of the *Borrelia* species *B. lusitaniae*. This is a species of *Borrelia* that might be expected along the coastline, as it is carried by migrating seabirds

The above mentioned ticks only account for a small number of the approximately sixty known tick species belonging to the *Ixodidae* family in Australia. A thorough examination of all tick species, to determine the pathogens they carry and to investigate whether they are can cause illness in humans needs to be conducted.

Multiple pathogens carried by Ticks, with a focus on Babesia

The clinical picture of Lyme may be altered by numerous factors, one of these being that a tick typically harbours numerous pathogens. Therefore, if bitten by a tick, a person may be exposed to an array of various bacteria, viruses and parasites (1). It is far beyond the scope of this paper to discuss the numerous pathogens that ticks carry; instead the brief discussion below highlights one of these, the protozoan parasite, *Babesia.* The numerous pathogens that *H. longicornis* and *R. Microplus* are known vectors of are very briefly discussed, with their ability to transmit certain *Babesia* species and the need for further research highlighted.

Babesia

Babesia is a red blood cell parasite that belongs to the Apicomplexa phylum, a group of parasitic organisms which also includes other piroplasms such as *Theleira* and the Plasmodium species that are the causative organisms underlying malaria. Infection from the *Babesia* parasite is known as Babesiosis, a malarial-like disease (2). *Babesia* is one of the most common animal parasites in the world (3), with over 100 species identified to date. Each species is broadly classified by numerous factors, including organism size and reservoir host, though the natural host is not always able to be identified (2).

A number of Babesia species have been found to be pathogenic to humans, with both the small and large *Babesia* parasites being able to cause illness in humans. The large *Babesia* species include bovine parasites *B. divergens, B. bovis, B. bigemina,* deer parasite *B.venatorum* and canine parasite *B. canis*. The smaller *Babesia* species include the rodent parasite *B. microti,* and *B duncani* (previously known as WA1). Although *B. duncani* has been found in the blood of sick humans, no natural reservoir host or tick vector has been identified for this species as yet. Of these, the four main species that have been identified as underlying human babesiosis are, *B. microti*, *B.duncani, B. divergens* and *B.venatorum,* with *B. bigemina, B. bovis and B. canis, also being* implicated in a number of cases of human infection (3-8).

B. bovis and *B. bigemina* are believed to have been introduced into Australia around 1872, the same time as the cattle tick (9, 10), with over 80% of tick fever outbreaks in Australia due to *B. bovis* (11). The first known case of human *Babesia* in Australia came to light as the result of a *Babesia microti* infection and subsequent death of a 56yo NSW male in April 2011 (12,13).

It should also be noted that a *Babesia i*nfection can be passed from mother to foetus (14-17). *Babesia* protozoa are also able survive in stored blood and be passed on through blood transfusions (17-19).

Various pathogens carried by H. longicornis and R. Microplus:

Similar to other ticks associated with *Borrelia* (eg: *I. ricinus* in Europe and *I. scapularis* in America), the *H.longicornis* species carries numerous pathogens. As well as its role in *Borrelia*, it is a known vector for: bacterial infections such as *Bartonella* ; Rickettsial infections including human rickettsiosis (*R. japonica*), *Anaplasma* and *Ehrlichia* ; Protozoal infections *Thelieria* and *Babesia*. Of the protozoa, *H. longicornis* is a vector for a number of species including : East Asian bovine theileriosis (*T. buffeli*) , *Theileria Equi*, Bovine babesiosis (*B. ovata*) and Canine babesiosis (*B. gibsoni*) (20-29). With its known vector capability with regards to some smaller *Babesia* species, examination of the capability of *H. longicornis* in Australia to carry and/or transmit *B. microti* and other *Babesia* species, would be highly appropriate.

Along with its role in various *Borrelia* species (ie: found to harbour *B. burgdorferi* and is a competent vector of Bovine *Borrelia*) *R. microplus* is the vector for many zoonotic pathogens; including those responsible for “Tick Fever”; *Babesia bovis, B. bigemina* and *Anaplasma marginale*, which may result in sickness and death in cattle (30-33) as well as humans, particularly those that are immune-compromised (30, 34). It is also suspected as a vector of *Theileria equi* (30), previously known as *Babesia equi*, and has been found to carry *Ehrlichia, Wolbachia*, and *Coxiella burnetti* (33).

It is long overdue that the health departments in Australia communicate information acknowledged in the rest of the world by updating the information such as that found on the Queensland Government: Agriculture, Fisheries and Forestry website: “People can find cattle tick on themselves after working with cattle or other animals. The ticks are easily removed and cause no lasting affect apart from the site itching for a few days” (31). It urgently needs to be acknowledged that the *Babesia* parasites these ticks can carry can be passed on to humans and result in clinical illness. *Babesia bovis* and *bigemina* may have only been implicated in a small number of cases of human babesiosis, but that possibility is there, as is the potential to transmit any other species / pathogens that the ticks may carry such as *Coxiella burnetti*, the pathogen underlying Q Fever.

F. The signs and symptoms Australians with Lyme-like illness are enduring, and the treatment they receive from medical professionals

Patient Signs and Symptoms: Worldwide Protest Video's 2013

The signs and symptoms of Australians with Lyme-like illness are expressed well in the pictures/ video links below. These pictures were a part of Australia's campaign to promote the Worldwide Lyme protest in 2013. National co-ordinator Janice Foster collated the photos and together with her husband Ryan Hollings put the fabulous videos together.

All the videos can be seen on the Worldwide Lyme Protest – Australia inaugural year website: http://worldwidelymeprotestaustralia.weebly.com/awareness-videos.html

A link to the highlights video on you-tube is: https://www.youtube.com/watch?v=u9c6jjyDYYU

Background: People living with Lyme were asked to take photos of themselves with signs completing the following sentences:

"I am…" "I've lost…" "I want…"

It was hoped that these photos, when compiled into a video, would give an insight into 'Lymie life', without putting the strain of ad lib discussion on participants.

Fellow Lyme patient, and talented vocalist/musician Emily Madden, volunteered to compose and perform a song, especially for the video's soundtrack.

We had anticipated receiving photos from approximately a dozen people, but ended up with contributions from over 70, totalling more than 230 photos! It seems we had misjudged the need of Lyme sufferers and their loved ones to be heard. As a result, the decision was made to release four videos –one to feature general highlights, and the others to cover the topics of "I am…", "I've lost…" and "I want…".

Denial and Lack of Treatment

Time to Recognise Lyme Clock

The 'Time to Recognise Lyme' Clock Project aims to show the human side of this disease and the devastation its denial and lack of treatment and medical care is creating in many lives. It is basically a Call to Action. A project to show that: Acknowledgement & Treatment Can Restore Hope & Health. That lack of awareness is leading to years of illness that progressively gets worse, and that the treatment/ denial of some medical practitioners leave many feeling hopeless and feeling like they will never recover.

[redacted]

Call to Action: Acknowledgement & Treatment Can Restore Hope & Health

[redacted]*:* Victoria: Age: [redacted] Health decline began in 2005, at the age of 12.
Since 2005 [redacted] health has been up and down. A severe downturn in 2014 saw her lose the use of her legs. Doctors had no idea what was wrong and she was told to 'get used to life in a wheelchair'.
[redacted] was diagnosed with Lyme & Co. early in 2015. After intensive treatment she has slowly regained the use of her legs (on 'good days'). She still has a long way to go to fully restore her health, but that opportunity is now there: made possible with a diagnosis and knowing what to treat.

Before More Lives Are Devastated By Illness

[redacted]*:* New South Wales. Age: [redacted] Sick for 16 years: Since the age of 11.
Presented to ER and admitted to hospital numerous times. Diagnosed with Lyme & Co. in 2014

[redacted]*:* South Australia. Age: [redacted] Tick Bite: Queensland 2008.
Diagnosed with Lyme & Co. in May 2012, as were his wife and twins later that year.

[redacted]*:* Queensland. Age: [redacted] Sick for 15 years .Initially diagnosed with ME/CFS in 2001
In 2010 health deteriorated dramatically and became housebound: Diagnosed with Lyme & Co. 2013

Or Lost Forever

[redacted]*:* New South Wales: Age: [redacted] [redacted] [redacted] – 14th July 2010
Bitten by tick July 2007, Northern Beaches, NSW: Diagnosed with Lyme & Co. 2008

[redacted]*:* Western Australia: Age: [redacted] [redacted] [redacted] - 25th July 2013
Multiple tick bites WA. Sick 14 years: Most of those years housebound: Diagnosed Lyme & Co. 2011

[redacted]*:* Western Australia: Age [redacted] [redacted] [redacted] [redacted] – 25th of February, 2015
Tick bite near Kojonup, WA. Over 6 years of illness: Diagnosed with Lyme & Co. 2014

[redacted]*:* Western Australia: Age: [redacted] [redacted] [redacted] – 17th November 2015
Collapsed in 2009 due to 'unknown' illness: Diagnosed with Lyme & Co. 2014

[redacted] Queensland: Age: [redacted] [redacted] [redacted] – 8th February 2016
Tick bite - Myocum NSW August 2012: Diagnosed after finding a Lyme Literate doctor later that year

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For more information on the above project and people on the clock see GLiIO's website:
http://www.globallymeinvisibleillness.org/

Red Shoe Day Background:

Red Shoe Day was established in memory of Australian Lyme Patient, Theda Myint who left this earth on the 25th July 2013. The inaugural Red Shoe Day was July 25th 2014, with this day quickly becoming established as an annual remembrance day to remember not only Theda, but all those lost to Lyme and other invisible illnesses worldwide.

Red shoe day, held on July 25th, is to remember all those we have lost to invisible illness such as Lyme, ME/CFS, Fibromyalgia and the many more illnesses that are invisible. In the broad sense of the term, invisible illnesses are those that are generally "invisible", not only from the outward appearance of the person, but also seemingly invisible to appropriate research, treatment and care of the thousands of people that are living with them. Many living with these illnesses are also "invisible" to society, as their health is such that they are confined to their houses (and many to their beds) for months, even years.

The online communities and support groups are a lifeline to many who are unable to leave their beds/houses and are also an excellent source of information for those looking for support in discussing treatment pathways and coping strategies. The people within these communities/groups understand the struggles and adversity with very little explanation. Finding "someone like you", leads to many friendships being developed, and the loss of someone from this community is felt by many, even those on the other side of the world.

Each death brings a heightened sense of anger (and a numerous range of other feelings) at the injustice of their illness being ignored. It is also hard, as whilst many offer comfort to those affected, it also brings a sense of one's own mortality (or that of the loved one you are caring for) to the fore.

We would therefore like to encourage the view that whilst the 25th of July is for remembering all those lost, it is not only to remember their passing, it also to celebrate their life and to remember and share the wonderful memories their time on this earth gave us.

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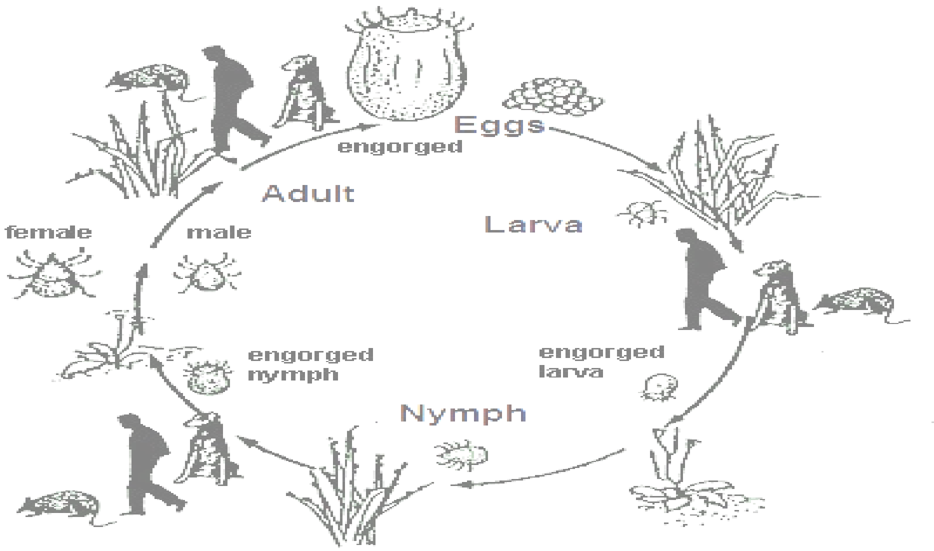
All other references throughout the paper are hyperlinked too or in text.

- Where information was copied from attachments, the references were not copied across (simply due to the sheer volume of them)

Lyme Disease:
A Counter Argument to the Australian Government's Denial



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Lyme Australia Recognition & Awareness
Shining A Light on Lyme

ISBN: 978-0-9923925-6-7

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Apart from the Executive Summary, the information in this counterpoint argument (and its complimentary report "*An overview of Lyme and direction for further research required in Australia*") was published on the Lyme Australia Recognition and Awareness (LARA) website (www.lymeaustralia.com) in July 2012, and was copyrighted at that time. The ISBN publishing date reflects the year of original online publication date (July 2012), rather than the date the research information was released in a PDF format.

As noted on the website: The information is intended to be disseminated in order to promote awareness and further research of Lyme in Australia; though I do ask that the source (myself) of the information is referenced appropriately. Information may not be used, distributed, or reproduced for any commercial purpose. Thank you. Karen Smith, B Psych (Hons).

Please note: Due to some spelling, grammatical and formatting errors unfortunately not noticed until after the first PDF publication of this research in Nov 2013 (ISBN: 978-0-9923925-4-3), the original version has been corrected and replaced with this 2nd and final version. While the changes did not alter the content of the counter-argument, as there have been numerous downloads of the original PDF report, a new ISBN (as noted top of this page) has been allocated to this current version of the report in order to acknowledge these changes and distinguish between the two released PDF versions.

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About Lyme Australia Recognition and Awareness (LARA)

Lyme Australia Recognition and Awareness (LARA) was founded by independent researcher, Karen Smith, B Psych (Hons). As well as her research work, Karen provides support and advocacy to patients and families living with Lyme disease through patient support forums and raising awareness of Lyme disease through organising and participating in awareness and protest events, both in the national and international arena. Research on the Counter-Argument, and its complementary report, *'Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia'* was started in early 2011, although work to bring the document to completion has been intermittent due to the author's health and treatment needs.

Acknowledgments

Thank you to Brendan D for his input on the first draft of this counter-argument. Brendan was a Victorian Lyme patient who sadly lost his battle and died in August 2011. Despite being so unwell, Brendan was always there to help and will be forever remembered. Thank you also to the numerous other people who have read and offered helpful suggestions throughout this lengthy research process and, particularly with the final draft: Tania Perich, Tony James, Kate Daniels, Amber Smith, Sherryn Jackson, Janice Foster

References

As noted on the Lyme Australia Recognition and Awareness website, any information regarding Lyme disease that is freely available at numerous locations on the Internet has not been referenced. For specific facts/arguments, see the reference list.

A further note for this hard copy format: As this research was originally started with the intention of expanding and viewing on a website platform, the references are separated into segments (Content Headings) for ease in updating information and, while not a conventional referencing style; links have also been provided to where the journals/information can be accessed on-line.

Executive Summary

Lyme disease (LD) is a disease caused by an infection from the *Borrelia* species of bacteria. As there are numerous species of *Borrelia* underlying Lyme disease it is also known as Borreliosis and, in continents such as Europe and Asia where the species responsible for neurological symptoms are more common, Neuroborreliosis. In the initial stages Lyme may simply present with flu-like symptoms; however, as the duration of the infection increases, the disease may present as a more chronic and difficult to treat condition due to the bacteria disseminating throughout the body's tissues and organs. In order to maximise the potential for early detection, treatment and full recovery, the recognition of the possibility of Lyme as a differential diagnosis is essential.

Lyme is the fastest growing vector borne disease in the world. In the United States of America (USA), the Centre for Disease Control (CDC) recently released figures of around 300,000 new cases of Lyme disease each year in America alone. Although there is no official collection of data, various sources reveal that the number of cases for the other continents, ie: Europe, Africa and Asia range from around 200,000 to 300,000 cases per year also. According to Australian Government Health departments, Australia is the one continent exempt from a disease that affects hundreds of thousands of people around the world each year. The 'No Lyme in Australia' stance is maintained, despite thousands of clinically suspected cases that date back as far as the 1980's. This position stems from research that was conducted on ticks and animals collected from New South Wales (NSW) over twenty years ago.

This Counter-Argument examines the research from the Department of Medical Entomology (DME), Westmead Hospital, NSW that underlies the denial in Australia, the majority of which was published in a paper by Russell et al., (1994) *Lyme disease: search for a causative agent in ticks in south-eastern Australia.* As the research paper is also the basis of the information regarding Lyme disease on the DME website, information from this site is also briefly explored. The aim of this document is to highlight that the research methodology has a number of flaws. There will always be problems encountered within research; it is in learning from these difficulties that science and knowledge can progress. While most studies address the problems that arise and offer possible alternative viewpoints or conclusions, the disturbing factor in the DME's investigations is that, despite being new to the field of Lyme research, the team at the DME assessed their own investigations as "expert" and ignored all other contradictory research that revealed there is a high probability that Lyme *is* in Australia.

In referring to Lyme disease, the DME website notes that the 1994 study was the result of "a multidisciplinary investigation" that began in 1988 to investigate the existence of Lyme disease in "coastal New South Wales". The individual components - clinical and serological studies, reservoir host, and vector study – are explored in detail in this Counter-argument.

Clinical & Serological Studies: Despite over 1000 suspected cases of Lyme disease per year at that time, it was concluded that patients were not positive according to international test criteria. The clinical and serological section examines the blood tests performed, outlining the fact that they are not appropriate for Australian patients. The international criteria that the DME and Russell et al., reference is the US Centre for Disease Control (CDC) criteria established for *surveillance* purposes in the USA. The Western Blot (WB) criteria were developed in order to monitor the activity of the *Borrelia burgdorferi* sensu stricto species, the most common species of *Borrelia* underlying Lyme disease in the USA. There is alternative European WB criterion that is recommended for use outside of the USA where other species from the *Borrelia* sensu lato class, such as *afzelii*, *garinii*, and *valaisiania* are more prevalent than *B. burgdorferi ss*.

Due to known variations and the differences in the immunological response to various *Borrelia* species, the criteria for a positive WB test is vastly different in Europe. These differences have been known since the early 1990's, although the literature on the diversity of *Borrelia*, and even the advice from the CDC that the USA criteria should not be used outside of America, seems to be totally ignored by the DME and Australian pathology laboratories. With the bird migratory pathways (it has been known since the 1980's that migrating seabirds and the ticks they carry play a role in spreading *Borrelia*) and the knowledge that many animals in Australia were imported from Europe and Asia, it would be more appropriate to utilise the European guidelines with regard to what is considered a positive WB test for Lyme in Australia.

Reservoir Host Studies: Seventeen (17) animals were examined by the Westmead team. As various strains of *Borrelia* are found within organs, rather than restricted to the skin, ear punch biopsy of animals is insufficient. The identification of reservoir hosts within the environment is crucial to identifying the pathogens present. Indeed, *Borrelia* was found in the blood of Australian mammals, including rodents, cattle, kangaroos and bandicoots in a Commonwealth Scientific and Industrial Research Organisation (CSIRO) study by Mackerras in 1959. Curiously, this information is given little regard by the DME. A study involving 17 animals can only be described as extremely limited in scope.

The concluding statement on the DME Website is: "None of the mammal species identified as reservoir hosts in the northern hemisphere are present in Australia". This is incorrect. The primary reservoir host for *Borrelia* in America is the white-footed mouse; it is a mammal, belonging to the *Rodentia* species of the *Muridae* family. While we do not have the white-footed mouse in Australia, over 20% of the mammal species belong to the *Muridae*, rat and mouse family. This includes the Australian Long-haired Rat, which in 1962 were the subject of a study in Richmond, north-west Queensland, in which a new species of *Borrelia* was identified and subsequently called *Borrelia queenslandica*.

The reservoir hosts section also briefly looks at four mammal species that have, in fact, been shown to be reservoir hosts in the northern hemisphere and have been introduced and are established in Australia. These include: Black Rats, Brown Rats, House Mouse, and European Hares. Many other mammal species are known reservoir hosts for *Borrelia*, including foxes, dogs, cats, horses and cattle. Other animal species such as birds, which include the European blackbird, Mallard duck and turkeys that have been introduced into Australia, are also known reservoir hosts of the *Borrelia* bacteria underlying Lyme disease.

Vector (Tick) Studies: The result of the research conducted on the ticks collected from the NSW coastline between 1990 and 1992 continues to be the primary basis for denial of Lyme disease in Australia today. Of the 12,000 ticks utilised in the study, over half were larvae, leaving less than 6,000 ticks that would have had a blood meal and have potentially been infected. No other study in the world uses tick larvae to ascertain the continent's infection rates of *Borrelia*. While 6,000 ticks may seem a relatively large number, it is not so when considering infection rates of ticks from different environmental areas and locations can vary anywhere from zero to ninety percent. The ticks in this study were collected from a small ecological niche of the NSW coastline that accounts for less than one eighth of Australia's entire coastline. The study ignored not only other ecological areas such as pasture or mountain areas in NSW, but also the seven other States and Territories of Australia.

This section on vector studies looks at the various methods used to ascertain infection within the ticks collected and argues that there were numerous problems contained within the methods used and conclusions drawn from the Russell et al, 1994 study. This counter-argument also presents the likelihood that what the study referred to as "spirochete-like objects" (SLO's) were indeed spirochetes, rather than contaminants of the culture as was concluded. The tick species from which the SLO's were cultured from included the Paralysis tick (*Ixodes holocyclus*), Wallaby tick (*Haemaphysalis bancrofti*), Bush/Scrub tick (*Haemaphysalis longicornis*) and Snake tick (*Amblyomma morelia*).

A few points as to why these findings should have encouraged further research, rather than simply dismissed the existence of Lyme include:

- *I. holocyclus* - As well as SLO's cultured from this species in this study, spirochetes were also cultured from *I. holocyclus* ticks collected from the Hunter Valley and Manning River district of NSW in research by Wills and Barry in 1991
- *H. bancrofti* - In Wills and Barry's research, spirochetes were also cultured from the *Haemaphysalis* species. The *H bancrofti* tick not only attaches to wallabies, its hosts also include kangaroos. In 1959, Mackerras reported the presence of *Borrelia* in Australian animals, including kangaroos
- *H . longicornis* - is a vector of *Borrelia* in China. It is also the tick species infesting a herd of cattle in which positive serology for *Borrelia* was reported in a cow in Camden NSW in 1989
- *A. morelia* - Snakes are capable reservoir hosts of the *Borrelia* species *B. lusitaniae*. This is a species of *Borrelia* that might be expected along the coastline, as it is carried by migrating seabirds
- The Seabird tick (*I. uriae*) is a known vector of *Borrelia*, it is found world wide – including Australia
- While it was originally presumed that only a small number of tick species were capable vectors of *Borrelia*, it is now known that over two dozen species of ticks are involved in the Borrelia cycle. This includes various species of ticks from the *Ixodidae* family, including *Ixode, Haemaphysalis* and *Amblyomma* species

With increasing Lyme awareness in recent years in Australia, the number of Lyme patients being diagnosed is rapidly rising. Sadly, due to formal denial of the existence of Lyme disease in Australia, many of these people have been sick for many years and the duration of infection allows for multi-systemic dissemination of symptoms. A prompt diagnosis and treatment is the best scenario for a rapid and full recovery from infection with Lyme bacteria. It is hoped that this Counter-Argument logically presents the real and potential problems and inconsistencies with the research by Russell et al. and that it highlights that the twenty year "freeze" on government research of Lyme in Australia urgently needs to be addressed.

Contents

A Counter-Argument to the Australian Government's Denial of Lyme Disease

Introduction

Lyme is a disease that is the result of an infection from spirochete bacteria of the *Borrelia* genus. In the initial stages, Lyme disease may simply present as flu-like illness, however as the duration of infection increases it can disseminate to become a multi-systemic inflammatory illness that may involve all organs, as well as the musculoskeletal, the peripheral and central nervous systems. When the infection is detected and treated early, the prognosis for a full recovery is excellent. Unfortunately, due to the various ways the illness can manifest, the lack of definitive laboratory tests for diagnosis and, more importantly the overall lack of awareness surrounding Lyme disease, many people may go undiagnosed for long periods of time, rendering the treatment and recovery process far more complicated.

Lyme disease may also be called Borreliosis (infection due to *Borrelia* bacteria) or Neuroborreliosis, due to the more neurological manifestations associated with some *Borrelia* species, such as *B. garinii* in Europe. A more detailed explanation of Lyme disease can be seen in this Counter-Argument's complementary report, *'Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia'* (1).

Australian Health Department Information Regarding Lyme

Since the 1980's in Australia, there have been over one thousand patients tested each year for suspected Lyme disease. Despite the enormous number of clinically suspected cases, as well as hundreds of patients diagnosed in Australia whose experiences were highlighted in a report released by the Lyme Disease Association of Australia (LDAA) in 2012 (2), the current position of the Australian Health Department continues to be that there is no evidence that Lyme disease is a threat to public health.

This stance is based on one study by Russell et al. (1994) *"Lyme disease: search for a causative agent in ticks in south-eastern Australia"* (3) and ignores all other previous research and studies undertaken during the same time period, in which the conclusions were highly suggestive of that the *Borrelia* bacteria which underlies Lyme disease does exist in Australia (eg: 4-14).

That the official Australian position denying Lyme disease continues to be based on this one study can be seen in the response that an Australian Lyme disease patient received in 2010 from then (2009-2011) Health Minister, Carmel Tebbutt. Her response explained that the relevant species *"have not been isolated in surveys of ticks collected in south-eastern Australia. Until there is solid evidence to indicate that locally acquired Lyme disease is a significant public health matter in Australia, specific measures to educate the general public or clinicians are difficult to justify."*

The Russell et al. study was also cited as evidence against Lyme disease in Australia by the "Lyme disease expert panel" (15) that convened in April 2011. One of the expert panel members, Dr Jeremy McAnulty of the NSW Health Department, consistently references this study in the "not a lot of evidence" stance with regard to Lyme being acquired in Australia. In addition, the results of this study are the basis of what appears on the New South Wales (NSW) Department of Medical Entomology (DME) website (16).

The following response addresses both the information on the DME website and the details of the Russell et al., 1994 study, providing further details and alternative viewpoints to the information and conclusions that they have provided. The information examined below will be identified as either being from the Department of Medical Entomology (DME) Website, or from Russell et al., study (citing the page number). Quotations or information from these sites/articles are italicised. Please note, Russell et al., has been published in numerous journals. In the following information, the page numbers referenced are those from:
[7]

Russell RC, Doggett SL, Munro R, Ellis J, Avery D, Hunt C, Dickeson D. (1994) Lyme disease: search for a causative agent in ticks in south-eastern Australia. *Epidemiology and Infection 112*: 375-384 (3).

Department of Medical Entomology (DME) Website : acknowledges that Lyme disease is the *"most frequently reported human tick-borne infection worldwide"*, it goes on to say that ***"****it has been reported from every continent (except Antarctic), although doubt remains as to whether it occurs in the southern hemisphere in general, and in Australia in particular".*

This doubt is based on the fact that - *"In 1988 at Westmead Hospital, a multidisciplinary investigation of putative LD in coastal New South Wales began, encompassing clinical, serological, vector and reservoir host studies."*

The individual components - clinical and serological studies, reservoir host, and vector study – of these multi-disciplinary investigations are examined in the following sections.

Clinical & Serological Studies

DME website: *"Despite clinical cases being reported from the early 1980's, there has been no confirmation that the disease occurs in Australia."*

Russell et al 1994 (Pg 376): *"The first Australian cases of a syndrome consistent with Lyme disease were reported from the Hunter Valley region of New South Wales in 1982. Further clinical cases were reported in 1986 from the south and central coast of NSW. In Queensland, in 1986-1989, the State Health Laboratories tested 1,247 patients for antibody response to B. burgdorferi, using an indirect fluorescent antibody test (IFAT), and reported 186 with positive (>64) titres". In 1988 a serological diagnostic service for Lyme disease was started at Westmead Hospital. Enzyme linked immunosorbent assay (ELISA) for IgG and IFAT for IgG and IgM, were used with antigens derived from a North American strain (B31) of B. burgdorferi. From 1988 to 1992, specimens were tested from 2,446 patients referred with suspected clinical Lyme disease; only 66 (2.7%) showed positive results by both methods indicating possible Lyme disease". These figures include seven patients infected outside Australia. More recent data from one of us (DD) indicate that to August 1993, 75 (2.2%) of 3458 local patients were positive for IgG by both methods. Less than 1% of the patients referred with suspected Lyme disease conformed with the United States national surveillance case definition for Lyme disease."*

DME webpage: The number of suspected cases referred to Westmead for testing by 1994 rose to 4,372. *"From 1988 to 1994 at Westmead Hospital, 78 (1.8%) of 4,372 from local patients with suspected LD were positive for IgG by ELISA and IFAT. All 78 were tested by WB, using North American and European strains of Borrelia; 46 sera showed one or more bands. None, including those with putative late stage disease, showed more than 4 specific bands and thus were all negative by international criteria."*

When observing these test results, it becomes evident lightly more than two percent of the patients tested were positive, and less than one percent of the patients were positive by what the DME terms "international criteria". It should be noted that the DME Website differs to what was published in the 1994 study, as it notes that "all were negative by international criteria".

With so few patients testing positive, why then is there the insistence that Lyme is in Australia?

- Lyme disease is a *clinical* diagnosis: Suspected clinical cases averaging around 1,000 patients per year (since the 1980's) is indicative that there is a urgent need for further research into why there are so many "suspected" cases of Lyme each year.
- CDC International criteria are for surveillance purposes, not clinical diagnostic criteria.
- Due to species variations of the *Borrelia* bacteria responsible for Lyme disease/Borreliosis, the "international criteria" are not recommended for use outside of America (where *B. burgdorferi* ss is not the primary species underlying Lyme). While the European, US-CDC surveillance criteria requires two tier testing – ELISA, then Western Blot (WB) – the interpretation of a positive WB is vastly different on each continent.

Lyme disease IS a CLINICAL Diagnosis

Clinical diagnosis is not a new phenomenon to the medical world. Diseases such as Parkinson's, Alzheimer's, Multiple Sclerosis and Motor Neurone all rely on the clinician's interpretation of medical history, symptoms and response to treatment for diagnosis. As the underlying cause for most of these diseases is unknown, they do not have an available diagnostic test to definitively rule in or out the diagnosis. While the cause of Lyme disease is known, the current available testing methods are inadequate due to a number of reasons, including the diversity of the *Borrelia* bacteria that can cause Lyme disease and the lack of standardisation of testing methods, which renders the diagnosis of Lyme primarily as a clinical diagnosis that "may be" supported by blood tests.

In Australia, between 1988 and 1992, there were 2,446 patients suspected of Lyme disease who were tested at Westmead Hospital, NSW. By 1993, the number of suspected cases and tests had risen to 3,458 and again to 4,372 by 1994. Add to these figures the Queensland patients that a 1994 study of Russell et al. mentions and this indicates there were at least 6000 suspected cases of Lyme disease in Australia in 1994. There is no further information publicly available after this date to indicate whether or not the growth of new suspected cases continued to average approximately 1,000 per annum. With so many suspected clinical cases each year, it is baffling how it can be logically asserted that Lyme disease does not exist in Australia.

CDC International Criteria is Surveillance, NOT Clinical Criteria.

The “international criteria” to which Russell and others refer is that of the Centre for Disease Control (CDC) in the United States of America. It was developed for surveillance purposes, and not clinical or diagnostic purposes. The *CDC Morbidity and Mortality Weekly Report* (1) states: “This surveillance case definition was developed for national reporting of Lyme disease; it is NOT appropriate for clinical diagnosis” (pg 20) (Emphasis not added). The case definition includes serological results, “For the purposes of surveillance, the definition of a qualified laboratory assay…” (2).

Testimony by Paul Mead, Medical Epidemiologist with the CDC, given to the Connecticut Department of Public Health and the Connecticut Attorney General's Office at a hearing regarding CDC's Lyme Disease Prevention and Control Activities in 2004 (3) notes: “A clinical diagnosis is made for the purpose of treating an individual patient and should consider the many details associated with that patient's illness. Surveillance case definitions are created for the purpose of standardization, not patient care.” It also points out that: “No surveillance case definition is 100% accurate. There will always be some patients with Lyme disease whose illness does not meet the national surveillance case definition. For this reason, CDC has stated repeatedly that the surveillance case definition is not a substitute for sound clinical judgment. Given other compelling evidence, a physician may choose to treat a patient for Lyme disease when their condition does not meet the case definition.”

CDC Western Blot Criteria was developed for use in America (B. burgdorferi ss species)

The problem of testing and species variations of *Borrelia* has been historically documented. Just a few of the known problems are:

- “The presence of at least 3 different species in Europe renders the diagnosis of Lyme Borreliosis by serological testing complicated and difficult” (4)
- “The antibody response is more limited in European *Borrelia* species; with these lower responses leaving the specificity and sensitivity of serodiagnostic tests lower” (4)
- “….it is clear from all accumulated studies on Lyme Borreliosis serology that serological testing should be used as a support of clinical diagnosis rather than a confirmation” (5: Pg S195).

Despite the well known problems with testing due to numerous *Borrelia* species worldwide, the first line of testing in Australia still utilises the *B. burgdorferi* species antigens. NSW Health does not acknowledge the differences in the European and United States Western Blot (WB) criteria and continue to ignore that Lyme disease is a clinical diagnosis that is supported, rather than confirmed or denied, by blood tests.

Advice for testing and the wording in the Fact Sheet, ‘Lyme Disease - Testing Advice for NSW clinicians’ (6) and the ‘Lyme Disease Fact Sheet’ by the Institute of Clinical Pathology and Medical Research (ICPMR), Centre for Infectious Diseases and Microbiology Laboratory Services, Westmead (7), is very ambiguous. The ‘Lyme Disease - Testing Advice for NSW clinicians’ (6) implies that antigens from all three species are utilised in testing yet, based on the ICPMR fact sheet (7), it appears that only the blood/samples that are ELISA positive with *B. burgdorferi* species/antigens may qualify to be further tested on the Western Blot (and therefore with the inclusion of European antigens).

The ‘Lyme Disease - Testing Advice for NSW clinicians’ fact sheet notes*: “The recommended testing strategy follows European and US-CDC guidelines for two-step serological testing with a screening immunoassay and a confirmatory immunoblot for antigens from Borrelia burgdorferi sensu lato genospecies (including B. afzelii, B. garinii)”.*

The Institute of Clinical Pathology and Medical Research (ICPMR), Centre for Infectious Diseases and Microbiology Laboratory Services, Westmead, Fact Sheet on Lyme Disease states : *“The screening test is an ELISA to detect combined B. burgdorferi IgG and IgM. The sensitivity of this kit is as high as 100% but specificity may be only 68% (unpublished data). False positive results may occur when the patient has other spirochaete diseases such as syphilis, leptospirosis and relapsing fever or has mononucleosis, lupus erythematosis or rheumatoid arthritis.*

All sera with positive or equivocal results on screening are tested by the Western immunoblot technique to determine specific IgG antibodies to particular proteins of B. burgdorferi (USA strain) and B. afzelii (European strain). At least five specific IgG immunoblot bands are required to confirm true Lyme disease after the first few weeks of infection (F. Dressler et al. J Infect Dis 1993;167:392-400) as recommended by the Second National Conference on Serologic Diagnosis of Lyme Disease, Centers for Disease Control,USA, 1994.”

The ICPMR fact sheet notes, *"The screening test is an ELISA...The sensitivity of this kit is as high as 100% but specificity may be only 68% (unpublished data)".* Unmentioned is that the ELISA as a screening test is only as sensitive as to the antigen/species of *Borrelia* tested for and the sensitivity of this test can range from as low as 30% (depending on duration of infection) and which testing kits are used (8). Ang and others (2011) note "ELISAs and immunoblots for detecting anti-*Borrelia* antibodies have widely divergent sensitivity and specificity and immunoblots for detecting anti-*Borrelia* antibodies have only limited agreement" (9).

The statement in the ICPMR Fact Sheet "*At least five specific IgG immunoblot bands are required to confirm true Lyme disease after the first few weeks of infection (F. Dressler et al. J Infect Dis 1993;167:392-400)",* is also a little confusing for a various reasons: Its reliance on American (rather than European) WB interpretation; the time frame for testing positive; and the reference to "true" Lyme disease.

The European and US-CDC guidelines do recommend two-step testing;. however, despite being known since the 1990's, what is not mentioned acknowledged or acted upon in Australian testing laboratories is that the European Western Blot (WB) criteria is very different. While the US surveillance criteria (10, 11) requires five bands (IgG) for a test to be considered positive, the WB criteria in Europe acknowledges that the immune response is lower in *Borrelia* species other than *B. burgdorferi* ss, and the requirement for a test to be considered positive is for one or two bands only, depending upon the species for which testing is being conducted- (12).

Regardless of whether using American or European Western Blot interpretation, the length of time of IgG responses is not 'set' to the "first few weeks". A few excerpts on this:

Craft, Fischer, Shimamoto and Steere (1986), whose article is referenced in the introduction in the Dressler et al paper to which the ICPMR fact sheet refers: "In 12 patients with early disease alone, both the IgM and IgG responses were restricted primarily to a 41-kD antigen. This limited response disappeared within several months...The IgG response in these patients appeared in a characteristic sequential pattern over months to years." (13;pg 934).

Strle et al., (1996) states: "Our work also highlighted the continuing problems associated with use of serological methods for patients with early disease. Fewer than 50% of cases demonstrated seropositivity at any time within the first 2months" (14; pg 64).

Aguero-Rosenfeld et al., (1996) report on the serological results from Culture-Confirmed cases of Lyme: "Although 89% of the patients developed IgG antibodies as determined at a follow-up examination, only 22% were positive by the IgG IB criteria of the Centers for Disease Control and Prevention-Association of State and Territorial Public Health Laboratory Directors. (15; pg 1).

This raises the question, what exactly does the Centre for Infectious Diseases and Microbiology at Westmead define as, or refer to, when they say "true" Lyme disease? At the time of their study it was known that there were various species of *Borrelia* responsible for Lyme disease. For example, in 1994, Steere (who first 'recognised' Lyme disease) described "Lyme disease or Lyme borreliosis as the result of an infection from *B. burgdorferi* ss, *B. afzelii* or *B. garinii*" (16). It has also been long known that there are numerous other *Borrelia* species in the burgdorferi sensu lato complex that may cause Lyme disease (eg: 17-22), which the testing advice provided by Westmead does not appear to acknowledge or take into account in their testing procedures.

In an interview with Doctor Jeremy McAnulty, the Director of Health Protection with the New South Wales Department of Health in July 2010, Bronwyn Herbert asked whether the testing methods for Lyme disease in Australia were adequate. The reply from Jeremy McAnulty *"Look they do seem to be and again we need to put in context who needs to be tested and when and the doctor's decision and advice about that. But there is a specialist laboratory at Westmead that's very expert in the range of tests that need to be done and can be done and they of course keep in contact with the experts around the world"* (23).

This raises the following questions and concerns:

- If Westmead's laboratory is in contact with experts around the world, why does their advice with regards to Lyme disease and testing procedures ignore over half the literature in the world?
- Why is the Australian laboratories first line of testing looking for *B. burgdorferi* ss species, especially when outside of America it is not the most commonly found species of *Borrelia*? For example, in a 2005 meta analysis of studies in Europe, it was noted that the *afzelii*, *garinii*, and *valaisiania* were more common than sensu stricto (21). In Asia, the presence of *B. burgdorferi* ss was not found (and then only in animals) until 2011 (22).
- With so many species of *Borrelia* being found worldwide, why are Westmead official's adamant a species of borrelia underlying Lyme cannot possibly be in Australia, denying any further government research for the last twenty years?

Reservoir Host Studies

DME Website: *"A small number (17) of native vertebrate animals were sampled by ear punch biopsy for culture and PCR investigation but there was no evidence of borreliae".*

Counterpoint: The reservoir host study's limitations speak for themselves with only **seventeen** (17) animals tested. Ear punch biopsy for culture and PCR investigation of only 17 vertebrate animals is also very limited and restrictive when considering that different species of *Borrelia* have different reservoir host preferences. For example, the *B. burgdorferi ss* species appears to have preferential preference for rodent hosts, whilst *B. valaisiania* has not been found in rodents, rather the preferred reservoir host is birds (1-3). Differences in *Borrelia* species can also extend to where in the host the bacteria can be detected, for example, in one study it was noted that "*B. garinii* infections were not detected in the skin of the rodents, but were confined to internal organs, particularly the brain" (3). Ear punch biopsy of 17 animals cannot be used to ascertain the presence, or lack thereof, of a *Borrelia* infection/species in Australian animals.

DME Website: *"None of the mammal species identified as reservoir hosts in the northern hemisphere are present in Australia".*

Counterpoint: This statement is simply not correct. Mammals that have been identified as reservoir hosts in the northern hemisphere include, rats, mice, hares, rabbits, foxes, cats, dogs and many other animals.

The primary reservoir host in America is the white-footed mouse (*Peromyscus leucopus*). It is a mammal, belonging to the rodentia species of the *Muridae* family. Whilst we do not have any white-footed mouse in Australia, "22 % of Australian mammal species are all in the rat and mouse family, *Muridae*" (4).

This includes the Australian Long-haired Rat (*Rattus villosissimus: Muridae* family). In 1962, these rats were the subject of a study in north-west Queensland in which a new species of *Borrelia* was identified and subsequently called *Borrelia queenslandica* (5). As well as this study, a 1959 CSIRO study of Australian animals reported that *Borrelia* was found in the blood of cattle, kangaroos, bandicoots and rodents (6).

The DME website briefly references these two studies**:** *"There are reports of spirochaetes in Australian native animals, and a local mammal could be a reservoir host for an indigenous spirochaete…"* With no indication of these studies in the further readings/reference section, the implications of this research are not given due respect or consideration. That is, if *Borrelia* has been found in animals in the Australian environment, then there must be a capable vector maintaining and disseminating the bacteria.

The following identifies just a few of the mammal species present in Australia which have been found to be reservoir hosts for *Borrelia* in the northern hemisphere:

Black Rat (*Rattus rattus*): This species of rats was introduced into Australia and is "spread throughout much of coastal Australia and is most commonly seen in urban environments" (7). Black rats have been shown to be competent reservoir hosts in Bulgaria and Germany (8,9).

Brown Rat (*Rattus norvegicus*): The brown rat was introduced into Australia around the same time as black rats (and mice). While not as abundant as the black rats, "the Norway or brown rat is found in or near human habitation, especially in coastal towns (10)". Brown rats are also competent reservoir hosts of borrelia (11,12).

House Mouse (*Mus musculus* : sub species *Mus m musculus, Mus m domesticus*) : House mice have a worldwide distribution. Early zooarchaeological evidence (13) suggests they were introduced into Australia late in the 18th century, around the time of the first European settlers. They are currently spread throughout Australia (14). *Mus musculus* was shown to be a competent reservoir/maintenance host of *Borrelia* within the environment in Bulgaria (8). *Mus musculus* are also frequently used in laboratory experiments due to their susceptibility to the *Borrelia* bacteria (15).

The Brown/ European Hare (*Lepus europaeus*): This hare species has been shown to be a competent reservoir host in Sweden (16, 17). Hares were first introduced into Australia from England in 1837. To increase numbers, presumably for hunting, "A breeding colony of hares was set up in 1863 on Phillip Island in Victoria by the Acclimatisation Society of Victoria to supply hares for further introductions to mainland Australia, Tasmania and New Zealand. These new introductions were successful and by 1870 hares were distributed throughout south-eastern Australia, including Victoria and parts of New South Wales, South Australia, Tasmania and Queensland" (18:pg 139).

As mentioned and referenced extensively in this Counter-argument's complementary report, *'Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia'* (19), there are numerous other mammal species in Australia that are reservoir hosts for the *Borrelia* bacteria. These include domestic animals such as dogs and cats, as well as other wild and farm animals such as foxes, sheep, deer, horses and cattle.

The DME's information also overlooks the fact that other animal classes, such as reptiles and birds, can be reservoir hosts for *Borrelia* species. While some *Borrelia* species, such as *B. burgdorferi ss* cannot survive in reptile blood, the preferred host for the *Borrelia* species *Lusitaniae* (which has been associated with Lyme disease/borreliosis in humans in Asia and Europe) is lizards (20). Bird species that are reservoir hosts of *Borrelia* and have been introduced into Australia include; song thrushes and common black birds, wild turkeys, pheasants, quails and mallard ducks (21-29).

Borrelia has been found in the blood of Australian animals (5, 6). The examination of 17 animals to rule out the existence of *Borrelia* bacteria responsible for Lyme disease cannot be seriously considered as "an encompassing reservoir host study". The following quotes highlight how it is imperative to thoroughly examine reservoir hosts in order to ascertain the presence of pathogens in the environment:

- From JS Gray's "*Review: The ecology of ticks transmitting Lyme borreliosis" (1998):* "Since the abundance of reservoir hosts in a habitat is crucial to the establishment of infected tick populations it is important to identify both the presence of particular reservoir hosts in a habitat and also their role in generating infected ticks" (30: pg 256)
- In a 2008, paper examining the identification of reservoir hosts of the Lyme disease spirochete (31) Daniel et al note: "To predict and prevent human risk of exposure to vector-borne diseases, it is vital to identify the reservoir hosts of the pathogens" (31: pg 535).

Vector Studies

DME Website: *"There are reports of spirochaetes in Australian native animals, and a local mammal could be a reservoir host for an indigenous spirochaete that occasionally infects humans through a tick vector and produces a clinical syndrome similar to LD; however, no spirochaete was detected in the 12,000 ticks or animals processed".*

As discussed in the reservoir host section, the total number of 'animals processed' (processed by, capturing and taking an 'ear punch biopsy') was only 17. Ear punch biopsy of 17 vertebrate animals cannot be used to ascertain the presence, or lack thereof, of the *Borrelia* species responsible for Lyme disease in Australia.

The 12,000 ticks processed is the primary research performed in 1994 by Russell et al., upon which the denial of the existence of Lyme in Australia is still currently based. This research is examined in detail below.

Lyme disease: Search for a causative agent in ticks in south-eastern Australia. Epidemiology and Infection. Russell RC, Doggett SL, Munro R, Ellis J, Avery D, Hunt C, Dickeson D. 1994. *Epidemiology and Infection* 112: 375-384.

Abstract: *"Attempts were made to identify the causative organism of Lyme disease in Australia from possible tick vectors. Ticks were collected in coastal areas of New South Wales, Australia, from localities associated with putative human infections. The ticks were dissected; a portion of the gut contents was examined for spirochaetes by microscopy, the remaining portion inoculated into culture media. The detection of spirochaetes in culture was performed using microscopy, and immunochemical and molecular (PCR) techniques. Additionally, whole ticks were tested with PCR for spirochaetes. From 1990 to 1992, approximately 12,000 ticks were processed for spirochaetes. No evidence of Borrelia burgdorferi or any other spirochaete was recovered from or detected in likely tick vectors. Some spirochaete-like objects detected in the cultures were shown to be artifacts, probably aggregates of bacterial flagellae. There is no definitive evidence for the existence in Australia of B. burgdorferi the causative agent of true Lyme disease, or for any other tick-borne spirochaete, that may be responsible for a local syndrome being reported as Lyme disease".*

Russell et al Pge 377: *"The study area comprised the coastal strip of NSW, from the Queensland border in the north to the Victorian border in the south".*

Pge 378: *"From January 1990 and December 1992, > 20,000 ticks were collected"*

Pge 375: *"From 1990 to 1992, approximately 12,000 ticks were processed for spirochaetes".*

Counterpoints: There were over 20,000 ticks collected and approximately 12,000 of these were examined in the study. There is no explanation as to what happened to the other 8,000 or more ticks that were collected, whether they died in storage, or how it was determined which ticks should be utilised.

It is noted that, 6,235 of the 12,000 ticks processed were questing (looking for a blood meal) larvae. From the numerous journal articles researched in relation to this topic, it is typically only ticks at the nymph and adult stages of development that are utilised in other studies examining *Borrelia* rates in the environment, as the transoveral infection rate of larvae is less than 1%. "In general, less than 1% of host-seeking larvae are infected, compared with between 10% and 30% of the nymphs and between 15% and 40% of adults" (1: pg13). Indeed, Russell et al., note in their introduction, "*Transmission to humans will only occur from ticks that feed first on infected reservoir hosts and then on humans"* (pg 376).

From the 12,000 ticks tested, approximately 5,770 ticks remain that had the potential ability to acquire *Borrelia* infection/spirochetes via a host/blood meal. While nearly 6,000 ticks 'may be' considered a significant quantity, the figure "12,000" is always referenced when using this study to justify the denial of Lyme in Australia.

What also needs to be taken into account is that infection rates of ticks from within the same country can vary dependant on species of tick, stage of tick (larval, nymph, adult), region and environmental area (pastures, mountains, forests, coastal) from which they are collected. Differences in infection rates can be vast, varying from 0 to <90% (1-6). Considering that the ticks examined in the Russell et al. study were collected from a 2,000km section of Australia's 35,000+ km coastline (one region/state of Australia and one environmental location), the 6,000 ticks collected for examination in this study cannot be considered a substantial or representative sample when used as the primary basis for the denial of Lyme disease throughout the entire continent of Australia. .

PCR testing

Russell et al Pge 378-9: *"1038 ticks tested using PCR, no amplification products which would suggest the presence of Borrelia were detected".*

Russell and others note their own limitations of the PCR testing of ticks in this study: *"It is possible that the monoclonal antibodies and PCR primers used in this study may not have been appropriate to identify indigenous Australian spirochaetes. However, the tick gut contents were also negative by culturing and dark field microscopy" (pg 381).*

The problems relating to the techniques used and conclusions drawn from the culturing and dark field microscopy examinations is the subject of the next section.

Spirochaete detection and isolation: Darkfield Microscopy and Culture.

Russell et al Pge 378-379 : *"Between January 1990 and December 1992, > 20,000 ticks were collected. Approximately 11,000, including all stages of four species, Ixodes holocyclus, I. tasmani, Haemaphysalis bancrofti and H. longicornis were dissected for spirochaete isolation. With the additional 1,038 ticks tested using PCR, no amplification products which would suggest the presence of Borrelia were detected. "*

Russell et al Pge 378: *"No spirochaetes were detected by dark field microscopy of the gut contents of the unfed ticks…"*

Counterpoints: The methods section of Russell et al, explains that the ticks were stored live until processed (pg 377), however does not explain the duration ticks were actually stored or give any understanding why only 12,000 of the 20,000+ ticks collected were subsequently processed in the study. Were they ticks stored from 1990 until processed in 1992? Had 8,000 ticks died while being stored?

The duration and method of tick storage is very relevant to whether or not spirochetes may or may not be able to be observed in the gut contents of ticks. In studies that examine poor environmental conditions, such as starvation, it has been observed that motile spirochetes convert into non-motile cyst forms until such time that their environment is more conducive to their requirements (7-9). The lack of detection of spirochetes in the gut contents of ticks that had been stored live, rather than immediately frozen or stored in ethanol to preserve their contents (10) for an indefinite duration, cannot rule out the presence of cystic forms of *Borrelia*. In addition, there are other detection methods, such as indirect fluorescent antibody (IFA), which have been shown to be more sensitive than dark field microscopy for detecting the presence of spirochetes (11), that may have been utilised.

Culture: Spirochaete like Objects (SLO's)

Russell et al Pge 379: *Spirochaete-like objects (SLO's)… were revealed by dark field microscopy in 92 cultures..." "Purified SLO's were obtained with 0.45um filters, but it was not possible to subculture them in the absence of bacterial contaminants…"*

Background of culture medium and counterpoints: BSKII medium is a specialized growth medium that may be used for culturing spirochetes although the quality of the medium is variable due to variations of medium components such as bovine serum albumin, rabbit serum and yeast extract and each batch mixed requires special care in preparation, filtering, and screening for its ability to support the growth of borrelia (12). Considering this variability, specialist laboratories examine each batch of medium prepared to assess its viability to maintain spirochetal growth. There is no indication that the batch of medium prepared by Russell et al., (a laboratory with no prior experience in culturing *Borrelia* spirochetes) was tested for its ability to maintain viable spirochetal growth prior to use in this study.

The use of 0.45um filter paper is ideal to obtain purified spirochetes as, unlike most other bacteria, *Leptospires* and *Treponemes* are able to migrate through filter papers (13). While Russell et al. concluded that what they obtained from the cultures were SLO's, the fact that the bacteria isolated was able to migrate through the filter paper is highly suggestive that they were indeed spirochetes.

As purified SLO's were obtained via filtration methods, it is feasible to assume that the bacterial contaminants in the subculture were likely to have been due to the BSK II medium, rather than contaminants from the ticks' blood-meal.

While the use of 0.45um filter paper has been found to be one way of culturing purified spirochetes, another method known to rid the culture of contaminants is the addition of antibiotics such as Rifampin, Phosphomycin, Amphotercin B (12,14) to which *Borrelia* are resistant. It has also been found that BSK medium containing Co-trimoxazole (15) or Rifampin, is "more efficient for spirochete isolation than unsupplemented BSK medium" (11). It is not possible to determine from the Methods section of the Russell et al., paper whether the use of antibiotics such as those previously mentioned was employed. The Methods section does however mention the use Skirrows supplement, which is an antibiotic supplement recommended for selective isolation of *Campylobacter* species and contains three antibiotics, Vancomycin, Polymixin and Trimethoprim (16), Spirochetes are susceptible to (killed by) both Vancomycin (17, 18) and Trimethoprim (19), rendering the choice of Skirrows supplement a less than ideal additive, considering the aim was to culture/grow (rather than kill) spirochetes.

Molecular identification & description of culture products

Russell et al page 379 : *"While a few positive results were obtained by IFAT using polyclonal antibodies, the results were both variable and inconsistent for the 18 SLO's tested."*

Counterpoint: Variability of positive IFAT results should be cause for further investigation: The quality of medium has been found to alter gene expression patterns (20), affect the morphology (length and number of coils) and motility of spirochetes, as well as alter the results of IFAT tests (21).

Russell et al page 380: *"PCR … successfully amplified a 950bp fragment in 92 of 92 SLO cultures, however the fragments amplified produced characteristic enzyme digestive products of a Bacillus sp. and not a Borrelia sp."*

Russell et al page 380: *".. the SLO's appeared straight, rigid and uniformly coiled, varied in length (10-300um)* and had 2-40 complete coils; all appeared to be non-motile."*

*It is assumed that 300um is a typographical error and should read *30um. This would be in line with the graphic (page 380) showing a 50um bar for comparison.

Counterpoints: The 950bp fragments amplified by 16S rDNA cannot be interpreted as being able to rule out *Borrelia* species, as enzyme digestive products with a 950bp have also been identified for *B. burgdorferi ss* (22). "…heterogeneities between 16S rRNA genes seems to be a common phenomenon and, that for species identification, 16S rDNA analysis has to be interpreted with care" (23: Pg 2246).

Bacterial species cannot be defined by DNA similarities alone (24) and what is more descriptive here is the appearance of the SLO's. *Bacillus* species are rod-like and 5-10um in length. *Borrelia* species are spiral shaped and 10-30um. The images provided in the journal article (page 380) and the description of the SLO's are more representative of the appearance of the *Borrelia* species rather than *Bacillus*.

Russell et al page 381 : *"Electron micrographs showed that these SLO's had no distinct cellular structure but were composed of fibre-like subunits, and were not spirochaetes."*

Counterpoint: Spirochetes do not have a distinct cellular structure and are composed of axial filaments which have one or more fibrials. The three brief quotations below expand on this:

"The outer sheaths of *S. plicatilis*, all *Borrelia* species, and *T. phagedenis* strains so far examined are characterized by a lack of structural detail" (25 :pg 118).

"Ultrastructural examination of spirochetes has established their procaryotic nature and the one ultrastructural feature - the axial fibril - that sets them apart from other prokaryotes" (25: pg 152).

"Spirochetes consist of three main structures: aprotoplasmic cylinder, an axial filament (consisting of one or more fibrils), and an outer envelope..." (26 pg: 1087).

While the conclusion was drawn by Russell and others that the 'objects' cultured from some of the ticks were spirochete-like objects (SLO's), the following section is based on the assumption that they were more than likely spirochetes and briefly examines the tick species from which they were cultured.

Tick Species Spirochete-like Objects (SLO's) were Cultured From

Russell et al page 379: *"The tick species yielding these SLO's were I. holocyclus, H. bancrofti, H.longicornis and Amblyomma morelia."*

Paralysis Tick (*Ixodes holocyclus*)

I. holocyclus is more commonly known as the paralysis tick, as bites from this tick can cause paralysis in animals and humans. This tick is found in Queensland, New South Wales, Victoria and Tasmania. The *holocyclus* range of hosts is extremely wide and includes both indigenous and introduced animals, including birds and reptiles. The mammalian hosts range from rodents to animals in the wild, such as kangaroos, koalas, bandicoots, to domesticated and farm animals such as dogs, cats, cattle, horses, pigs and sheep. Humans may occasionally become accidental hosts (27-29).

The *I. holocyclus* is the tick "presumed" most likely to be the vector for *Borrelia* in Australia and, as such, is the only tick species, in Australia (that I am aware of) to have been examined in relation to its capability of transmitting Borrelia species from the burgdorferi sensu lato family. In 1991, Piesman and Stone (30) conducted a study that examined the ability of *I. holocyclus* to acquire, maintain and transfer the *Borrelia burgdorferi* ss species. It was found that, while larval *I. holocyclus* could ingest the spirochetes, the infectivity was not maintained once the tick had "moulted" to its next cycle, the nymphal stage. The conclusion was, "These experiments should be repeated with Australian strains of spirochetes" (30). However, in the intervening 21 years, no further studies have been performed. Further research to identify uniquely Australian spirochetes has not been conducted in the intervening 21 years; nor have Australian ticks been studied to indentify the presence the more common European strains of *Borrelia such as afzelii*, *garinii*, and *valaisiania*.

Taking into consideration the knowledge that certain tick species may only transmit species of *Borrelia* (e.g. 31) common to their country of origin, it is inappropriate to rely on one study (30) that examined the ability of a single species of indigenous Australian to transmit a *Borrelia* species most common to America. As Piesman and Stone (30) concluded, additional research should be performed. As well as the knowledge that SLO's were cultured from this species of tick by Russell et al, further information justifying additional research on this species' ability as a vector is that Borrelia-like spirochetes were also cultured from *I. holocyclus* ticks collected from the Manning River district of NSW in research conducted by Wills and Barry in 1991 (32). Additionally, many of the animal hosts of *I. holocyclus* serve as capable reservoir hosts for *Borrelia*, for example, mice, rats, cats, dogs, cows, horses and birds. This further justifies the need for additional research into what pathogens the ticks may carry, as well as the ability of this tick to carry/transmit *Borrelia* species more common in Europe and Asia.

Wallaby Tick *(Haemaphysalis bancrofti)*

H. bancrofti is informally known as the Wallaby tick as their principle hosts are wallabies. This species has also been collected from kangaroos, bandicoots and other mammals and livestock including cattle and sheep. *H. bancrofti* is found in Queensland, New South Wales and on Kangaroo Island, off South Australia (33, 34).

As *H. bancrofti* is only found in Australia and New Guinea, countries that have not typically been associated with *Borrelia*, there does not appear to have been any research to determine its capabilities as a vector. What is known is that *H. bancrofti* is a vector of *Theileria* (*Piroplasm*) (35-37) and this tick species is thought to be involved in the transmission of severe outbreaks of the disease which resulted in the death of over 800 in cattle on NSW farms in 2008 (37, 38). In international research there has been found to be an association between ticks that transmit *Piroplasms* and *Borrelia* (eg:39, 40).

Considering this association, as well as the fact that Russel et al cultured SLO's from *H. bancrofti ticks*, it would seem apparent that further research on this tick species' vector capabilities would be appropriate. This is especially so when you also add in the information that Wills and Barry reported that they cultured *Borrelia*-like spirochetes from *Haemaphysalis* species of ticks in 1991, and that many of the animal hosts of *H. bancrofti* are capable reservoir hosts for *Borrelia*, including cattle, kangaroos, bandicoots and rodents in which a 1962 study (41) reported *Borrelia* in the blood of these Australian animals.

Scrub/Bush Tick *(Haemaphysalis longicornis)*

The *H. longicornis* is more commonly known as the scrub or bush tick. It was introduced into Australia on cattle from Northern Japan and was first recognised in 1901 in north eastern New South Wales. This tick species is now established along coastal areas in Queensland, New South Wales, and through north eastern Victoria (esp. Murray Valley) and Western Australia (42-44).

The hosts of the *H. longicornis* tick (45) include numerous animals that have been found to be reservoir hosts for *Borrelia* and have been introduced or imported into Australia from countries in which Lyme disease is endemic (45,46). These animals include the smaller reservoir hosts listed previously in this Counter-argument, i.e. mice, rats and hares, as well as domestic animals such as dogs and cats (47-52) and medium to large animals such as foxes (53,54), cattle, horses (55-62), sheep and deer (63-65) that have been introduced into Australia and have varying levels of reservoir competence for *Borrelia*.

Examination of *H. longicornis* as a possible vector of Lyme in Australia is warranted not just because Russell et al., cultured SLO's from the species in their study, but for other compelling reasons which include: The role of *H. longicornis* in the Borrelia cycle in China (66-70) ; *H. longicornis* was the tick species infesting cattle in cases of suspected Lyme disease in cattle at Camden NSW in 1989, in which positive IFAT serology for *Borrelia burgdorferi* was reported: "the herd from which these cases came was heavily infested with the Bush tick, *Haemaphysalis longicornis*, at the times of presentation..." (71: pg 298). Given these factors, it would seem apparent that research on this tick species role in the *Borrelia* cycle in Australia is long overdue.

Due to its known role in the *Borrelia* cycle in China, the *H. longicornis* tick is covered in more depth in this Counter-argument's complementary report, '*Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia'.*

Snake Tick *(Amblyomma morelia)*

Amblyomma morelia is more commonly known as the snake tick. While snakes are its preferred host, this species is also found on other reptiles such as lizards and monitors (72). In Australia it is found in Queensland, New South Wales, Victoria, and the Northern Territory (73).

Although snakes and lizards were initially thought to be incompetent reservoir hosts for Borrelia, one species, *B. lusitaniae* has been associated with lizards in several studies (74, 75). Further examination of *A. morelia* is warranted because, although the number of this tick species in the Russell et al study was limited to 14 (4 nymphs and 10 adults), SLO's were cultured. Also of interest would be the examination of smaller rodents such as mice and rats upon which, the larvae may have initially fed due to their close natural environmental coexistence.

As well as the above-mentioned ticks, there are numerous other species from the *Ixodidae* genera in Australia. This includes the Seabird tick (*Ixodes uriae)* and a Bird tick (*Ixodes auritulus)* that are known vectors of *Borrelia* (76-80).

The *I. uriae* tick is found worldwide, including Australia and its offshore islands (81). The role of migrating seabirds and the *I. uriae* tick in spreading *Borrelia* has been known of since the early 1990's (82). In a 1993 study by Olsen et al., *Borrelia* DNA was found in *I. uriae* ticks from Crozet and Campbell Islands, off the New Zealand coast, again suggesting Lyme is in the Southern hemisphere (83).

The *I. auritulus* is a native tick of Tasmania (84-85). The first reports of *Borrelia* being found in this tick species were from Canada in 2005 (80). *I. auritulus* attach to bird hosts such as the European blackbird and song thrushes. Both of these bird species have been introduced into Australia (86-88) and both are known reservoir hosts of *Borrelia* (89-92). These two tick species, as well as others from the *Ixodidae* genera, are covered in more detail in *'Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia'*.

Conclusion

In concluding the examination of the various components - clinical and serological studies, reservoir host, and vector – of the multidisciplinary investigations performed at the Department of Medical Entomology, Westmead Hospital, hopefully it has been made apparent that Australia's official position regarding Lyme disease has relied for far too long on the 'not a lot of evidence' rhetoric about the absence of Lyme in Australia.

The major issues of this Counter argument can be summarised as follows:

(1) Clinical and serological studies: There have been over 1000 clinically suspected cases of Lyme disease each year since the 80's & 90's in Australia, along with the hundreds of diagnosed cases reported in the Lyme Disease Association of Australia's survey. Despite the fact that Lyme disease is primarily a clinical diagnosis, supported by blood tests, the official denial of Lyme disease continues. This denial is based on interpretation of tests that are not recommended outside of the United States of America and are vastly different to European recommendations. The continued use of outdated and incorrect serology techniques to justify the denial of Lyme disease in Australia is highly inappropriate and negligent.

(2) Reservoir host studies: As noted, the examination of 17 animals should be considered a very limited research sample upon which to base significant conclusions. The denial of the existence of mammal reservoir hosts for *Borrelia* in Australia is also contentious when mammals such as mice, rats, and hares, known to be capable reservoir hosts in the Northern hemisphere, are also present here. Larger imported mammals, as well as other animal species such as snakes and birds, are also known reservoir hosts of *Borrelia*.

(3) Vector: Ticks collected from a 2,000 kilometre section of Australia's 35,000+ km coastline, 20 years ago really should not be the basis for the continued denial of Lyme disease in Australia. A study with many inconsistencies, including variable IFAT results and the culturing of "spirochete-like objects", should never have been used to deny the existence of Lyme in Australia, not then and certainly not twenty years later. There are numerous species of ticks, including one in which Russell et al., cultured 'spirochete like objects' that have been shown to be a vector for *Borrelia* in the Northern Hemisphere. Further research, including the examination of numerous tick species from all Australian terrains needs to be conducted in order to ascertain what pathogens Australian ticks carry.

Despite numerous other publications around the 1980's and 1990's that were highly suggestive of the presence of *Borrelia* in Australia, the 1994 study by Russell et al at the Department of Medical Entomology (DME), Westmead, is the only study officially acknowledged by the Australian Government. As this counter-argument highlights, numerous erroneous conclusions seem to have been drawn., Rather than concede there were inconsistencies and utilise the study as the basis for further research, the study's authors, the DME at Westmead, and Government health departments have continued to utilise this study to deter any further investigation and government research with regard to Lyme disease in Australia for the past twenty years.

The lack of advice - or worse still, the vehement insistence that Lyme is not in Australia - to both clinicians, and patients with regard to Lyme disease by the Health Department of Australia means that, rather than having access to all information that would allow recognition and short term treatment in the initial stages of Lyme disease, people are left undiagnosed for many years which then leads to disseminated long-term infections which are much harder to treat. Up-to-date research urgently needs to be undertaken with regard to identifying the pathogen underlying Lyme disease in Australia.

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A note re reference presentation: As this research was originally started with the intention of expanding and viewing on a website platform, the references are separated into segments (Content Headings) for ease in updating information and, while not a conventional referencing style; links have also been provided to where the journals/information can be accessed on-line.

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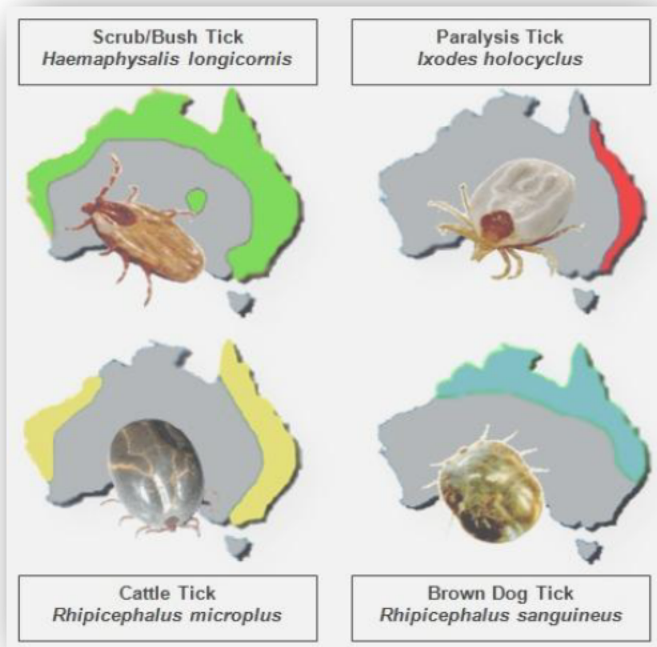
Lyme Disease / Borreliosis
An Overview of Lyme and Direction for Further Research Required in Australia



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Lyme Australia Recognition & Awareness

Shining A Light on Lyme

ISBN: 978-0-646-90428-3

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The information in this review (and its complimentary report, *Lyme Disease: A Counter Argument to the Australian Government's Denial)* was published on the Lyme Australia Recognition and Awareness (LARA) website (www.lymeaustralia.com) in July 2012. The ISBN publishing date reflects the year of original online publication (July 2012), rather than the date (2014) the research information was released in a PDF format.

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About Lyme Australia Recognition and Awareness (LARA)

Lyme Australia Recognition and Awareness (LARA) was founded by independent researcher, Karen Smith, B Psych (Hons). As well as her research work, Karen provides support and advocacy to patients and families living with Lyme disease through patient support forums and raising awareness of Lyme disease through organising and participating in awareness and protest events, both in the national and international arena.

Acknowledgments

Thank you to Brendan D for his input on the first draft of this counter-argument. Brendan was a Victorian Lyme patient who sadly lost his battle and died in August 2011. Despite being so unwell, Brendan was always there to help, and will be forever remembered. (Research on *Lyme Disease / Borreliosis: An overview of Lyme and direction for further research required in Australia',* and its complimentary report*, 'Lyme Disease: A Counter Argument to the Australian Government's Denial, '* was started in early 2011, although work to bring the documents to completion was intermittent due to the author's health and treatment needs).

Thank you also to the numerous other people who have read and offered helpful suggestions throughout this lengthy research process, in particular with the final drafts for this paper; Tania Perich, Tony James, Janice Foster, Amber Smith, and Sherryn Jackson.

References

As noted on the website: Any information with regards to Lyme disease that is freely available at numerous locations on the internet has not been referenced. For specific facts/arguments, see the reference list.

A further note for this hard copy format: As this research was originally started with the intention of expanding and viewing on a website platform, the reference section is separated into segments (content headings) for ease of updating information, and whilst not conventional referencing style, links have also been provided to where the journals/information can be accessed on-line.

Executive Summary

Lyme disease (LD) is due to an infection from the species of bacteria belonging to the *Borrelia Burgdorferi sensu lato* complex. There are numerous species of *Borrelia* in this complex and as such LD is also known as Borreliosis and in continents such as Europe and Asia where the species responsible for neurological symptoms are more common, Neuroborreliosis. When the infection is detected and treated early, the potential for full recovery is excellent. However, due to the various ways the illness can manifest, the lack of definitive laboratory tests for diagnosis and more importantly the overall lack of awareness surrounding Lyme disease, many people may go undiagnosed for long periods of time, rendering the treatment and recovery process complicated.

Lyme is the fastest growing vector borne disease in the world. In the United States of America (USA), the Centre for Disease Control (CDC) recently released figures of around 300,000 new cases of Lyme disease each year in America alone. Although there is no official collection of data, various sources reveal that the number of cases for the other continents (Europe, Africa and Asia) range from around 200,000 to 300,000 cases per year also. According to Australian Government Health departments, Australia is the one continent exempt from a disease that affects over half a million people around the world each year.

The 'No Lyme in Australia' stance is maintained, despite thousands of clinically suspected cases that date back as far as the 1980's. This position stems from research that was conducted on ticks and animals collected from New South Wales (NSW) over twenty years ago. The research was conducted by the Department of Medical Entomology (DME), Westmead Hospital, NSW and published in a paper by Russell et al., (1994) *Lyme disease: search for a causative agent in ticks in south-eastern Australia.*

The complimentary report to this overview - *'Lyme Disease: A Counter Argument to the Australian Government's Denial'* by Karen Smith (2012), - examines the research by Russell and others and outlines a number of issues with the methods utilised and questions a number of the erroneous conclusions drawn. In short, it highlights how the findings from the Russell et al., 1994 research should have encouraged further investigation, rather than simply dismissing the existence of Lyme and putting a twenty year freeze on government research.

While the counter-argument focused more exclusively on examining the problems with methods used and conclusions drawn with regards to the research underlying the denial of Lyme in Australia, the aim of this current review is to provide a brief outline of Lyme. What it is and the clinical picture and symptoms associated with the disease as well as detailed information on how it is transmitted and maintained in the environment. By outlining the basics and providing background information, it is hoped that the 'mystery' surrounding Lyme is lifted and that it can be very plainly seen that the likelihood that the bacteria responsible for Lyme is in Australia is quite high, and that there is an urgent need for further investigation and thorough research in this field.

❖ Lyme Disease

- Lyme disease is a multi-systemic inflammatory disease resulting from an infection due to bacteria from the *Borrelia* family – more specifically bacteria from the *Borrelia burgdorferi sensu lato class*.
- ***Clinical Picture:*** The clinical picture can vary depending on the species of *Borrelia* underlying the infection, the strength of a person's immune system and any co-infections that may be acquired at the same time. Initial stages Lyme disease may present with flu-like symptoms, however as the length of time of infection increases, and the bacteria disseminates widely throughout the body's tissues, organs, peripheral and central nervous systems.
- ***Symptoms:*** The *Borrelia* bacterium is a spirochete and is able to move through semisolid environments, such as the body's connective tissue, which typically inhibits the movement of most other bacteria. This action, in combination with other properties of the spirochete, allows the *Borrelia* bacteria to infect the entire body, resulting in symptoms that are extremely varied.
- ***Associations / Misdiagnosis:*** The ability of *Borrelia* to invade every organ in the body and the widespread inflammation induced is one reason that Lyme disease has been misdiagnosed as multiple diseases including: those that effect the brain/ nerves - meningitis, encephalitis, stroke ; Demyelinating and degenerative diseases - Parkinson's disease, Motor Neurone Disease (MND) ; Heart problems - transient atrioventricular blocks ; Systemic inflammatory diseases - arthritis.
- ***Co-infections:*** A tick or other vector may transmit more than one pathogen (bacteria, virus, protozoa) at once. Infection with one or more of these pathogens at the same time can alter the severity of illness.

❖ Lyme Disease History and Borrelia Species

- ***Brief History:*** Initial investigations regarding Lyme began in 1975. Due to the clinical picture of a cluster of children in Old Lyme, Connecticut, in the United States of America, Lyme was initially thought to be primarily arthritic in nature. In the years since, research and clinical cases have revealed that there are different species of *Borrelia* underlying Lyme and that the disease also has neurological and dermatological manifestations.
- ***Borrelia Species:*** In the last thirty years over 20 *Borrelia* species worldwide have been associated with Lyme or Lyme like illnesses***.***
- ***Table 1**: **Borrelia Species Associated with Lyme Borreliosis***
  - *Pathogenicity and species diversity issues underlying identification of Borrelia*: The ability to understand the pathogenicity and the development of adequate diagnostic procedures is made more difficult due to the 100's of strain variations within the *Borrelia* species.

❖ Lyme Disease Transmission and Maintenance within the environment

- ***Blood sucking insects (other than ticks):*** Biting flies, mosquitoes and mites have been found to carry *Borrelia*, and are the suspected vectors in some clinical cases of Lyme.
- ***Contact Transmission:*** Contact transmission has been observed in mice, with spirochetes being found to be viable for 18-24 hours in the urine of infected animals.
- ***Human to Human:***
  - *Sexual Transmission:* There is no direct evidence that Lyme is sexually transmitted, however spirochetes have been found in semen.
  - *Mother to baby:* The National Institute of Health and the CDC in America have both published information that Lyme can be passed on through pregnancy.
- *How Lyme is Transmitted and Maintained* ***within*** *the Environment**:*** The transmission and maintenance of *Borrelia* within the environment requires the tick (or vector) and the tick host and / reservoir animals. The host animals may be thought of as either reservoir hosts, which are small to medium size animals that carry/maintain the spirochete infection within their blood and the larger host animal for which the adult of a particular species of tick has an affinity.
- *Ticks and Lyme Disease:* Ticks are divided into two families, the *Ixodidae* (hard ticks) and *Argasidae* (soft ticks). Both are vectors for human disease, though in the case of the *Borrelia* underlying Lyme, it is the Ixodidae family that has been associated with transmission. The family of *Ixodidae* tick itself has over 600 different species, divided into numerous genera including; *Ixodes, Amblyomma, Haemaphysalis, Rhipicephalus* and *Dermacentor.*
- ***Table 2: Tick Vectors of Lyme Disease / Borreliosis:*** Original investigations showed the number of ticks to be involved in the *Borrelia* cycle as limited. Over the years, research and knowledge about the number of ticks involved has grown exponentially. The existence of Lyme in Australia is still denied due to the lack of presence of the first four ticks originally found to be associated. As the table reveals, numerous other species of the Ixodidae family are implicated, and we do have some of the tick species mentioned here in Australia.

❖ Tick Vectors and Reservoir Hosts of Lyme / *Borrelia* in Australia

- The discussion in this segment examines four tick species (*Ixodes uriae, I. auritulus, Haemaphysalis bispinosa and H. longicornis*) from the Ixodidae family that are listed on Table Two as being involved in *Borrelia* transmission, and that have been recorded as being in Australia. The ticks are also explored in relation to their respective animal hosts, with the presence of both the bird and mammal hosts in Australia being examined.
- ***Examination of Ixode Ticks and Bird species involved in the Borrelia cycle in Australia:***. Birds can carry pathogens, including *Borrelia*, in their blood, as well be carriers of ticks (and other vectors). This means that not only can birds drop infected ticks into new environments but as reservoir hosts, immature ticks that feed on them may become infected and spread the disease to other birds and mammals during their next feed. Land birds can spread *Borrelia* across continents, whilst migrating seabirds can spread the disease around the world.
- ***Seabird Tick Ixodes uriae and Associated Bird Vector & Reservoir Hosts:*** The *I. uriae* species is found Australia-wide, including offshore islands and is associated with many species of marine birds. With over 20 million migrating seabirds and 3 million plus shore-birds breeding on Australian Islands and shores each year, it is unbelievable that the health departments of Australia continue to ignore the long established knowledge that migrating birds contribute to the spread of *Borrelia*.

- ***Bird Tick Ixodes auritulus and Associated Bird & Reservoir Hosts:*** The *I. auritulus* is a native bird tick species of Tasmania. Birds that have been introduced into Australia, and are competent reservoir hosts of *Borrelia*, include: European blackbirds, song thrushes, wild turkeys, pheasants, quails and Mallard ducks.
- ***Examination of Haemaphysalis Ticks and Mammals involved in the Borrelia cycle in Australia:***. The Haemaphysalis ticks are discussed in conjunction with mammal hosts that have been shown to be either hosts for the tick, or those that are also reservoir hosts of the *Borrelia* bacteria. In order to outline the role that mammals play in the maintenance and spread of *Borrelia* within the environment, this section also briefly examines clinical illness in animals, contact transmission and the animals that have been introduced/ imported into Australia.
- ***Haemaphysalis bispinosa:*** Very similar attributes and animal hosts as the *H. longicornis* tick.
- ***Scrub Tick Haemaphysalis longicornis and Associated Mammal Vector & Reservoir Hosts:*** More commonly known as the scrub or bush tick (or cattle tick in New Zealand). It was introduced into Australia on cattle from Northern Japan and was first recognised in 1901 in north eastern New South Wales. It is now established throughout many coastal areas of Australia.
  - Clinical Illness in Animals: Apart from humans, the only animals that appear to develop an illness due to Lyme are dogs, cats, horses and cattle.
  - Contact Transmission in Animals: Spirochetes have been found in the urine of infected mice, dogs, horses, and cattle. Mouse studies show that the spirochetes in urine remained viable for 18-24 hours and that contact with urine appeared to be another method of transmission (similar to Leptospirosis).in rodents. Further studies are required for larger animals and humans.
  - Importation of Animals into Australia: Examines Dogs, Foxes, Cattle, Horses, Sheep and Deer: These larger mammals are all involved in the *Borrelia* cycle, both as reservoir hosts and tick hosts. Touched on briefly also is the presence of the smaller reservoir hosts, European hares, black and brown rats in Australia that are reservoir hosts of *Borrelia* in the Northern hemisphere.
- ***Other Ixodidae Tick Species:*** A number of other Ixodidae tick species that have been implicated as being involved in the *Borrelia* cycle are examined briefly.
- ***Rhipicephalus Ticks:*** Ticks from this species have been found to carry the *Borrelia* spirochete and are possible vectors.
- ***Brown Dog Tick: Rhipicephalus sanguineus:*** This species has been found to harbour *Borrelia* in ticks both America and Europe. It is also the suspected tick vector of *Borrelia* in Mexico.
- ***Cattle Tick: Rhipicephalus Microplus:*** *B. burgdorferi (Bb)* has been isolated from this tick species. Though its ability as a vector of *Bb* is yet to be further examined, it is a known vector of *B. theileri,* the species responsible for bovine borreliosis.
- ***Dermacentor Species:*** This species of ticks is not found in Australia. They are briefly mentioned in order to demonstrate that when looking at the vector competence of a particular species of ticks that findings may be altered when ticks are examined in co-feeding studies.
- ***Various Ixodidae Tick Species:*** *Paralysis Tick (Ixodes holocyclus), Wallaby Tick (Haemaphysalis bancrofti), Snake Tick (Amblyomma Morelia):*1994 research reported that spirochete like objects were cultured from these tick species. These findings are looked at briefly.

Multiple Pathogens carried by Ticks, with a focus on Babesia

A tick typically harbours multiple pathogens, therefore if bitten by a tick, a person may be exposed to an array of various bacteria, viruses and parasites. The clinical picture of Lyme / severity of illness may be altered by other pathogens that a person is exposed to on tick / vector bite.

- **Babesia:** Babesia is a red blood cell parasite similar to malaria**.** The first known case of human *Babesia* in Australia came to light after the death of a 56yo NSW male in April 2011.
  Babesia protozoa can cross the placenta and be passed from mother to foetus and they are also able survive in stored blood and be passed on through blood transfusions.
- **Various pathogens carried by *H. longicornis* and *R. Microplus:*** The scrub (*H. longicornis*) and cattle (*R. Microplus*) ticks carry numerous pathogens including *Borrelia* and *Babesia*. They are implicated in being the vector of both of these pathogens.

Conclusion

Current research investigating the pathogens that Australian ticks and the animals that are known to be reservoir hosts for Lyme */ Borrelia* is essential to maximise the potential for early detection and treatment of Lyme and other vector borne diseases.

Contents

Lyme Disease

Lyme disease is a multi-systemic inflammatory disease resulting from an infection from spirochete bacteria of the *Borrelia* family. Spirochetes are long, thin, spiral-shaped bacteria that have flagella (tails), which aids their movement throughout the body. The periplasmic flagellum of the spirochete underlies the highly invasive abilities of this bacterium as it allows them to move through semisolid environments, such as the body's connective tissue, which inhibits the movement of most other bacteria (1, 2). Bacteria of the spirochete family include those responsible for diseases such as syphilis (*Treponema pallidum*), Leptospirosis (*Leptospira*) and Relapsing Fever (eg*: B. hermsii, B. recurrentis*). In the initial stages Lyme disease may simply present as a flu like illness, however as the length of time of infection increases Lyme disease "appears as a chronic progressive disease that involves multiple organs, including the heart, the liver, the kidneys, the musculoskeletal system, the skin, and the central and peripheral nervous systems (3:pg 1711)". When the infection is detected and treated early, the prognosis for a full recovery is excellent. Unfortunately, due to the various ways the illness can manifest, the lack of definitive laboratory tests for diagnosis and more importantly the overall lack of awareness surrounding Lyme disease, many people may go undiagnosed for long periods of time, rendering the treatment and recovery process much more complicated.

To account for the numerous species that can underlie Lyme disease (see *Borrelia* Species section, page 8), it may also be called Lyme borreliosis, or neuroborreliosis, due to the more neurological manifestations associated with some *Borrelia* species, such as *B. garinii* and *B. valaisiania*.

Clinical Picture

The clinical picture can vary depending on the species of *Borrelia* underlying the infection, the strength of a person's immune system and any co-infections that may be acquired at the same time. The most prevalent species originally found to cause human disease are *B. burgdorferi sensu stricto* (ss), *B. garinii*, and *B. afzelii*. The B. burgdorferi ss species is associated with an arthritic clinical picture, whilst the first two species identified in Europe have more dermatological (*B. afzelii*) and neurological (*B. garinii*) manifestations (1).

Initial symptoms may be an Erythma Migrans (EM), a bulls-eye rash (though the number of patients that get this is reported as being anywhere between 30 to 70%) or other type of rash, followed by flu like symptoms. After a short period of localised infection, the bacteria begin to spread throughout the blood to the lymph nodes, joints, heart and the nervous system. Some people may develop worsening symptoms within a month or two of initial infection, whilst in others, once the bacteria has moved out of the blood stream (to avoid detection by the immune system), it may lay dormant for an extended period of time before symptoms become noticeable. This is very much like the bacteria responsible for tuberculosis, in which initial symptoms of the primary infection may be minor, and it is not until months or years later that the disease becomes "re-activated". This may be due to a person's immune system being compromised or weakened (2) by events such as: an accident; an operation; severe trauma or stress; pregnancy; heavy metal toxicity; mould exposure, vaccinations and immunosuppressant drugs such as steroids.

Symptoms

Early symptoms of Lyme disease include: "flu-like" feeling, headaches, fevers, muscle soreness, fatigue.

"Within days to weeks after disease onset, B. burgdorferi often disseminates widely. During this period, the spirochete has been recovered from blood and cerebrospinal fluid, and it has been seen in small numbers in specimens of myocardium, retina, muscle, bone, spleen, liver, meninges, and brain (1:pg 1096)".

Disseminated symptoms: Once the bacteria start to spread throughout the body, symptoms broaden to include: persistent swollen glands; sore throat; joint pain/swelling/stiffness; muscle pain, cramps or weakness; bone pain; numbness, tingling, burning; twitching of the face or other muscles; jaw pain, stiffness, or temporomandibular joint disorder (TMJ); constant headaches; hearing loss; sound and light sensitivity; eye pain, vision problems such as floaters, blurry vision, vision loss; difficulty thinking/concentrating; poor short term memory; mood swings, irritability, depression; anxiety, panic attacks; psychosis (hallucinations, delusions, paranoia); tremors; seizures; Bells Palsy (may be early or latent symptom); chronic fatigue (2).

As can be seen by the symptom list, the symptoms associated with Lyme are wide and varied. A few basic reasons as to why this is so:

A) The spirochete can cause damage to a person's tissue, organs and bones: The specialised flagella (tail) of the spirochete allow it to move away from macrophages (A white blood cell of the immune system) whose role is to "ingest" infectious bacteria (3). Their axil filaments (endoflagella) also mean they move in a corkscrew like fashion and are able to "screw" their way into bone, tissue, muscles and organs (4).

B) The immune system's response to the spirochetes' presence in the body and their bacterial lipoproteins: Bacterial Lipoproteins have strong stimulatory properties and whilst most other bacteria only have 3 genes for coding lipoproteins, *Borrelia* has over 105 (5). Basically, the bacterial lipoproteins - which play a role in adhesion to host cells (resulting in vasculitis), modulation of inflammatory processes and virulence factors - of *Borrelia* "cause a dysfunction in the immune system by triggering a complex imbalance of chemical immune mediators (cytokines). These cytokines regulate the immune system and when they are over stimulated, they produce harmful reactions from the immune system, such as pain, inflammation, and even apoptosis (cell death)" (6).

Constant inflammation within the body is associated to many problems: it can increase the risk of cancer (7) and is associated with many autoimmune diseases such as rheumatoid arthritis, endocrine disorders, celiac disease and those that affect the brain such as multiple sclerosis (8,9). Tom Grier gives one explanation as to how inflammation can affect the brain "When the human brain becomes inflamed, cells called macrophages respond by releasing a neuro-toxin called quinolinic acid. This toxin is also elevated in Parkinson's disease, MS, ALS, and is responsible for the dementia that occurs in AIDS patients. What quinolinic acid does is stimulate neurons to repeatedly depolarize. This eventually causes the neurons to demyelinate and die. People with elevated quinolinic acid have short-term memory problems" (10).

(C) Stimulation of inflammatory and anti-inflammatory cytokines: In many patients, symptoms seem to migrate from one area of the body to another, or be worse from one day to the next: As well as the stimulatory properties of the bacterial lipoproteins, they are also able to induce anti-inflammatory cytokines, which may "explain the focal and transient nature of inflammatory episodes in Lyme disease" (5).

Associations/Misdiagnosis of other diseases

Due to the protean (variable and versatile in their ability to change frequently) manifestations of the disease, and the fact they are both due to infections of a spirochete bacteria, Lyme is often likened to Syphilis: "Lyme disease is like syphilis in its multisystem involvement, occurrence in stages, and mimicry of other diseases (1:pg 2378)." The ability of *Borrelia* to invade every organ in the body and the widespread inflammation that they induce is an underlying reason that Lyme disease has been misdiagnosed as multiple disorders/diseases including: those that effect the Brain / Nerves – Brain tumour, Meningitis, Encephalitis, Stroke, Bells Palsy, Seizures/Epilepsy (2-8) ; Cognitive/ Psychiatric disorders - Alzheimer's, Psychosis (9-11) ; Demyelinating and degenerative diseases - Multiple Sclerosis, Parkinson's Disease, Motor Neurone Disease (MND) known as Lou Gehrig's disease or Amyotrophic Lateral Sclerosis (ALS) in some countries (12-18); Heart problems - including Myocarditis and Transient atrioventricular blocks (19-22) ; Musculoskeletal disorders - Bone erosion, Osteomyelitis (23-24) ; Systemic Inflammatory diseases - Rheumatoid arthritis, Juvenile arthritis, Sarcoidosis (25-27); Skin / Hair disorders - Pityriasis rosea, Hair loss/ alopecia (28-30).

Co-Infections

As Lyme is a vector borne disease (see: Lyme Disease Transmission and Maintenance within the Environment section, page 11), there is the possibility of acquiring other infections that may be transmitted at the same time. These include: parasitic infections such as Babesia/Theileria and bacterial infections such as Bartonella and the Rickettsial diseases – Rickettsia (either: typhus group, spotted fever group or scrub typhus), Ehrlichia, Anaplasma and Coxiella (Q fever). Immuno-compromised individuals may also be more susceptible to acquiring opportunistic bacterial infections such as Mycoplasma and Chlamydophila (Chlamydia) pneumoniae (CpN) and viral infections such as Epstein - Barr virus (EBV), and ParvoB19.

Co-infections are mentioned briefly here to note that acquisition of one or more of these infections at the same time may alter the severity/course of Lyme disease. It is also noteworthy that whilst other countries recognise that infections due to pathogens such as *Babesia* (discussed in more detail on page 23) , can cause severe illness in humans as well as animals (and can be transmitted via blood transfusions), Australia is yet to acknowledge the potential risks for human disease, even after the death of a NSW male in 2011. (1)

Lyme Disease History and *Borrelia* Species

Brief History

Investigations first began into Lyme disease (LD) in the USA in 1975 after two concerned mothers, Polly Murray and Judith Mensch from Old Lyme in Connecticut contacted the health department about their sick children and what they felt was an abnormally high number of children with “juvenile rheumatoid arthritis” in their area. One of the scientists involved in the research of the cluster of patients in Connecticut, Willy Burgdorferi, identified the bacteria responsible for Lyme disease as a spirochete belonging to the *Borrelia* genre in 1981 (Two dates 1981/1982 seem to be used interchangeably in various literature: 1981 is the year the ‘discovery’ was made, whilst 1982 is the publishing date of the journal article in which the finding is described). As such this first species was named *Borrelia burgdorferi*, and being the first species identified, it is typically known *as B. burgdorferi sensu stricto* (in the strictest sense).

Due to the original beginnings/investigation, LD was initially presumed to be a primarily arthritic condition, however it was soon found to have dermatological and neurological manifestations. In Europe, clinical aspects of LD have been written about in medical journals since the 1800’s. A skin condition which is now associated with chronic LD, acrodermatitis chronic atrophicans (ACA), was noted in patients of a German doctor, Alfred Buchwald in 1883, whilst the rash that some LD patients observe, known as erythema migrans (EM) was originally described in 1910 by a Swedish dermatologist, Arvid Afzelius as erythema chronicum migrans (ECM). In 1922, French physicians, Garin and Bujadoux, described neurological (Meningopolyneuritis) symptoms which occurred in a patient after an Ixodes hexagonus tick bite.

In the thirty years since the original investigations began, numerous other species of *Borrelia* have been identified and along with *B. burgdorferi sensu stricto*, are collectively classified as belonging to the *Borrelia burgdorferi sensu lato complex*. Whilst all the species in the sensu lato complex may be classified as belonging to the Lyme borreliosis group (1, 2), another group of *Borrelia*, *B. miyamotoi*, has recently been reported to cause relapsing fever and Lyme disease-like symptoms in humans (2,3). *B. miyamotoi* was first described in Japan in 1995 as a new species of *Borrelia* (4) that resemble relapsing fever species in some ways and Lyme borreliosis species in others” (5: Pg 1129) **.** Spirochetes that were found to be closely related to *B. miyamotoi* (*B. miyamotoi sensu lato*) have been reported in a number of studies in the United States from 2001 (eg: 6-8) and Europe since 2002 (9). Genetic sequencing of *B. miyamotoi* has revealed that it is closely related to the *B. lonestari* species of *Borrelia* (1). *B. lonestari* is associated with a “Lyme-like” disease known as, Southern Tick Associated Rash Illness (STARI), or Masters disease, which is reportable to the Centre for Disease Control (CDC) as Lyme disease (10).

Borrelia Species

Worldwide there has been over 20 *Borrelia* species identified as being associated to Lyme, or Lyme-like disease in humans. Species that have been identified in various continents are detailed in Table 1 on the following page (page 10). To avoid some confusion that may come about when reading literature with regards to *Borrelia* species and infections, it is worthwhile to point out that spirochetes of the *Borrelia* family are also responsible for other known diseases in humans and animals. Some of these include:

Relapsing Fever in humans: eg: *B. duttonii, B. hermsii,* B. turicatae and *B. recurrentis* (*B. recurrentis*, is transmitted by the human body louse, and is the only species acknowledged as being transmitted via an insect rather than a tick)

Spirochetosis in birds: eg: *B. anserina* (*Borrelia* species such as *B. garinii* and *B. valaisiania* responsible for Lyme disease in humans are also carried in birds)

Bovine borreliosis: eg: *B. theilerii and B. coriaceae* (As well as being able to cause disease in humans, both the *B. burgdorferi ss* and *B. garinii* species have also been found associated with borreliosis in cattle)

Borrelia responsible for the above diseases are differentiated from the *Borrelia* species that are responsible for Lyme disease/borreliosis in humans, by genetic and vector (different tick species) differences. Although it should be noted that differentiating via tick species that transmit the disease is starting to become more ambiguous with species such as *B. miyamotoi*, in which the vectors differ from the typical pattern. Typically, spirochetes responsible for Lyme disease are transmitted via hard ticks, whist relapsing fever is transmitted via soft ticks, however with the *Miyamotoi* species, both hard and soft ticks have been found capable of transmitting the disease, and also unlike other *Borrelia* species responsible for Lyme disease, the bacteria is passed from the female tick to the egg/larvae (eg 1, 5, 6).

Table 1: *Borrelia* Species Associated with Lyme Borreliosis

Continent/ Country	*Borrelia* Species
North America:	*B. burgdorferi ss*, B. americana, B. andersonii, B. bissettii*, B. californiensis, B. carolinensis, B. garinii*, B. kurtenbachii. B. miyamotoi sl*** and *B. lonestari****
Canada:	B. *burgdorferi ss*, B. bissettii*,* BC genotypes (3 distinct though as yet unnamed species)
Europe:	*B. burgdorferi ss*; B. afzelii*, B. bavariensis** (previously known as *B. garinii OspA serotype 4*), *B. bissettii*, B. garinii*, B. finlandensis, B. lusitaniae*, B. spielmanii*, B. valaisiania* and B. miyamotoi sl***
Asia:	*B. afzelii*, B. garinii*, B. lusitaniae*, B. sinica, B. valaisiania* , B. yangtze* and *B. miyamotoi*** (The first isolation of *B. burgdorferi ss** in Southern China (11) was from a hare in 2011)
Japan	*B. garinii*, B. japonica, B. tanukii, B. turdi, B. valaisiania** and *B. miyamotoi*** (Whilst Japan is a part of the Asian continent; the studies examining LD differentiate as Japan is a "stand-alone" island)
Australia	*B. queenslandica* (*Borrelia* species found and cultured from rats in Richmond, Nth Queensland in 1962)

* Known to be pathogenic to humans **Relapsing Fever/ Lyme-like disease ***Lyme-like illness

See references 12-16 for sensu lato species and pathogenicity

Pathogenicity and species diversity issues underlying identification of Borrelia

The pathogenicity of bacteria (or any organism able to cause illness) refers to its ability to bring about disease in a host. *Borrelia* species vary in their ability to cause illness in different animal species, including humans. While all the species listed in Table One above have been isolated and identified from ticks and animals, and therefore can potentially cause disease, it is not until a species has been isolated from human tissue, that it is acknowledged as pathogenic to humans.

The ability to understand the pathogenicity of each species and the development of adequate diagnostic/ testing procedures to ascertain human infection status is made that much more difficult by the fact that within the above mentioned species there are 100's of strain variations (eg:17-24) involved. For example, until recently *B. bavariensis* was known *as B. garinii OspA serotype 4*. Sequence analysis and testing revealed that this strain (serotype 4) was specific to rodent hosts (and unable to survive bird serum), with the opposite being shown for *B. garinii* serotypes 3,5,6 and 7, which are bird associated strains, and unable to survive in rodent serum. Due to the sequence analysis and host differences, *B. garinii OspA serotype 4* was therefore classified as a separate species, *B. bavariensis* (17). Another brief example is that vector differences, as well as sequence analysis, reveals that the *B. garinii* and *B. valaisiania* strains from Europe differ from the *B. garinii* and *B. valaisiania*-related strains from Asia (18,19).

These above brief examples outline why it is "important to develop alternative identification tools which are able to distinguish *Borrelia* strains not only at the specific level but also at the intraspecific level" (25: Pg 509). Understanding that there is such an enormous number of strain diversities, even within species of *Borrelia*, allows for a better appreciation as to why Lyme disease is primarily a clinical diagnosis. When testing for *Borrelia* infection, it is imperative that there is an understanding that the accuracy of the tests are limited by various factors, one of which is the species diversity, and that for more accurate testing and diagnosis, "the choice of a *B. burgdorferi sensu lato* strain for an antigen in serological testing is important" (26: Pg 52).

Lyme Disease: Transmission and Maintenance within the Environment.

Lyme disease (LD) is described as a vector-borne disease as it is spread via the bite of arachnids (ticks). It should be noted however that there is also some evidence that it can be transmitted via other means, which are outlined briefly below.

Blood sucking insects *(other than ticks)*

In clinical cases of Lyme disease, biting flies (1-3), mosquito's (3, 4) and mites (5) are suggested to have been responsible for the infection. The *Borrelia* bacteria has been found in: numerous species of mites (6); fleas (6-8) ; biting flies, ie: bot flies, deer flies, horse flies (6,7, 9-11) ; and mosquito's (8, 9, 11-14), indicating that these insects are capable of maintaining the bacteria and are potential vectors.

Contact transmission

Borrelia spirochetes have been found in the urine of infected dogs (15,16), horses (17,18), cattle (18) and mice (19,20). Studies on mice have found that the spirochetes in urine remained viable for 18-24 hours and concluded that "Urine may provide a method for contact non-tick transmission of *B. burgdorferi* in natural rodent populations particularly during periods of nesting and/or breeding" (19: pg 40). Evidence for direct contact transmission has been demonstrated in mice (20). These findings suggest that further research is needed to ascertain whether, like the spirochete that causes Leptospirosis, the *Borrelia* spirochete is able to spread by the urine of infected animals to humans.

Human to human transmission

Sexual transmission

There is no direct evidence for sexual transmission, although spirochetes have been found in semen (21), suggesting that it is a possibility. Lyme disease has also been likened to another spirochetal disease, syphilis, which is a sexually transmittable infection (22).

Mother to baby

The possibility of placental transmission is acknowledged, although there are mixed reports regarding exactly what health risk congenital Lyme disease poses to the foetus/newborn. A brief dialogue of various positions:

Allan MacDonald (1989) notes that adverse reactions, such as foetal death and cortical blindness, have been associated with gestational Lyme disease and suggests the need for further research in order to ascertain whether the associations are co-incidental or related to the infection (23).

The International Disease Society of America (IDSA) guidelines downplay any risk, associated with Lyme, and conclude that "there is little evidence that a congenital Lyme disease syndrome occurs" (24).

The Centre for Disease Control (CDC) notes that while "Lyme disease can be dangerous for your unborn child", and "may lead to infection of the placenta and may possibly lead to stillbirth" (25,26), it follows the IDSA guidelines that "favorable outcomes can be expected when pregnant women with Lyme disease are treated with standard antibiotic regimen" ; Contrary to this statement, there are reports of adverse outcomes, including the death of newborns, with (27) or without (28) antibiotic treatment of the mother.

CDC Publications include the *Pregnancy Fact Sheet* - "Untreated, Lyme disease can be dangerous to your unborn child. Lyme disease that goes untreated can also cause you to have brain, nerve, spinal cord, and heart problems", and the *Lyme Disease Resource Brochure* - "Prevention and early diagnosis of Lyme disease are important during pregnancy. Rarely, Lyme disease acquired during pregnancy may lead to infection of the placenta and may possibly lead to stillbirth".

The National Institutes of Health puts it short and sweet: "If you are pregnant, be especially careful to avoid ticks in Lyme disease areas because you can pass on the infection to your unborn child" (29: pge 15).

This leads us back to the original message, further research is urgently required with regards to Lyme disease and pregnancy. For now, in order to address the lack of recognition of Lyme disease in Australia, the focus of the following information is on the well known ability of the tick to spread Lyme disease.

How Lyme is transmitted and maintained within the environment

The transmission and maintenance of the bacteria responsible for LD within the environment requires the tick and host animals. The host animals may be thought of as either reservoir hosts, which are small to medium size animals that carry/maintain the spirochete infection within their blood and the larger host animal for which the adult of a particular species of tick has an affinity (30). There is some question as to whether or not larger mammals, such as sheep, deer, horses and cattle simply serve to amplify the infection within the environment, by providing the tick with a host blood meal or whether they also serve as reservoir hosts of *Borrelia*. In general, the studies show mixed conclusions. These findings are discussed further in the 'Scrub Tick Haemaphysalis longicornis and associated Mammal Vector & Reservoir Hosts' section (Page 18). With regards to the smaller/medium animals, there are over 50 mammalian and avian species that are reservoir hosts of *Borrelia* (31) and include various mammal species such as: mice, rats, voles; hares; rabbits; squirrels; hedgehogs; dogs: as well as numerous species of marine and land birds including puffins, blackbirds and pheasants.

Ticks and Lyme Disease

Ticks are classified as arachnids (eg: spiders, mites, scorpions), as they have eight legs, rather than six as with insects (32). There are approximately 850 species of ticks worldwide that are divided into two families, the *Ixodidae* (hard ticks) and *Argasidae* (soft ticks). Both are vectors for human disease, although in the case of Lyme disease it is the Ixodidae family that has been associated with transmission. The family of *Ixodidae* tick itself has approximately 650 different species, divided into 13 genera including; *Ixodes, Amblyomma, Haemaphysalis, Rhipicephalus* and *Dermacentor* (33).

The first ticks found to be competent vectors of *Borrelia* were of the *Ixodes* genera: *I. scapularis* (Previously known as *I. dammini*, before being shown to be same species), and *I. pacificus* (Black-legged Tick), commonly known as deer ticks in America. In Europe and Asia, the vectors were found to be the *I. ricinus* (Castor Bean/Sheep Tick) and *I. persulcatus* (Taiga Tick). Since these early investigations, many more species of ticks have been identified as vectors. This includes over a dozen more species of *Ixodes* ticks, as well as ticks from other *Ixodidae* genera's including, *Amblyomma, Haemaphysalis, Rhipicephalus* and *Dermacentor*. (A table of these ticks is presented at the end of this section).

The basic implication of these findings is that there are many ticks that are capable of carrying and transmitting the bacteria that causes Lyme disease. What all of the ticks typically have in common is that they are three-host ticks. This simply means that they attach to a different host in each stage of their life development. Once the tick egg hatches to the larvae, the larvae need to find a host to attach to for a blood-meal, it then drops off and molts into a nymph. The nymph repeats the action of finding a host for a blood-meal before molting into an adult. The final blood-meal is then sought by the adult before dropping off, with the females then laying eggs. It is due to the attachment on three different hosts that these ticks are able to firstly be infected and then spread/maintain the disease within their environment.

Typically the larvae and nymphs feed on smaller animals within the environment, with the adult ticks then attaching to larger hosts (eg: deers for *I. scapularis*; sheep in the case of *I. ricinus*). It is the smaller/medium sized animals that the larvae and nymphs feed on that act as reservoir hosts for the *Borrelia* bacteria that play a large role in maintaining the infectious cycle. When the larvae or nymph ticks feed on the reservoir hosts, they are then infected, and upon attaching to their next host, may pass that infection on. Whilst humans are not the preferred host, if they inadvertently come into contact with ticks, (walking through bush or long grass) then they may be at risk. It is usually at the nymphal stage that humans are infected, as at this stage of its life, the tick is barely large enough to be noticed and as ticks inject an anaesthetic into the skin of the host when attaching, the tick may feed and drop off without a person evening realising.

On the following two pages (pages 13-14) is a table of tick vectors involved in the transmission and maintenance of Lyme. The table is by no means a fully comprehensive list of tick vectors involved. It does not contain the ticks suspected as being vectors for less studied continents, or countries where Lyme is yet to be acknowledged.

Table 2: Tick Vectors of Lyme Disease / Borreliosis

Continent/ Country	Ixodidae Genera	Tick Species and Preferred Hosts
North America:	***Ixodes:***	***I. scapularis***: Deer Tick / Black-legged Tick: {I} small rodents, reptiles, birds {A} small-medium mammals including dogs and deer *NB: In early research this tick is generally reported as I. dammini, before it was realised it was the same species and was re-classified as I. scapularis* ***I.pacificus:*** Western black-legged Tick: {I} rodents, reptiles, birds {A} large mammals ***I. dentatus:*** Rabbit Tick: {I} birds {I A} small rodents, rabbits ***I. affinis:*** {I} rodents, birds {A} med-large animals including, moles, squirrels, racoons, deer ***I. jellisoni:*** member of *I. ricinus* complex: {IA} rodents, primarily Californian kangaroo rat ***I. spinipalpis:*** Mouse tick: {IA} rodents ***I. neotomae*:** {IA} rodents *NB: Research in 1997 found that I. neotomae and I. spinipalpis were one species, I. neotomae was subsequently re-classified as I. spinipalpis* ***I. angustus:*** {IA} rodents ***I. minor:*** {I} birds {IA} rodents; ***I. muris:*** {I} birds {IA} rodents
	Amblyomma:	***A. americanum:*** Lone Star Tick: {I} small rodents, birds {A} variety large mammals. The vector of STARI, or Masters disease ("lyme-like" illness)
	Haemaphysalis:	***H. leporispalustris:*** Rabbit Tick: {I} birds {IA} small rodents, rabbits, hares
Canada:	***Ixodes:***	***I. auritulus*** {IA} birds ***I. scapularis ; I. pacificus ; I. spinipalpis ; I. angustus ; I. muris***
	Haemaphysalis:	***H. leporispalustris***
Europe:	***Ixodes:***	***I. ricinus:*** Castor Bean/Sheep Tick: {I} small and medium sized mammals, reptiles and birds {A} Med. and large sized mammals including dogs ***I. hexagonus:*** Hedgehog Tick/European dog Tick: {IA} main hosts of all stages are hedgehogs and carnivorous mammals of the Mustelidae (eg: badger, ferrets and Canidae (eg; foxes, wolves, dogs) families ***I. canisuga:*** Dog/Fox Tick: {IA} Medium to large mammals including dogs, foxes, badgers and cats ***I. frontalis*:** Passerine tick: {IA} birds ***I. trianguliceps:*** Shrew/Vole Tick: {IA} small mammals such as shrews, rodents
Asia:	***Ixodes:***	***I. ricinus,*** ***I. persulcatus:*** Taiga Tick: {I} small to med mammals including birds {A} Medium and large sized mammals *This tick (I persulcatus) is sometimes included in Europe literature as it is also found in Russia, whose borders span both Europe and Asia* ***I. sinensis:*** ({I} small to medium mammals {A} larger animals such as goats cows ***I.ovatus:*** {I} rodents, hares {A} various large domestic and wild mammals ***I. nipponensis:*** {I} small mammals, lizards, birds {A} medium to large mammals ***I. granulates:*** {IA} small to medium rodents such as rats, squirrels, rabbits and hares

Table 2 Continued Next Page

Table 2 Con't : Tick Vectors of Lyme Disease / Borreliosis

Continent/ Country	Ixodidae Genera	Tick Species and Preferred Hosts
Asia Con't:	***Haemaphysalis:***	***H flava:*** {I} birds, small to medium mammals {IA} various, prefer hares and dogs ***H. bispinosa:*** {I} birds, {A} various large domestic and wild mammals, ie: dogs, sheep, goats, deer, cattle ***H. longicornis*:** {I} birds, hares {A} same as bispinosa: ie: dogs, sheep, deer, cattle
Japan *A part of the Asian continent ; though in LD studies; stand-alone island*	***Ixodes:***	***I. Persulcatus ; I. Ovatus ;*** ***I. columnae:*** {IA} birds and rodents ***I. tanuki****:* {I} rodents {A} small to medium carnivorous mammals such as raccoon dog, weasels and badgers ***I. turdus***: {IA} birds
	Haemaphysalis:	***H flava***
Worldwide	***Ixodes:***	***I. Uriae*** (Seabird Tick)

A key to reading the Tick Vectors of Lyme Disease/ Borreliosis Table*:* The relevant ticks are listed, firstly under the country/continent in which they are found and then under their relevant Ixodidae genera, eg: *Ixodes, Amblyomma, Haemaphysalis, Rhipicephalus* and *Dermacentor*. The "scientific" name for the tick is firstly given, with the more common name (if applicable) in brackets; Animal hosts of the ticks are mentioned, with: {I} denoting hosts of Immature ticks ie: larvae and nymphs and {A} for the animal hosts of the adult ticks; If it is a second listing for the tick, that is, the tick is found in more than one continent/country, the animal hosts of the tick are not listed again.

*See reference list for source of tick location, animal hosts and journal articles with regards to vector capabilities of each of the above listed ticks (referenced in order of mention).

**Ticks such *as I. jellisoni, I. trianguliceps* and *I. spinipalpis* are known as nidicolous ticks (found in the burrows and nests of their hosts) and as these ticks do not actively look for hosts, their roles as vectors is associated with maintaining the *Borrelia* (and numerous co-infections such as *Babesia microti*) within the environment, rather than transmitting it to humans (1-3). However, in cases where they do come into contact with people, such as with *I. spinipalpis* (4), transmission to humans may occur.

***The tick species that have been recorded as being in Australia are highlighted in red.

The above table, though comprehensive, is not a complete list of ticks involved in the *Borrelia* cycle around the world. The main aim of the table is to show how many various genera of the Ixodidae tick family are involved in the Lyme disease/ borreliosis cycle. The existence of Lyme disease in Australia was denied by Russell et al., (1994) and continues to be denied by the NSW Department of Medical entomology (of which Russell was the Director until his retirement in mid 2012), and the NSW Health Director of Communicable Diseases, Dr Jeremy McAnulty, in part due to the fact that Australia does not have any of the first four ticks (ie: *I. scapularis, I. pacificus, I. ricinus, I. persulcatus*) that were initially identified as vectors of Lyme.

Tick Vectors and Reservoir Hosts of Lyme / Borrelia in Australia

Initial investigations into Lyme disease in the Northern Hemisphere revealed that four Ixodes species (*scapularis, pacificus, ricinus, persulcatus),* from the Ixodidae family of ticks underlay the transmission of Lyme disease/ borreliosis. As Table Two (Tick Vectors or Lyme Disease / Borreliosis) demonstrates, since the early research into Lyme, numerous other species of ticks have been found to be implicated in the Lyme transmission cycle.

The discussion in this segment examines four tick species from the Ixodidae family that are listed on Table Two that have been recorded as being in Australia. The ticks are also explored in relation to their respective animal hosts, with the presence of both the bird and mammal hosts in Australia being discussed. A number of other Ixodidae tick species that have been implicated as being involved in the *Borrelia* cycle are also examined.

In order to fully appreciate why the information presented in this section is relevant to understanding the extremely high possibility that the *Borrelia* bacteria underlying Lyme is in the Australian environment, an outline of this segments discussion is as follows:

- *Examination of Ixode Ticks and Bird species involved in the Borrelia cycle in Australia:* Ixodes ticks that are listed in Table Two as capable tick vectors of Lyme and that have been recorded in Australia include the *I. Uriae* and *I. Auritulus* species*.* As these are both bird ticks, their role in the *Borrelia* cycle is discussed in conjunction with bird hosts that have been shown to be either simply hosts/carriers of the tick, or those that are also reservoir hosts of the *Borrelia* bacteria. Also discussed are various birds that have been introduced into Australia, and are known reservoir hosts in the Northern Hemisphere.

- *Examination of* Haemaphysalis *Ticks and Mammals involved in the Borrelia cycle in Australia:* Haemaphysalis ticks that are listed in Table Two as capable tick vectors of Lyme and that have been recorded in Australia are the *H. bispinosa* and *H. longicornis* species. While the immature (larvae, nymph) tick may feed on birds, these ticks are associated more so with their mammal hosts. These two ticks are discussed in conjunction with mammal hosts that have been shown to be either hosts/carriers of the tick, or those that are also reservoir hosts of the *Borrelia* bacteria.

  In order to explain a little the importance of animal introduction and importation, the way in which Lyme can present as a clinical illness and contact transmission in animals is briefly outlined. The introduction and importation of various mammal species into Australia that have been shown to have varying reservoir host competence of *Borrelia* underlying Lyme is also discussed.

- *Rhipicephalus Ticks: R. sanguineus* and *R. Microplus.* These tick species are found in Australia. They are not listed in the above tick vector table, however they have also been implicated in the *Borrelia* cycle, in that they have been found to carry the *Borrelia* spirochete and are therefore possible vectors of *Borrelia*.

- *Dermacentor Ticks*: Although this family of ticks is not in Australia, this species is also briefly mentioned in order to demonstrate that when looking at the vector competence of a particular species of ticks that findings on competence may be altered when ticks are examined in co-feeding studies (numerous tick species feeding together - which would emulate the natural environment), as opposed to 'traditional laboratory' studies where only one tick species is commonly examined.

- *Various Ixodidae Genera:* In 1994 research reported by Russel et al., spirochete like objects were cultured from a number of tick species. These included the *Ixodes holocyclus*, *Haemaphysalis bancrofti* and the *Amblyomma Morelia.* These findings are looked at very briefly.

Examination of Ixode Ticks and Bird species involved in the Borrelia cycle in Australia

The role of the seabird (*I. uriae) and bird (I. auritulus)* ticks is maintaining/spreading the *Borrelia* bacteria to the animal hosts within their environment. However, unlike nest dwelling ticks whose ecosystem is limited, the fact that birds are the hosts has widespread ramifications. Birds can be both biological carriers (reservoir hosts) of many different pathogens including *Borrelia* (1), as well as parasitic carriers of blood sucking insects such as ticks. Anderson and Magnarelli first reported the importance of birds as reservoir hosts and their role in transmitting the *Borrelia* bacteria and ticks into new geographic areas in 1984 (2). In combination this means that not only can birds drop infected ticks into new environments (3-8), but as reservoir hosts, immature ticks that feed on them may become infected and spread the disease to other birds and mammals during their next feed.

Land birds can spread *Borrelia* across continents, whilst migrating seabirds can spread the disease across the Northern and Southern hemispheres (9-16). It must also be noted that while the primary role of *I. uriae* appears to be the widespread dispersal of *Borrelia*, these ticks are known to bite humans (17-18) and are the suggested vector for human disease on the Faroe Islands (18).

Seabird Tick Ixodes uriae and Associated Bird Vector & Reservoir Hosts

The *I. uriae* species is found Australia-wide, including offshore islands (19). It is prevalent in both the Northern and Southern hemispheres and is “closely associated with many species of colony-nesting marine birds” (20). In 1993 Olsen and others (20) extended on the finding that land-birds as well as mammals could be infected by *Borrelia*, with their research revealing that even in the absence of mammals, *Borrelia* was maintained by seabirds within the environment. A further study in 1995 (21) revealed “a significant role for seabirds in a global transmission cycle by demonstrating the presence of Lyme disease *Borrelia* spirochetes in *Ixodes uriae* ticks from several seabird colonies in both the Southern and Northern Hemispheres.” It was noted that: “Of particular interest is the finding of suspected cases of Lyme disease in Australia and South Africa, although no Lyme disease-causing spirochete has been isolated from these regions yet. Most of the findings in Australia are based on serological data and clinical cases with symptoms typical of Lyme disease. Our finding of *Borrelia* DNA in I. uriae ticks obtained from the Crozet Islands and Campbell Island [New Zealand coast] suggests that Lyme disease enzootic foci are present in that part of the world” (21: Pg 3272-3).

There are numerous species of marine birds that migrate between the Northern and Southern Hemispheres to Australia, as well as birds that migrate between New Zealand and Australia each year. In fact, of the 359 species of marine birds worldwide, 78 different species breed on Australian islands and shores. In comparison to other countries, Australia is second only to New Zealand who, with 84 species has the greatest diversity of marine birds anywhere in the world (22). These marine birds are generally broken down into either seabird or shorebird/wader families (23-25). The seabirds consist of around 20 species and are those that are most commonly found on, over or near the ocean, including shearwaters (more commonly known as mutton birds), albatrosses, penguins, frigatebirds, gulls, cormorants and terns. Some seabirds (such as cormorants) may also be found in other areas surrounding water, such as lakes and wetlands, and can become common in urban areas. Shorebirds/ waders are those which are commonly found on coastal shores, including beaches, rocky shores, mudflats, tidal wetlands and lagoons. These include many species of plovers, sandpipers, stilts, curlews and snipes.

In Australia (and many other countries) seabirds and shorebirds are not restricted to separate areas and share many locations with each other as well as land birds and mammals, including humans: “Some seabird colonies are very accessible to large numbers of people. This is especially true of small islands in mainland estuaries or islands that are linked to the mainland in some way or are close to big cities (26: Pg 74)”. The shorebirds from the East Asian-Australasian Flyways alone have 118 internationally important sites that encompass the coastline as well numerous inland areas of Australia (27: Fig 20; pg 210), whilst seabirds nest in many areas on the mainland, as well as on numerous islands off almost every state in Australia. (See Attachment A – Seabird areas for more specific locations, including those on mainland Australia)

Seabirds such as the Sooty and Short-tailed Shearwaters, Common and Little Tern, Gulls, and shorebirds such as; Bar tailed Godwits, Red Knots, Sandpipers, Curlews and Snipes migrate to Australia from California, Europe, Asia (including Russia) and Japan (26-34). Lyme disease is endemic in all of these regions. With over 20 million migrating seabirds and 3 million plus shore-birds breeding on Australian Islands and shores each year, it is inconceivable that the health departments of Australia continue to ignore the long established knowledge that “Migrating birds contribute to the spread of B. burgdorferi sl and of infected tick vectors along migration routes” (35).

Along with the seabird tick (*I. uriae*), a number of different ticks have been associated with *Borrelia* and different bird hosts (eg: *I. auritulus, I. dentatus, I. frontalis, H. flava, H. leporispalustris*). Of interest for Australia is the finding that the *I. auritulus* tick is a vector of *Borrelia* (36-38).

Bird Tick Ixodes auritulus and Associated Bird & Reservoir Hosts

The *I. auritulus* is a native tick species of Tasmania (39-41). Birds continually spread the known distribution range of ticks (eg: 37-38) and as numerous species of birds, such as the Silvereye (Zosterops lateralis: passerine), migrate from Tasmania and disperse into regions of Victoria, New South Wales and south-eastern Queensland there certainly is the possibility this tick has been spread throughout mainland Australia. The common blackbird (passeriforme) is also abundant in Tasmania (and other areas of Australia), and is a bird that has been regularly identified as a reservoir host of *Borrelia*.

Birds of the Passeriforme order, or passerine birds, are more commonly known as perching or song birds (42), and include over 5000 species grouped into approximately 110 families that may be partially (travelling long distances within the same continent) or fully (travelling across continents) migratory. Numerous passerine species have been identified as reservoir hosts of *Borrelia* and include; Robins, Thrushes, Redstarts (formerly thrush family), Sparrows and Tits (eg:2, 9-11,38-40). Thrushes (Turdiae family) appear to be extremely competent reservoir hosts: *Borrelia* is thought to have been introduced into Japan from two species of thrush (Turdus cardis and pallidus) that migrate from Asia (43-45), whilst Song thrushes (Turdus philomelos) and the Eurasian/Common Blackbirds (Turdus merula) are consistently found to be competent reservoir hosts of *Borrelia* in Europe (46-49).

Both Song thrushes (Turdus philomelos) and the Eurasian/Common Blackbirds (Turdus merula) have been introduced into Australia: Song thrushes are established in Melbourne after being introduced in the 1850’s. The Eurasian/Common blackbirds were introduced into Melbourne and South Australia in the 1860’s and 1870s and are now widespread. They range throughout coastal and lower inland regions of South Australia, the whole of Victoria and New South Wales and spread into Queensland in 1986, breeding in regions around Toowoomba and the Highfields (50-52). They are also “abundant in Tasmania and have successfully colonised offshore islands such as Lord Howe Island, Norfolk Island, Kangaroo Island and Flinders Island” (50: pg 8).

It appears that at least one government department in Australia is aware that Blackbirds can carry *Borrelia*. A risk assessment report from the Queensland State Government (Biosecurity Queensland), examining the potential spread of Blackbirds into Queensland, makes this note with regards to the diseases associated with Blackbirds: “Blackbirds are often infected with intestinal and haematozoan parasites, as well as external parasites such as ticks, which can then infect other blackbirds with illnesses such as Lyme disease” (50: pg 7). Unfortunately, they do not seem to understand the full impact of that statement, which is, that the ticks which feed on both bird and mammal hosts can also spread Lyme disease to other animals within the environment, including humans.

There is the possibility that the *Borrelia* bacteria was brought to Australia with the introduction of blackbirds. However, the presence of the Blackbirds in Tasmania, mainland coastal areas and offshore islands of Australia would no doubt mean that the largest threat of the Blackbirds (and the other reservoir hosts) acquiring and spreading *Borrelia* to other animals and birds would come from sharing the environment with the millions of marine birds that migrate to Australia each year.

In addition to the song thrushes and common blackbirds (Passeriformes), other species of birds that have been introduced into Australia, and are competent reservoir hosts of *Borrelia*, include birds from the order of *Galliformes*: wild turkeys (53), pheasants (54-55), quails (56) and *Anseriformes*: Mallard ducks (57).

Examination of **Haemaphysalis** *Ticks and Mammals involved in the Borrelia cycle in Australia*

The *Haemaphysalis* tick species, *bispinosa* and *longicornis* have both been recorded in Australia and have been found to be involved in maintaining and transmitting *Borrelia*. Whilst the immature (larvae, nymph) tick may feed on birds, these tick species also have a close association with mammal hosts. Bearing in mind this association, these ticks are discussed in conjunction with the mammal hosts that have been shown to be either simply hosts of the tick or those that are also reservoir hosts of the *Borrelia* bacteria. In order to further outline the role that mammals play in the maintenance and spread of *Borrelia* within the environment, the following section also briefly examines clinical illness in animals. This not only serves to give a practical example of which animals are reservoir hosts and can carry *Borrelia* (as well as develop a clinical illness); it also helps to reveal the concerns associated with the introduction and importation of numerous mammal species into Australia.

The *H. bispinosa* and *H. longicornis* ticks are very similar, and have the same host preferences. For example, immature ticks feed on birds and hares and hosts of the adult tick include various large domestic and wild mammals such as dogs, sheep, goats, deer, cattle, horses (1-2). Both tick species have been found to be vectors of *Borrelia* in southern China (3-6). *Borrelia* strains isolated from the *H. longicornis* tick include *B.garinii*, *B. afzelii* (5), and *B. valaisiania* (6). Studies also show that as well as a high infection rate of *Borrelia*, *H. longicornis* also carries co-infections such *as Bartonella, Anaplasma*, and *Ehrlichia* (7-8).

Haemaphysalis bispinosa

The H. Bispinosa tick species has been recorded in Australia (9-10). Further research reveals that the ticks recorded were found to be synonymous with *H. longicornis* (11), and Hoogstraal and others (12) reclassified the species of *H. bispinosa* from Australia and New Zealand as *H. longicornis*. Despite the reclassification, this species is mentioned here due to its original listing as being in Australia, its immense similarities with the *H .longicornis,* and that these two ticks are listed as synonymous on many occasions in the literature. It is also worthwhile noting that there have been other tick vectors of *Borrelia* that have been originally thought to be two separate species before it was found they were in fact the same species. These include; *I. scapularis* and *I. dammini*: When it was found that they were in fact the same species of tick, *I. dammini* was re-classified as *I. Scapularis* ; *I. spinipalpis* and *I. neotomae*: Research in 1997 found that *I. neotomae* and *I. spinipalpis* were actually one and the same species, *I. neotomae* was subsequently re-classified as *I. spinipalpis*.

Scrub Tick Haemaphysalis longicornis and Associated Mammal Vector & Reservoir Hosts

The *H .longicornis* is more commonly known as the scrub or bush tick (or cattle tick in New Zealand). It was introduced into Australia on cattle from Northern Japan and was first recognised in 1901 in north eastern New South Wales. It is now established along coastal areas in Queensland, New South Wales, and through north eastern Victoria (esp Murray Valley) and Western Australia (13-14). The bush tick was first recognised at Walpole in Western Australia in 1983, though for how long it had been in the state is unknown. As there have been no reports of the tick in South Australia or the Northern Territory, its presence in Western Australia cannot be attributed to the natural spread of the tick and “The source of introduction to Western Australia has never been traced” (15). Two possible methods of introduction to consider are: Either via cattle transported to the district from states in Australia where the tick is common, or via migrating birds. In a study of New Zealand tick fauna it was noted that “Haemaphysalis spp. could be introduced …by migrating birds from Asia, a major source of members of this genus” (16). Walpole, where the bush tick was first recognised in Western Australia, is adjacent to Nornalup and Walpole Inlet Marine Parks, home to around 150 bird species including migrating shore and sea birds (17-18).

The hosts of the *H. longicornis* tick (19) include numerous animals that have been found to be reservoir hosts for *Borrelia* and have been introduced or imported into Australia from countries that are endemic for Lyme disease. These animals include; smaller reservoir hosts - mice, rats and hares : domestic animals - cats and dogs : medium to large animals - foxes, cattle, horses, sheep and deer (20) that have varying levels of reservoir competence. Importation of animals carrying *Borrelia* can occur as the animal may show no obvious signs of clinical illness.

To examine the very real likelihood of the bacteria underlying Lyme being in Australia, the following extends a little on clinical illness in animals, reservoir competence and the introduction/importation of the aforementioned animals into Australia.

In looking at animals brought into Australia from countries where Lyme disease is endemic, it should be noted that while the first reported cases described as Lyme disease were in the 1970's, DNA studies of ticks from museums has revealed that the *Borrelia* bacteria underlying Lyme has been in the environment since the 1800's (21-24). A study in Europe concluded, "residents of Europe have been exposed to diverse Lyme disease spirochetes at least since 1884, concurrent with the oldest record of apparent human infection" (21), and a study in America revealed, "These studies suggest that the agent of Lyme disease was present in a suitable reservoir host in the United States before the turn of the century and provide evidence against a hypothesis of recent introduction of this zoonotic agent to North America" (23).

Clinical Illness in Animals

In addition to humans, the only animals that may develop a clinical illness due to a *Borrelia* infection appear to be dogs, cats, horses and cattle (25). The primary symptom in all these animals is arthritic in nature, where inflammation of joints and limbs may lead to lameness.

Dogs are competent reservoir hosts (26) and seem to be the most susceptible to developing a clinical illness (25, 27). As they are generally in close contact with humans, rates of *Borrelia* infection/exposure in dogs has also been studied in order to try and ascertain what the degree of risk of *Borrelia* exposure to humans may be within particular areas/environments (28-30). Apart from lameness (shifting leg lameness in particular), other symptoms in dogs may include; anorexia/weight loss, malaise, neurological dysfunction (25), severe polyarthritis (27), renal lesions (31,32), splenomegaly/ lymphadenopathy, intraocular inflammation (33) abnormal gait and convulsions (34). Cats are more prone to asymptomatic infections (33), though as well as lameness they may develop; fever, anorexia, fatigue (35-36), and kidney problems (37).

Asymptomatic infections seem to be the most common in horses and cattle (38-41), although clinical illness can develop with symptoms in both animals including lameness, uveitis and weight loss (38, 41-43). Other signs in cattle include decreased milk production and abortion (42, 44,45), with head tilt, encephalitis (46,47), aborted, reabsorbed foetuses and foal mortality also being reported in clinical disease in horses (48,49).

Contact Transmission in Animals

Borrelia spirochetes have been found in the urine of infected dogs (31, 50) horses (45, 51) and cattle (45), in both symptomatic and asymptomatic animals. Studies on mice found that the spirochetes in urine remained viable for 18-24 hours and concluded that "Urine may provide a method for contact non-tick transmission of B. burgdorferi in natural rodent populations particularly during periods of nesting and/or breeding" (52: pg 40). Evidence for direct contact transmission has been demonstrated in mice (53) and further studies are required in larger animals to ascertain the potential for the *Borrelia* spirochete to be transmitted simply by being in close contact with an infected animal.

Importation of Animals into Australia: *Dogs, Foxes, Cattle, Horses, Sheep and Deer and their involvement in the maintenance and transmission of Borrelia*

Dogs are currently able to be brought into Australia from numerous countries in Europe, Asia and the United States (54). They are subjected to a 30 day quarantine, with requirements for rabies vaccination and blood tests for various pathogens (ie: *Ehrlichiosis, Brucellosis, Leishmaniosis, Leptospirosis*), though this does not include *Borrelia* infections (55). Red foxes (*Vulpes vulpes*) are competent reservoir hosts (56-57) and may also carry tick vectors into new geographical areas (58). Foxes were introduced into Australia from Europe in the 1870's. Their range spread across southern Australia in the late 1800s and early 1900s and foxes are now widespread across the continent (59). They are considered a pest in all regions of Australia (eg: 59-60), and in NSW they are listed as responsible for the extinction of several species of native fauna including numerous species of ground-nesting birds (59). On Middle Island in Victoria (home to Little Penguin, Short-tailed Shearwater and Black Cormorant colonies), foxes and dogs that crossed to the island at low tide reduced the penguin numbers from 600 to less than a dozen in between 2000-2005 (61).

The foxes and dogs interaction with the birds has the potential to spread *Borrelia* through the exposure to ticks and from consumption of the birds. If ticks attach to the foxes and dogs, not only can the ticks directly pass on any pathogens they carry, the ticks are also relocated into environments that the animals roam. As with contact transmission, a vector (tick) may not need to be involved in spreading the *Borrelia* bacteria, with research examining relapsing fever *Borrelia* species revealing that infection can be passed on through the consumption of *Borrelia* infected brains and organs (62:cited in). Further research to determine whether this mechanism of transmission may also occur in the *B.B sensu lato* or *B. Miyamotoi Borrelia* groups is required.

Cattle and horses are “low level” reservoir competent hosts, dependent on varying strains of *Borrelia* (63), with reservoir competency still to be assessed with a number of different pathogenic strains. Cattle importation to Australia was suspended relatively recently due to outbreaks of Bovine Spongiform Encephalopathy (BSE) in other countries. Until the BSE outbreaks, cattle were imported from the United Kingdom (UK) until 1988 and from other European countries until 1991, with the suspension being extended to include cattle from Japan in 2001, Canada in 2003 and the United States (US) in 2004 (64-65). Lyme disease has been reported from all of these countries since the late 1970’s, and/or early 1980’s. Horses are still able to be imported from many countries, including the US and with regards to Lyme disease they only require vet certification that “After due inquiry, for 60 days immediately before export, the horse has not resided on any premises in the United States where clinical, epidemiological, or other evidence of contagious …. equine piroplasmosis, horse pox, or Lyme disease has occurred during the previous 90 days” (66). With some animals carrying asymptomatic infections, this certification does not rule out that animals imported will be free of *Borrelia* bacteria.

Sheep and deer may develop antibodies to *Borrelia* infections (67-70), though studies regarding their role as reservoir hosts are mixed, with some studies concluding that they are competent reservoir hosts (68-72), and others finding that their role is limited to that of a host animal supplying a blood meal for the tick (73-75, 63). As with many animals, the differences found in reservoir competency with regards to sheep and deer may be due to species diversity of the animals (eg: there are around 44 recognised species of deer within 17 genera) or *Borrelia* species differences (eg: lizards are not a competent reservoir hosts of the *B. burgdorferi ss*, species, however they are for *B. lusitaniae*) and needs further examination (63). Currently sheep are only permitted to be imported into Australia from New Zealand, with importations from other countries ceasing in 1952 (65). Deer have been introduced into Australia from Europe since the late nineteenth and early twentieth century’s. Whilst over a dozen species of deer have been introduced, only six of these species survived the Australian environment (76). These deer (fallow, red, chital, rusa, sambar, and hog deer) have formed wild populations in Australia, with population numbers estimated to be 200 000 in 2004 (77). Commercial farming of four of these species (rusa, red, fallow, and chital) began in 1971, and in order to increase commercial herd numbers, the importation of a fifth species, the North American elk (wapiti), from Canada began in 1985 (78-79).

Apart from varying levels of reservoir competency, the medium to large animals are regarded as maintaining the *Borrelia* bacteria within the environment by providing the tick with a host for a blood meal, with studies finding deer populations correlated with tick density and human incidence of Lyme disease (80-81). The presence of larger host animals may also amplify the *Borrelia* infection within the environment through tick co-feeding (73, 82), with one study concluding that sheep “can transmit localized infections from infected to uninfected ticks co-feeding at the same site on the sheep's body” (73: pg 591).

In addition to the larger animals discussed above, smaller mammals that are competent reservoir hosts of *Borrelia* in the Northern Hemisphere, that have also been introduced into Australia include; the house mouse, the black and brown rats and the European Hare. The introduction of these mammals’ and their role in the *Borrelia* cycle is discussed in greater detail in this overview’s complimentary report, *‘Lyme Disease: A Counter Argument to the Australian Government’s Denial’.*

As well as the possibility that the previous and ongoing importation of animals into Australia has seen the introduction of various *Borrelia* species, it should also be noted that research from the 1950’s revealed *Borrelia* in Australian animals. A study conducted by Mackerras in 1959 reported that *Borrelia* was found in the blood of cattle, kangaroos, bandicoots and rodents (83). The *Borrelia* in cattle was identified as *Borrelia* theleri (agent of bovine borreliosis), transmitted by the cattle tick (*R. microplus*) (83), whilst the *Borrelia* found in rats in north-western Queensland (Richmond area) was determined to be a new species of *Borrelia* and named *B. queenslandica* (84). The vector *of B. queenslandica* was not ascertained (84) and the species of *Borrelia* in kangaroos and rodents not identified (83). Further to the 1950’s research, other reports involving animals in Australia include the findings of positive serology (Immunofluorescence antibody test - IFAT) for *Borrelia burgdorferi* on a cattle property in Camden NSW in 1989 (85), with another study of dogs in NSW revealing that 6 of 239 (2.5%) of the dogs tested in were seropositive for borrelia (86).

Other Ixodidae Tick Species

Rhipicephalus Ticks

Borrelia has been found in ticks of the *Rhipicephalus* genera, though their competence as vectors (rather than just carriers) is an area of contention that requires much further research. Two Rhipicephalus species that are in Australia are discussed briefly below.

Brown Dog Tick: Rhipicephalus sanguineus

R. sanguineus, or the brown dog tick, is located worldwide. In Australia, it is verified as present in every state apart from Tasmania (1: CSRIO info, last updated 2004). It is a tick of "great medical and veterinary significance being the vector and reservoir of many human and animal pathogens" (2: pg 349). Human pathogens include *Bartonella*, several species of *Rickettsia*, and *Coxiella burnetii* (Q fever). Animal pathogens include; *Ehrlichia canis*, several *Babesia* species such as *Canis vogelli* and *gibsoni* and is a suspected vector of *Anaplasma* (2-4). It is also involved in the transmission of *Theileria* (a protozoa that is closely related to *Babesia*) species such as *Theileria parva,* otherwise known as East Coast Fever and *Theileria ovis* (5,6).

Vector competence has not been established with regards to *Borrelia*, although it has been found to harbour *Borrelia* in both America (7) and Europe (8). It is also the suspected vector in Mexico, where a 2008 study in Mexicali, Baja California (a Mexico-US Border City) reported "the existence of B. burgdorferi past/present infection in dogs in an area where the only identified tick is R. sanguineus" (9). This species should be examined both for the *Borrelia* species they may carry and their vector capabilities.

Cattle Tick: Rhipicephalus microplus

R. microplus (previously known as *Boophilus microplus*), otherwise known as the cattle tick, is considered the most important parasite of livestock in the world (10). It was first introduced into Australia (Darwin) in 1872 on cattle from Indonesia. By 1895 it had spread to Western Australia, reaching Queensland in 1891 and New South Wales in 1906 (11). This tick differs from all other ticks mentioned in the *Borrelia* cycle, in that it is a one host (rather than three host) tick, meaning that it spends its entire life (much shorter cycle than other ticks also) on the one host. As the name suggests, the primary hosts of this tick are cattle, though it may also be found on horses, sheep, goats, camels, alpacas, llamas, deer and dogs (10, 12,13). Although not a common occurrence, these ticks may also attach to humans who come into contact with them (10, 12, 14). While it may not come into contact with humans on a regular basis, this tick may serve to keep the *Borrelia* cycle active within the environment.

Borrelia burgdorferi has been isolated from *R. microplus* (14-16), though it ability as a vector of this species of *Borrelia* is unclear. It is however a known vector of *Borrelia Theileri,* the species responsible for bovine borreliosis. "To date, only *B. burgdorferi ss* and *B. garinii* have been described in bovine Lyme disease. However, two other spirochetes, *B. theileri and B. coriaceae* have been described in cattle and considered as the agent of bovine borreliosis and as the putative agent of epizootic bovine abortion, respectively" (17:pg 2). *B. theileri* has been noted in Australian cattle for over 50 years (18).

DNA sequencing reveals that *B. theileri* is in the same clade as *B. lonestari* and *B. miyamotoi*, the species of *Borrelia* that are responsible for relapsing fever/ lyme-like disease in humans (19, 20). Indeed, they are that similar it has been postulated that due to the eradication of the *R. microplus* ticks from America, the lonestari *Borrelia* species that is found in the *A. americanum* tick may have originally been due to the *Borrelia theileri* bacteria relocating from the *R. microplus* tick to the *A. americanum* (14).

With the presence of *B. theileri* in Australia, combined with the possibility of host shifting and adaptation of various *Borrelia* species, along with the importations of cattle from countries where Lyme is endemic, further investigations of *R. Microplus* ticks to ascertain what pathogens they carry and whether they are infectious to humans is certainly warranted.

Dermacentor Species

Borrelia has been found in ticks of the *Dermacentor* genera, though similar to the *Rhipicephalus* genera, their competence as vectors is controversial and requires further investigation. The controversy with regards to the *Dermacentor* species lays in the fact that while ticks of this species may be found to be incompetent vectors when feeding alone, in studies where they are co-fed with other species of ticks, they are found to be competent vectors. Although there are no ticks of the *Dermacentor* genera in Australia, this family of ticks is examined briefly below due to the significance of these findings.

Species from the *Dermecentor genera* include those found in America: *D. variabilis* (American Dog Tick), *D.andersoni* (Rocky Mountain Wood Tick), and Europe/Asia: *D. reticulates* (Marsh tick or Ornate cow tick) and *D. marginatus* (Ornate sheep tick).

Borrelia has been found in both *D. andersoni* (Rocky Mountain Wood Tick) (1) and *D. variabilis* (American Dog Tick) (1- 5). Whilst this indicates their ability to acquire infection from a host animal, whether they maintain that infection through there next molt/life cycle, or are able to pass it on to another host is unknown. Studies on *Dermacentor* ticks are mixed: When the tick is examined in isolation, it is not considered/found to be a competent vector, however, when "they feed in conjunction with Ixodes scapularis ticks, the *Dermacentor* ticks can acquire and transmit *Borrelia* burgdorferi sensu stricto" (6). The combination of different salivary factors of the ticks feeding in close proximity is believed to be the underlying factor in this finding.

Two *Dermacentor* species found in Europe / Asia are the *D. reticulates* (Marsh or Ornate cow tick) and the *D.marginatus* (Ornate sheep tick). Both species may feed on humans, particularly the scalp (7), and both have been found to harbour *Borrelia* (8-10). *D. reticulates* has been suggested to be involved in the transmission cycle of *Borrelia* in Europe (11) and a case of human Lyme disease after the bite of a *D.marginatus* in Bulgaria has been reported (12).

Considering that in the natural environment many different species of ticks may be found on the host animal, further co-feeding studies of various tick species are warranted and urgently required to further understand the co-feeding phenomenon revealed through examination of the Dermecentor genera.

Various Ixodidae Tick Species: *Paralysis Tick (Ixodes holocyclus), Wallaby Tick (Haemaphysalis bancrofti), Snake Tick (Amblyomma Morelia)*

Other species of the *Ixodidae* family in Australia include the *Ixodes holocyclus (*Paralysis Tick), the *Haemaphysalis bancrofti (*Wallaby Tick) and the *Amblyomma Morelia (*Snake Tick). In research reported in 1994 by Russell et al., *Lyme disease: search for a causative agent in ticks in south-eastern Australia* (1), spirochete-like objects (SLO's) were cultured from these three species of ticks, as well as from the *Haemaphysalis longicornis* (Scrub Tick) species.

Further information on these tick species, as well as an in-depth review of the research methods and conclusions about the research findings drawn by Russel et al., can be seen in this papers complimentary report, *'Lyme Disease: A Counter Argument to the Australian Government's Denial'* (2). For an outline of the findings / completeness of discussion in this review paper, below is the summary of the information with regards to these tick species (as well as *H. longicornis*) as shown in the *Counter Arguments* (2) executive summary:

- *I. holocyclus* - As well as SLO's cultured from this species by Russel et al., spirochetes were also cultured from *I. holocyclus* ticks collected from the Hunter Valley and Manning River district of NSW in research by Wills and Barry in 1991
- *H. bancrofti* - In Wills and Barry's research, spirochetes were also cultured from the *Haemaphysalis* species. The *H bancrofti* tick not only attaches to wallabies, its hosts also include kangaroos. In 1959, Mackerras reported the presence of *Borrelia* in Australian animals, including kangaroos
- *H. longicornis* - is a vector of *Borrelia* in China. It is also the tick species infesting a herd of cattle in which positive serology for *Borrelia* was reported in a cow in Camden NSW in 1989
- *A. morelia* - Snakes are capable reservoir hosts of the *Borrelia* species *B. lusitaniae*. This is a species of *Borrelia* that might be expected along the coastline, as it is carried by migrating seabirds

The above mentioned ticks only account for a small number of the approximately sixty known tick species belonging to the *Ixodidae* family in Australia. A thorough examination of all tick species, to determine the pathogens they carry and to investigate whether they are can cause illness in humans needs to be conducted.

Multiple pathogens carried by Ticks, with a focus on Babesia

The clinical picture of Lyme may be altered by numerous factors, one of these being that a tick typically harbours numerous pathogens. Therefore, if bitten by a tick, a person may be exposed to an array of various bacteria, viruses and parasites (1). It is far beyond the scope of this paper to discuss the numerous pathogens that ticks carry; instead the brief discussion below highlights one of these, the protozoan parasite*, Babesia.* The numerous pathogens that *H. longicornis* and *R. Microplus* are known vectors of are very briefly discussed, with their ability to transmit certain *Babesia* species and the need for further research highlighted.

Babesia

Babesia is a red blood cell parasite that belongs to the Apicomplexa phylum, a group of parasitic organisms which also includes other piroplasms such as *Theleira* and the *Plasmodium species* that are the causative organisms underlying malaria. Infection from the *Babesia* parasite is known as Babesiosis, a malarial-like disease (2). *Babesia* is one of the most common animal parasites in the world (3), with over 100 species identified to date. Each species is broadly classified by numerous factors, including organism size and reservoir host, though the natural host is not always able to be identified (2).

A number of Babesia species have been found to be pathogenic to humans, with both the small and large *Babesia* parasites being able to cause illness in humans. The large *Babesia* species include bovine parasites *B. divergens, B. bovis, B. bigemina,* deer parasite *B.venatorum* and canine parasite *B. canis*. The smaller *Babesia* species include the rodent parasite *B. microti,* and *B duncani* (previously known as WA1). Although *B. duncani* has been found in the blood of sick humans, no natural reservoir host or tick vector has been identified for this species as yet. Of these, the four main species that have been identified as underlying human babesiosis are, *B. microti*, *B.duncani, B. divergens* and *B.venatorum,* with *B. bigemina, B. bovis and B. canis, also being* implicated in a number of cases of human infection (3-8).

B. bovis and *B. bigemina* are believed to have been introduced into Australia around 1872, the same time as the cattle tick (9, 10), with over 80% of tick fever outbreaks in Australia due to *B. bovis* (11). The first known case of human *Babesia* in Australia came to light as the result of a *Babesia microti* infection and subsequent death of a 56yo NSW male in April 2011 (12,13).

It should also be noted that a *Babesia i*nfection can be passed from mother to foetus (14-17). *Babesia* protozoa are also able survive in stored blood and be passed on through blood transfusions (17-19).

Various pathogens carried by H. longicornis and R. Microplus:

Similar to other ticks associated with *Borrelia* (eg: *I. ricinus* in Europe and *I. scapularis* in America), the *H.longicornis* species carries numerous pathogens. As well as its role in *Borrelia*, it is a known vector for: bacterial infections such as *Bartonella* ; Rickettsial infections including human rickettsiosis (*R. japonica*), *Anaplasma* and *Ehrlichia* ; Protozoal infections *Thelieria* and *Babesia*. Of the protozoa, *H. longicornis* is a vector for a number of species including : East Asian bovine theileriosis (*T. buffeli*) , *Theileria Equi*, Bovine babesiosis (*B. ovata*) and Canine babesiosis (*B. gibsoni*) (20-29). With its known vector capability with regards to some smaller *Babesia* species, examination of the capability of *H. longicornis* in Australia to carry and/or transmit *B. microti* and other *Babesia* species, would be highly appropriate.

Along with its role in various *Borrelia* species (ie: found to harbour *B. burgdorferi* and is a competent vector of Bovine *Borrelia*) *R. microplus* is the vector for many zoonotic pathogens; including those responsible for "Tick Fever"; *Babesia bovis, B. bigemina* and *Anaplasma marginale*, which may result in sickness and death in cattle (30-33) as well as humans, particularly those that are immune-compromised (30, 34). It is also suspected as a vector of *Theileria equi* (30), previously known as *Babesia equi*, and has been found to carry *Ehrlichia, Wolbachia*, and *Coxiella burnetti* (33).

It is long overdue that the health departments in Australia communicate information acknowledged in the rest of the world by updating the information such as that found on the Queensland Government: Agriculture, Fisheries and Forestry website: "People can find cattle tick on themselves after working with cattle or other animals. The ticks are easily removed and cause no lasting affect apart from the site itching for a few days" (31). It urgently needs to be acknowledged that the *Babesia* parasites these ticks can carry can be passed on to humans and result in clinical illness. *Babesia bovis* and *bigemina* may have only been implicated in a small number of cases of human babesiosis, but that possibility is there, as is the potential to transmit any other species / pathogens that the ticks may carry such as *Coxiella burnetti*, the pathogen underlying Q fever.

Conclusion

In order to maximise the potential for early detection, treatment and full recovery, the recognition of the possibility of Lyme as a differential diagnosis when presenting with an illness is essential. To date many Australians have come forward, believing that not only have they contracted Lyme disease, but that they have done so in Australia. A lack of awareness and acknowledgement of Lyme by the health authorities in Australia has meant that many people are undiagnosed, or have been misdiagnosed for years, with treatment delays costing some people their lives.

It is anticipated that the information contained in this overview highlights the fact that the likelihood of Australia being the only continent in the world that is free of the *Borrelia* bacteria that underlay's Lyme is quite minimal. Research spanning decades indicates that there is *Borrelia* in the blood of animals in Australia. With the past and ongoing introduction / importation of animals, their interaction with other mammals and birds within the Australian environment the spread of pathogens is inevitable. Migrating seabirds, the ticks they carry and their interaction in the Australian environment also means that new pathogens are able to be introduced into the environment at any given time. As noted above, this fact was highlighted with the death of the New South Wales male in 2011 due to a *Babesia microti* infection. *Babesia microti* is not endemic to Australia; rather it is an American species of *Babesia.* Research on how these protozoa came to be in the Australian environment, and how someone contracted it, and subsequently died, still does not appear to have garnered research or public education with regards to *Babesia* in Australia.

Thorough and up to date investigations are required in order to identify the various *Borrelia* species within the animals in Australia, and to ascertain what species they are and whether they are pathogenic to humans. Research should also include examination of potential tick vectors, especially the tick species examined in this overview, to ascertain what bacteria, viruses and protozoa they carry.

It must be acknowledged that a number of areas regarding the presence and the transmission of Lyme disease in Australia have been completed ignored for many years. The absence of adequate research makes the rebuttal of the existence of Lyme in Australia premature and arguably naive. Up to date research is necessary in order to better understand, diagnose and treat not only Lyme, but other vector borne diseases that may be undiagnosed in thousands of Australians.

References

NB: Reference section is separated into segments for ease of updating information. As this research was originally started with the intention of expanding and viewing on a website platform, the reference section is separated into segments (content headings) for ease of updating information, and while not conventional referencing style, links have also been provided to where the journals/information can be accessed on-line.

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Lyme Disease Tick Vectors (Table)

I. scapularis and I. pacificus: Well known vectors

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I. affinis:
Maggi RG, Reichelt S, Toliver M and Engber B (2010) Borrelia species in Ixodes affinis and Ixodes scapularis ticks collected from the coastal plain of North Carolina. Ticks Tick Borne Dis;1(4):168-71. Epub 2010 Oct 20. http://www.ncbi.nlm.nih.gov/pubmed/21771524

I. jellisoni:
Lane RS, Peavey CA, Padgett KA and Hendson M (1999) Life history of Ixodes (Ixodes) jellisoni (Acari: Ixodidae) and its vector competence for Borrelia burgdorferi sensu lato. J Med Entomol;36(3):329-40. http://www.ncbi.nlm.nih.gov/pubmed/10337104

I. neotomae: (Also ; or now known as I spinaplpis – see Norris et al, 1997):
Keirans JE, Brown RN and Lane RS (1996) Ixodes (Ixodes) jellisoni and I. (I.) neotomae (Acari:Ixodidae): descriptions of the immature stages from California. J Med Entomol;33(3):319-27. http://www.ncbi.nlm.nih.gov/pubmed/8667376

Norris DE, Klompen JS, Keirans JE, Lane RS, Piesman J and Black WC 4th (1997)
Taxonomic status of Ixodes neotomae and I. spinipalpis (Acari: Ixodidae) based on mitochondrial DNA evidence. J Med Entomol; 34(6):696-703. http://www.ncbi.nlm.nih.gov/pubmed/9439125

I. spinipalpis:
Dolan MC, Maupin GO, Panella NA, Golde WT, Piesman J (1997) Vector competence of Ixodes scapularis, I. spinipalpis, and Dermacentor andersoni (Acari:Ixodidae) in transmitting Borrelia burgdorferi, the etiologic agent of Lyme disease. J Med Entomol; 34(2):128-35. http://www.ncbi.nlm.nih.gov/pubmed/9103755

I. angustus:
Peavey CA, Lane RS and Damrow T (2000) Vector competence of Ixodes angustus (Acari: Ixodidae) for Borrelia burgdorferi sensu stricto. Exp Appl Acarol;24(1):77-84. http://www.ncbi.nlm.nih.gov/pubmed/10823359

I. minor:
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I. muris:
Dolan MC, Lacombe EH and Piesman J (2000) Vector competence of Ixodes muris (Acari: Ixodidae) for Borrelia burgdorferi. J Med Entomol; 37(5):766-8. http://www.ncbi.nlm.nih.gov/pubmed/11004792

A. Americanum:
Schulze TL, Jordan RA, Schulze CJ, Mixon T and Papero M (2005) Relative encounter frequencies and prevalence of selected Borrelia, Ehrlichia, and Anaplasma infections in Amblyomma americanum and Ixodes scapularis (Acari: Ixodidae) ticks from central New Jersey. J Med Entomol;42(3):450-6. http://www.ncbi.nlm.nih.gov/pubmed/15962799

H. leporispalustris:
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Full copy at: http://www.jwildlifedis.org/cgi/reprint/24/1/1
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Canada Communicable Disease Report (1995) Vol 21-10. ISSN 1188-4169
http://www.collectionscanada.gc.ca/webarchives/20071127051546/http://www.phac-aspc.gc.ca/publicat/ccdr-rmtc/95pdf/cdr2110e.pdf

I. auritulus:
(a) Scott JD, Anderson JF and Durden LA (2011) Widespread dispersal of Borrelia burgdorferi-infected ticks collected from songbirds across Canada. J Parasitol Aug 24. [Epub ahead of print] http://www.ncbi.nlm.nih.gov/pubmed/21864130
(b) Scott JD, Lee MK, Fernando K, Durden LA, Jorgensen DR, Mak S and Morshed MG (2010) Detection of Lyme disease spirochete, Borrelia burgdorferi sensu lato, including three novel genotypes in ticks (Acari: Ixodidae) collected from songbirds (Passeriformes) across Canada. J Vector Ecol;35(1):124-39. http://www.ncbi.nlm.nih.gov/pubmed/20618658
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I. ricinus: Well known vector

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