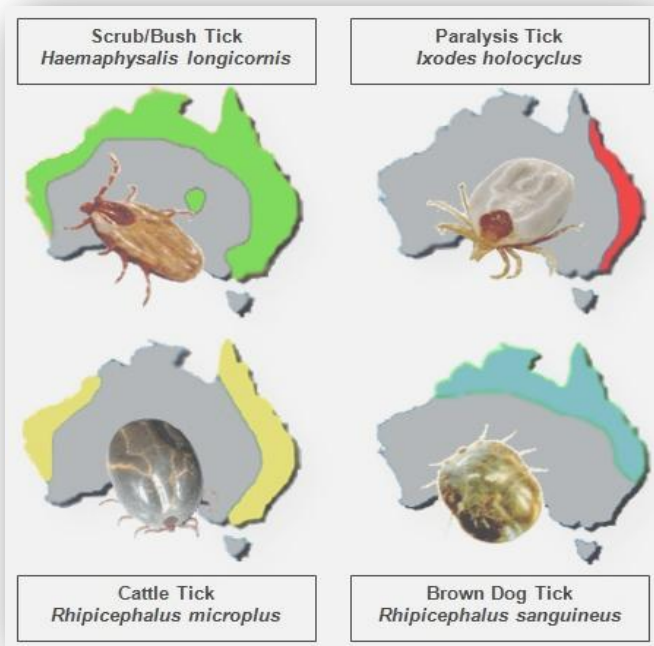
Lyme Disease / Borreliosis
An Overview of Lyme and Direction for Further Research Required in Australia



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Lyme Australia Recognition & Awareness

Shining A Light on Lyme

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Please note: The original PDF version of the Overview has been corrected as of July 2017 (The content/message remains the same – changes were grammatical/spelling/formatting errors).

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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.

As noted on LARA's website: The information in this overview 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).

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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, in the acute stage, 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 of complicated due to the infection having widely disseminated.

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, 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. The information discussed in each segment of this paper is briefly outlined below.

❖ 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. In the 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 the symptoms become more wide-ranging.
- ***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** (Page 10)*
  - *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** (Pages 13-14)*
  - 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 on the table 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, while 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 one, 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 following a 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: pge 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 more complicated due to the chronic disease process.

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: pge 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: pge 9).

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: pge 7).

(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:pge 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 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 (pge 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 of *Borrelia* 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 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 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 (pge 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 even realising.

On the following two 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 in the Lyme cycle.

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

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)

*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 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 in the United States and Europe. As the tick table demonstrates, there are numerous tick species that are involved in the Lyme borreliosis cycle and these species can be different in various countries. Australia has a number of tick species (highlighted in red) that are involved in the cycle, and these are discussed in further detail in the following segment.

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 of 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 (pages 13-14) 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 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 by Russel et al., it was reported that spirochete like objects were cultured from a number of tick species. These tick species included *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 to maintain and/or spread 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 host of these tick species 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, while 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: pge 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 two classes, 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 and include birds such as, 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: pge 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; pge 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: pge 70).

Along with the seabird tick (*I. uriae*), a number of different tick species (eg: *I. auritulus, I. dentatus, I. frontalis, H. flava, H. leporispalustris*) have been associated with *Borrelia* and different bird hosts. 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 high possibility that 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), while 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).

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: pge 8).

It appears that at least one government department in Australia is aware that Blackbirds can carry *Borrelia* species underlying Lyme disease. 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: pge 7). Unfortunately, they do not seem to understand the full impact of that statement, which is, that the ticks are able to infect more than other blackbirds with pathogens. The ticks feed on both bird and mammal hosts and can also spread the Lyme disease bacteria 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: pge 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 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: pge 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 it 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 their 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 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 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 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 *Theileria* 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 *Babesia* species, the four main ones 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 *Theileria* 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.

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. As this overview has outlined, with the past and ongoing introduction / importation of animals known to be reservoir hosts of borrelia, 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 another vector borne infection, *Babesia microti*. *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.

Research spanning decades indicates that there is *Borrelia* in the blood of animals 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 completely 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.

Lyme Disease

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Clinical Picture

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I. angustus:
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I. muris:
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http://www.collectionscanada.gc.ca/webarchives/20071127051546/http://www.phac-aspc.gc.ca/publicat/ccdr-rmtc/95pdf/cdr2110e.pdf

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

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

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Other Ixodidae Tick Species

Rhipicephalus Ticks

Brown Dog Tick: Rhipicephalus sanguineus

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