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Known and potential ticks and tick-borne pathogens of Micronesia[1]

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Abstract—Ticks have long been known to be the vectors of diseases, to both humans and animals. Yet very little work has been done regarding tick species found in Micronesia, and much of that is now decades old. Many parts of Micronesia have long undergone considerable change by outside influences and hence the natural and social environments have undergone major upheavals. Ticks as vectors of veterinary disease have long been documented in Micronesia, but ticks connected with human disease are often presumed not to exist. Hence another look would seem justified. This paper provides an initial review of information on tick species reported from Micronesia. Some diseases that such ticks transmit are presented, along with some hypothetical consideration of other diseases potentially associated with ticks of Micronesia. As this information on the ecology of ticks in Micronesia and the environments and circumstances allowing for the possibility of transmission of disease to humans come together, there emerges an intriguing picture of an often-overlooked part of the environment in which humans live in Micronesia.

Introduction

TICKS

In recent years it has become more and more apparent that ticks play a major part in the transmission of diseases. Ticks are hence now considered "second only to mosquitoes as vectors of disease-causing agents in humans and are the most important arthropod transmitting pathogens to domestic and wild animals," and to "transmit a greater variety of pathogenic micro-organisms than any other arthropod vector group" including such pathogens as "protozoa, rickettsiae, spirochaetes and viruses" (AFPMB 1998, Estrada-Peña & Jongejan 1999, You et al. 2003, Jongejan & Uilenberg 2004). According to a report by the Center for Health Promotion and Preventive Medicine, *Information Paper On Assessing Threats From Ticks At U.S. Army Installations*: "From 1983 to 1987

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tickborne diseases accounted for 95% of the vectorborne infections in the United States reported to the federal Centers for Disease Control (CDC)" (Center for Health Promotion and Preventive Medicine undated).

Worldwide, there are over 850 species of ticks, members of the suborder Ixodida in the arachnid subclass Acari. They are parasites on vertebrates – amphibians, reptiles, birds, and mammals. The two main families of ticks are the Argasidae or Soft Ticks, and the Ixodidae or Hard Ticks. The "soft" or "hard" is in reference to the scutum or shield or plate right behind the head, not whether or not engorged ticks are soft or not (Levi & Levi 1968, AFPMB 1998). Many ticks have a three-host life cycle. These feed on one host during their larval stage, drop back to the ground, molt, then find another host for their nymphal stage, drop, molt, and then again locate a host and feed when they are adult. These hosts are typically not only different individuals, but also different species. Some ticks, however, are one-host ticks and spend their entire existence on one animal (AFPMB 1998).

Up until quite recent times, Glen M. Kohls' 1957 work, "*Insects of Micronesia: Acarina: Ixodoidea*" has been considered to be the authority on the ticks of the region (Joyce 1971, Samuelson & Nishida 1987, Chang et al. 2006). In this work, Kohls identified six species of ticks from the former Trust Territory of the Pacific Islands, Guam, and Kiribati. He considered two of those species to be wide-ranging introductions, and the other four as native. That report is now over fifty years old and with the tremendous ecological, social, and other changes that have occurred since then, as well as the expanding research into ticks and tick-borne diseases, revisiting the subject was warranted.

MICRONESIAN ECOLOGY AND POTENTIAL TICK HOSTS

For the purpose of this investigation and paper, "Micronesia" was expanded to include not only the region covered by Kohls, but all areas that are either biogeographically or politically part of Micronesia.

Nauru has always been biogeographically part of Micronesia but was not part of the United States Trust Territory of the Pacific Islands. Also, Wake Island (atoll) was included because geographically and traditionally, it is the most northern of the Ratak Chain of atolls, most of which are now part of the Republic of the Marshall Islands. Furthermore, the outlying chains of the Line Islands and the Phoenix Islands, although not geographically considered Micronesia, are in the modern political entity of the Republic of Kiribati.

The biodiversity of Micronesia has long been changed through contact from outside regions, not just nearby Asia, but also Europe and the Americas. Guam in particular has suffered from the onslaught of exotic species, as well as the extirpation and extinction of many of its native and endemic species. As early as 1668, 'a young bull, a cow and sheep' were introduced to Guam, along with 'three macaws' (Ansaldo 1669). Other records tell of host vertebrates being imported from Mexico, the Philippines, California, Peru and other areas. For instance, records from the expedition in the early nineteenth century by Freycinet (1819) tell of the importation into Guam and the Marianas of donkeys and goats from Mexico, cattle from New Spain-California, cattle, deer, goats, sheep, pigs, ducks, and chickens from the Philippines, ducks and pigs from Lima, Peru, and turkeys from America, as well as horses, cats, and dogs from unspecified locations. Towards the end of the nineteenth century, in order to bolster the economy, the Spanish administrators of Guam declared that the island "be open for trade to all vessels, Spanish and foreign alike" and that "seeds and animals be imported from Europe and the Philippines" (del Valle [Driver] 1991). A few decades later, when Japan controlled Micronesia, a different assortment of exotic animals and plants were introduced for domestic and agriculture use (Peattie 1988).

Micronesia also lies within the migratory routes of birds, some of which are known to harbor ticks capable of transmitting disease (Pratt et al. 1989, Yamauchi & Mori 2004).

COMPILATION OF INFORMATION

This paper presents an extensive, although not exhaustive, review of literature and information on the subject (historic documents, scientific journals, and popular works). The vast amount of available references in the Armed Forces Pest Management Board electronic library (www.afpmb.org) proved to be extremely useful, but other sources were also used.

Results

TICKS

A total of eleven species of ticks were found to be in Micronesia, as briefly discussed below, and are listed in Table 1. Eleven of these are based on published reports with the species identified. One species was not identified but based on a reliable anecdotal account. Another species, which Kohls (1957) discounted as being highly improbable, is mentioned below but, as Kohls did, it is not included in the tabulation.

Amblyomma breviscutatum Neumann, 1899 = ***Amblyomma cyprium*** Neumann, 1899

One of the ticks of Micronesia with a relatively wide distribution is the swine tick, *Amblyomma breviscutatum,* reported from Palau, Guam, Northern Marianas Pohnpei, Kosrae, and the Marshalls. In has been found on pigs, cows, rats and humans (Prowazek 1913, Schulze 1935, Kohls 1957, Jackson 1962, Joyce 1971). This tick was confirmed in 2008 as still being present on Guam.

Amblyomma loculosum Neumann, 1907

The southern ocean bird tick, *Amblyomma loculosum*, was not reported by Kohls (1957). It has a wide distribution in the Indian Ocean and was collected on the red-footed booby (*Sula sula*), sooty tern (*Sterna fuscata*) and humans on Helen's Reef of Palau. In other parts of its range, this tick has been found on many seabird species which are also known throughout Micronesia (Hoogstraal et al. 1976).

Amblyomma squamosum Kohls, 1953

When Kohls described the monitor lizard tick, *Amblyomma squamosum*, he considered it to be an endemic species found only on Guam and only on the mangrove monitor lizard (*Varanus indicus*) (Kohls 1953). No information beyond the original description and repetition thereof was found (Durden & Keirans 1996). Other lizards on Guam have suffered terrible decimation in recent years (United States Geological Survey 2005). If *Amblyomma squamosum* was actuality a parasite of more lizards than just the monitor, including one or more of the native and/or endemic lizards which early in the environmental upheaval of the last century were extirpated, this could possibly explain the lack of information about this tick (pers. comm. R. Robbins). Or it may be that it has escaped notice. Herpatologist Ronald Crombie (pers. comm.) observed ticks on monitor lizards and skinks of Guam and other Mariana Islands, as well as the Caroline Islands of Yap and Palau, but no identification was made of these parasites to know if these were the endemic *Amblyomma squamosum* or some other wider ranging monitor lizard tick or ticks.

Carios capensis (Neumann, 1901) = ***Ornithodoros capensis*** Neumann, 1901

Kohls (1957) reports that in 1945, on Guam, one female of the seabird soft tick, *Carios capensis.* which was reared from a larva, and several other larvae of this wide-ranging soft tick were found from brown noddies (*Anous stolidus*). This species is closely related to the following cosmopolitan *Carios denmarki* and differentiation is best done only in the larval state. However, in Amerson's report of the Central Pacific, (1968), additional Micronesian hosts were identified, primarily seabirds.

Carios denmarki (Kohls, Sonenshine & Clifford, 1965) = ***Ornithodoros denmarki*** Kohls, Sonenshine & Clifford, 1965

Despite of the difficulty in differentiating *Carios denmarki* and the above *C. capensis*, Amerson (1968) said that this tick has "been found to be associated with sea birds breeding on islands in the Central Pacific region" when discussing easternmost Micronesia. He distinguished between and reported both of these soft tick species from various seabirds. The most common host reported was the ground nesting sooty tern (*Sterna fuscata*).

Table 1: Ticks Reported from Micronesia[a]

species	Palau	Yap	Guam	N. Mar.	Chuuk	Pohnpei	Kosrae	Mar. Is.	Wake	Nauru	Kiribati	Line-Phoenix
Amblyomma breviscutatum	K		K			K	K					
Amblyomma loculosum	H											
Amblyomma squamosum			K									
Carios capensis [b]			K	X				A	A			A
Carios denmarki[c]								A				A
Ixodes amersoni												A
Ixodes eichhorni	K[d]											
Haemaphysalis longicornis	S2										S1	
Rhipicephalus (Boophilus) microplus	K		K	K		K	Sar?					
Rhipicephalus sanguineus	X		K	K	X			Sch		X	K	
Unidentified species from *Laticauda colubrina*	X											

[a] References: A = Amerson 1968; H = Hoogstraal et al. 1976; K = Kohls 1957; Sch = Schee 1904; S1 = Saville 1996; S2 = Saville 1999; Sar? = Sarfert 1919—probably this species but not certain; X = anecdotal report

[b] *Ornithodoros capensis* in other reports

[c] *Ornithodoros denmarki* or *Ornithodoros capensis* group in other reports

[d] as *Ixodes mindanensis* Kohls, 1950

Ixodes amersoni Kohls, 1966

Initially *Ixodes amersoni* was known from only two islands in the Phoenix Islands group of Kiribati, and only from the white tern (*Gygis alba*) and the red-footed booby (*Sula sula*) (Amerson 1968, wikipedia.org). However, its endemicity was never certain. Even following the discovery of the type specimens of *Ixodes amersoni* in the Phoenix Islands in 1966 as part of the Smithsonian's extensive ecological survey of the Central Pacific, Amerson (1968) remarked that he figured that "in time it probably will be found on other islands of the southern Central Pacific area as well." In 2006, as part of the preparation of the Phoenix Island Conversation Area, "Extensive searches for the tick, *Ixodes amersoni*, were completed on other Phoenix Islands (besides Enderbury and Rawaki), but the tick was not found" (Uwate & Teroroko 2007). However, this tick species has been found on the white-headed petrel (*Pterodroma lessoni*) on Kermadec Island (Heath et al. 2011).

Ixodes eichhorni Nuttall, 1916 = ***Ixodes mindanensis*** Kohls, 1950

Another obscure tick, *Ixodes eichhorni* has been only documented a few times. The Micronesian record is from 1945, from a chicken on Peleliu, Palau was classified by Kohls as *I. mindanensis*, which previous to that find, had only been reported on an island thrush (*Turdus poliocephalus*) in Mindanao, Philippines. Thereafter, it was determined to be a synonym of *I. eichhorni* (Petney & Keirans 1994). That species had been collected initially from a human in New Guinea and an unspecified kingfisher in the Admiralty Islands (Nuttall 1916).

Haemaphysalis longicornis Neumann, 1901

The scrub tick, *Haemaphysalis longicornis*, a livestock pest, has been found, on dogs in Kiribati (Saville 1999), and provisionally in Palau on cattle (Saville 1996). The latter record would seem certain as bovine theileriasis from *Theilera orientalis* (= *buffeli*) was also reported for Palau (Saville 1996). Although bovine theileriasis is not considered highly pathogenetic, this disease is only transmitted through infected ticks, and in the case of Palau, the likely vector being the scrub tick, *Haemaphysalis longicornis*. Elsewhere the scrub tick has been reported on a wide variety of mammals and some birds. It has implicated in various diseases in some areas, but even without any pathogen, a heavy infestation of this tick has been known to cause the death of its livestock host (Cane 2010).

Ixodes ornithorhynchi Lucus, 1846

Kohls (1957) discounted the platypus tick, *Ixodes ornithorhynchi*, for Micronesia, and that seems correct. The 1899 report was from "Isle Marianne" (Rainbow 1906). If not referring to the Mariana Islands, but to the Australian island "Mary Anne," it is still problematic because that island does not have the habitat for its host either. It would be interesting to re-examine the collected specimen to determine what actually was found. This tick is not included in the listing of Table 1.

Rhipicephalus* (*Boophilus*) *microplus (Canestrini, 1888)

The cattle tick, *Rhipicephalus* (*Boophilus*) *microplus*, is a widespread vector of livestock disease. Kohls (1957) considered it an early introduction into Micronesia. In 2008, this tick was collected in vast numbers from Philippine deer (*Cervus mariannus*) and in far lesser numbers from a pet carabao (*Bubalus bubalis*), both on Guam. Some earlier reports on Micronesia tell of the presence of another cattle tick, *Margaropus annulatus* or *Boophilus annulatus* (now *Rhipicephalus*) (Barber 1916, Alicata 1948). Kohls (1957), however, discounted those accounts as misidentifications of the above species, and hence the latter tick is not included in Table 1.

Rhipicephalus sanguineus (Latreille, 1806)

The brown dog tick, *Rhipicephalus sanguineus* is probably the tick which the public in Micronesia is most familiar. Kohls (1957) reported it on dogs on Guam, Saipan and Kiribati. Previous to this, Schnee (1904) reported it from cattle in the Marshalls. It is known to be a pest of a wide array of animals. Over fifty years ago, Kohls (1957) considered this tick to be "nearly cosmopolitan."

Unidentified species from sea krait (*Laticauda colubrina*)

In their work on Palau, Crombie & Pregill (1999) mention that the sea krait "*Laticauda* must come ashore to lay eggs (unlike the live-bearing sea snakes) and they often spend enough time on land to accumulate ticks." In personal communication with Crombie, he said that he had also found ticks associated with this species of sea snake when it hauled out on land but no identification of the ticks had been made. Although the ticks of sea snakes are poorly studied, other reports tell of *Amblyomma* (*Aponomma*) *fimbriatum* and *Amblyomma nitidum*, wide ranging ticks, known from this reptile (Rageau & Vervent 1959, Hoogstraal 1982, Voltzit & Keirans 2002, Easton 2003, Nadchatram 2006). None of the other species of ticks reported for Micronesia were found to be associated with sea snakes.

Through the compilation of previous studies, it was found that twenty-nine species of vertebrate hosts are known have been reported as having ticks in Micronesia. These are listed in Table 2.

As with insects, the natural dispersal of ticks is undoubtedly "quite fortuitous," (Gressitt & Yoshimoto 1963). Therefore, there is reason to suspect and speculate that the species listed in Table 1 are probably not the only ticks to be found in the area if a careful search were to be undertaken at this time. In extensive studies of Arno Atoll in the Marshall Islands, which documented many other ectoparasites of both animals and humans, no ticks were reported (Usinger & La Rivers 1953). On a recent visit, however, residents there were quite familiar with ticks.

VECTORS

About forty bird species which regularly migrate to Micronesia and are known to have ticks and /or tick-borne pathogens. There are also rare vagrants, bird species that are blown off course or in some other way have strayed from their normal route. As some ticks can remain on a host for a couple of weeks and it only takes 'one tick to import a disease,' there is constant opportunity for introduction. Potentially, disease carrying ticks have been found on migrating birds, and although some researchers surmise that many ticks would not remain attached to their bird hosts long enough to make an extensive migration, a tick-borne pathogen could remain in a bird's system for the duration of such a flight, hence allowing for the potential spread of tick-borne diseases (Gylfe et al. 2001, Morshed et al. 2005).

The constant influx of exotic vertebrates offers another potential avenue for tick introduction into the area. While it is always hoped that quarantine and/or customs agencies would prevent the importation of unauthorized species, this is often not the case. For example, the red-vented bulbul (*Pycnonotus cafer*) and the green anole (*Anolis carolinensis*) arrived on Majuro, Marshall Islands with no record of exactly how or when they came in (Vander Velde 2002). Both these species are known to be host to disease spreading ticks in other areas (Levin et al. 1996, Islam & Williams 2000). Similarly, on Guam, many non-native turtle species have come in recently without the knowledge of the authorities beforehand (Leberer 2003). At least some of these can serve as host to the neotropical tortoise tick (*Amblyomma sabanerae*), a poorly known tick, so its implications in human and animal disease is still uncertain (Burridge 2001).

KNOWN AND POTENTIAL PATHOGENS AND PROBLEMS

In an article a few years ago in the Guam newspaper, *Pacific Daily News*, concern was expressed about the potential of tick-borne diseases spreading on Guam. In 2008, the diagnosis by a veterinarian of over eighty cases of tick-borne diseases a month over a six month period, led to speculation that such diseases could spread, even infecting people (Kelman 2008).

But tick-borne diseases have been recorded in Micronesia for over a hundred years. Reports regarding "Texas fever" [Texas cattle fever] were found as early as 1901 by Fritz and others (see below). So these were less than a decade after the landmark discovery that ticks were responsible for transmission this disease, the first documentation of tick transmission of a parasite (Smith 1889, Smith & Kilbourne 1893).

An 1801 report describes how on the Mariana Islands “ticks, which fasten upon the limbs and bodies of men, and bury their heads under the skin” made the islands undesirable for settlement (W. Smith 1813). A century later, there was still a "Zeckenplage auf Tinian” or "tick plague on Tinian" with ticks attaching “cows, dogs, and sometimes human beings” (Prowazek 1913). It was figured that “the existence of the Texas-tick on Saipan” was the reason why cattle could not survive there (Fritz 1901). On Kosrae during approximately the same period, ‘cows were inflicted a great deal by tick’ to the extent that people tried to rid their animals of such pests by letting them swim in the sea (Sarfert 1919). Furthermore, while only four host species—humans, dogs, cows and carabao—have been reported as having tick-borne diseases in Micronesia, concern for tick problems and diseases should not be confined to these four host species.

Even without the presence of any pathogen, when the concentrations of ticks are heavy enough, some birds will abandon their nests. This occurs with the ground nesting sooty tern (*Sterna fuscata*) and the seabird soft tick (*Carios capensis*), a host-parasite combination known from Micronesia (Amerson 1968, Samuelson & Nishida 1987, Duffy 1991).

Nesting sea turtles on occasion have ticks (Amerson 1968). There is some evidence that these parasites might adversely affect the health of these sea reptiles, perhaps even contribute to the development of tumorous fibropapilloma (NMFS & USFW 1998).

International travel to and from all parts of Micronesia is ever increasing and hence also increasing the likelihood of the spread of ticks and their pathogens. This situation is occurring worldwide: “an increase in the number of people traveling to foreign countries to participate in recreational activities, including hiking, camping, and hunting, in nondeveloped or rural areas can result in increased contact with ticks and tick-borne pathogens endemic to that region” (Parola et al. 2005).

Additionally, climate change is altering the ecology around the world. Ranges of animals and migration routes of birds are shifting worldwide, including species which are known to spread tick-borne diseases (Crick 2004, Ogden 2008, Brinkerhoff et al. 2009). The full detail of the historic distribution of these diseases is not known. However, we discuss below suspect, likely and known tick-borne diseases from Micronesia.

Babesiosis

Worldwide, there are over one-hundred species of the protozoa *Babesia* that have been identified, all being “obligate parasites of red blood cells” (Vannier et al. 2008). These species are members of the larger order Piroplasmorida, or piroplasms, which are “parasitic apicomplexan protozoa which inhabit erythro-

Table 2: Vertebrate Hosts Reported As Having Ticks in Micronesia

Host	Tick	Region (reference)
Mangrove Monitor Lizard (*Varanus indicus*)	*Amblyomma squamosum*	Guam (Kohls 1957, Durden & Keirans 1996)
Sea Krait (*Laticauda colubrina)*	unidentified species	Palau (pers. comm. R. Crombie)
undetermined skink species	unidentified species	Palau, Yap (pers comm. Crombie)
Red Junglefowl / Chicken *(Gallus gallus*)	*Ixodes eichhorni*	Palau – Peleliu (Kohls 1957, Joyce 1971)
Bulwer's Petrel (*Bulweria bulwerii*)	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Phoenix Petrel (*Pterodroma alba*)	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Christmas Shearwater (*Puffinus nativitatis*)	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Wedge-tailed Shearwater (*Puffinus pacificus*)	*Carios denmarki* / *capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Polynesian Storm-Petrel (*Nesofregetta fuliginosa)*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Red-tailed Tropicbird (*Phaethon rubricauda*)	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Masked Booby (*Sula dactylatra*)	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Brown Booby (Sula leucogaster	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Red-footed Booby (*Sula sula*)	*Amblyomma loculosum*	Palau – Helen's Reef (Hoogstraal et al. 1976)
	Carios denmarki / capensis group	Kiribati – Line-Phoenix Islands (Amerson 1968)
	Ixodes amersoni	Kiribati – Phoenix Islands (Amerson 1968)
Lesser Frigatebird (*Fregata ariel)*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
Great Frigatebird (*Fregata minor)*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)

Black Noddy (*Anous minutus*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968), Marshall Islands –Enewetak) (Samuelson & Nishida 1987)
Brown Noddy (*Anous stolidus)*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968), Marshall Islands – Enewetak (Samuelson & Nishida 1987)
White Tern (*Gygis alba)*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands (Amerson 1968)
	Ixodes amersoni	Kiribati – Line-Phoenix Islands (Amerson 1968)
Greater Crested Tern (*Sterna bergii*)	*Carios denmarki / capensis* group	Marshall Islands – Erikup Atoll (Amerson 1968)
Sooty Tern (*Sterna fuscata*)	*Amblyomma loculosum*	Palau – Helen's Reef (Hoogstraal et al. 1976)
	Carios denmarki / capensis group	Marshalls (Enewetak Atoll, Taka Atoll, Bokak, Bikar), Kiribati – Christmas Island, Line-Phoenix Islands, Wake (Amerson 1968)
Spectacled Tern (*Sterna lunata)*	*Carios denmarki / capensis* group	Kiribati – Line-Phoenix Islands, Wake (Amerson 1968) (Amerson 1968)
European Rabbit (*Oryctolagus cuniculus)*	*Carios capensis* group	Kiribati (Phoenix Island) (Amerson 1968)
Human (*Homo sapiens*)	*Amblyomma breviscutatum*	"Micronesia" (Kohls 1957)
	Amblyomma loculosum	Palau – Helen's Reef (Hoogstraal et al. 1976)
	Carios capensis group	Kiribati – Line-Phoenix Islands, Wake (Amerson 1968)
	Rhipicephalus sanguineus	Guam (Pinkovsky 1986)
Domestic / Feral Dog (*Canis familiaris*)	*Haemaphysalis longicornis*	Kiribati (Saville 1996)
	Rhipicephalus sanguineus	Guam, Saipan, Kiribati (Kohls 1957), Chuuk (pers. comm. B. Alik), Marshall Islands (Schnee 1904, coll. 2006/ det. R. Robbins), Nauru (pers. comm. G. Harris) presumably most, island entities

Table 2, continued

Host	Tick	Region (reference)
Domestic / Feral Cat (*Felis catus*)	*Rhiphicephalus sanguineus*	Guam (Pinkovsky 1986)
Domestic/Feral Pig (*Sus scrofa*)	*Amblyomma breviscutatum*	Guam (Kohls 1957), Pohnpei (Jackson 1962, presumably, as *Amblyomma* sp.)
Philippine Deer (*Cervus mariannus*)	*Rhipicephalus* (*Boophilus*) *microplus*	Guam (Kohls 1957, collected February 2008, identified by R. Robbins), Pohnpei (Kohls 1957)
Domestic Cow / Cattle (*Bos taurus, Bos indicus*)	*Amblyomma breviscutatum*	Palau, Pohnpei, Kosrae (Joyce 1971), Guam (Kohls 1957, Tenquist & Carlston 2001), Northern Marianas – presumed host (Prowazek 1913), Marshalls – presumed host) (Schulze1935)
	Haemaphysalis longicornis	Palau (Saville 1999)
	Rhiphicephalus (*Boophilus*) *microplus*	Palau (Joyce 1971, Saville 1999), Guam (Joyce 1971, Duguies et al. 1999), Pohnpei (Kohls 1957, Jackson 1962, Joyce 1971)
	Rhipacephalus sanguineus	Marshalls (identified R. Robbins)
Carabao, Water Buffalo (*Bubalus bubalis)*	*Rhiphicephalus* (*Boophilus*) *microplus*	Guam (Kohls 1953, collected 2- 2008, identified R. Robbins)
Domestic / Feral Goat (*Capra hircus)*	*Rhiphicephalus* (*Boophilus*) *microplus*	Guam (Kohls 1953)
Domestic Horse (*Equus caballus)*	*Rhiphicephalus* (*Boophilus*) *microplus*	Guam (Kohls 1953)
Black Rat (*Rattus rattus)*	*Amblyomma breviscutatum*	Guam (Kohls 1953 – as *Rattus* sp., Kohls 1957, Voltzit et al. 2002), Pohnpei (Jackson 1962 – as *Amblyomma* sp., Kemp & Wilson 1979])

cytes, and sometimes other cells of vertebrates, but do not form pigment from haemoglobin." While they are all parasitic in a wide range of reptiles, birds, mammals, even fish, veterinarily and medically the most significant and widespread members of this order are the Babesiidae, which are transmitted by hard ticks (Humber 1996, Jefferies 2006).

Texas cattle fever or bovine babesiosis, "is a protozoal disease caused by *Babesia bigemina* or *Babesia bovis*", transmitted by the cattle ticks *Rhipicephalus* (*Boophilus*) *microplus* and *Rhipicephalus* (*Boophilus*) *annulatus* which were spread throughout the world on the livestock of Spanish colonialists (Pelzel 2005). Evidence of the presence of this babesiosis in Micronesia has been documented by a wide variety of reports, from recent times and reaching back over a hundred years. Initially referred to as "Texasfieber" in German accounts, it was said to be the likely cause of death to cattle on Tinian and the cause of suffering to cows on Saipan (Fritz 1901 & 1904). Later it was reported on Guam and Pohnpei (Alicata 1948, Richard 1957, Duguies et al. 1999). Yet, despite efforts at introducing special breeds of cattle into Micronesia that were hoped to be more resistant to ticks and their disease, survival of cows in the region was poor: "Casualties [to cattle] were especially heavy at Ponape [Pohnpei] where all but four succumbed to cattle ticks" (Sproat 1954, Richard 1957). This disease is still known to be in the cattle of the Commonwealth of the Northern Marianas and Guam (Duguies et al. 1999, pers. comm. I. dela Cruz).

Tick-borne babesiosis can also infect dogs. Canine babesiosis is caused primarily by *Babesia canis*, and to a lesser extent by *B. gibsoni*. (Shaw et al. 2001). According to the Canine Vector-Borne Diseases website: "*Rhipicephalus sanguineus* [brown dog tick] is the primary vector for *Babesia* in warmer regions worldwide (CVBD 2011).

Furthermore, *Babesia* species can also cause sickness in humans. When people are involved, babesiosis can share many features with malaria. Generally, babesiosis is considered to be a less severe infection than malaria in humans. In humans: "The spectrum of disease is broad, ranging from an apparently silent infection to a fulminant, malaria-like disease," characterized by fever, malaise and fatigue, chills and sweats, headache, arthralgia, myalgia, and anorexia, (Dvoraková & Dvorácková 2007, Vannier et al. 2008).

Hepatozoonosis

Another group of tick-associated intracellular protozoan are the members of the genus *Hepatozoon*. While ticks are the major vectors of these pathogens, they have also been found in other bloodsucking invertebrates (Smith 1986, Ahantarig et al. 2008). Transmission among mammals is when the vertebrate host physically ingests an infected tick (Smith 1986, O'Dwyer 2011). *Hepatozoon canis* is a cosmopolitan parasite of domestic dogs, transmitted primarily the brown dog tick (*Rhipicephalus sanguineus*). So far, *Hepatozoon* spp. are not considered to be serious pathogens to humans. Nonetheless, it has been opined that it is "essential to take precautions in working with infected dogs or when removing ticks from their bodies" (Ivanov & Tsachev 2008).

The brown tree snake (*Boiga irregularis*), which has proved to be ecologically devastating to Guam, has a hepatozoon, *Hepatozoon* (*Haemogregarina*) *boigae,* in its native range (Jakes et al. 2003). It had been speculated that its population explosion Guam was due to the lack of that parasite, however studies have showed "that all known natural diseases and parasites are not known to have demographic significance (or even clinical significance) as a biocontrol agent" (Caudell et al. 2002, Rodda & Savidge 2007).

Rickettsial Infections

A large proportion of the dogs on Guam have erhlichiosis and canine anaplasmosis, and on Palau, it has been estimated that twenty percent of the dogs which have not been treated for ticks have *Ehrlichia* (per. comm. M. Muresanu, T. Poole). This number is conceivably much higher.

Cattle and carabao have shown positive titers for anaplasmosis on Guam, and the cattle of Commonwealth of the Northern Marianas are well known to suffer from this pathogen (Duguies et al.1999, pers. comm. I. dela Cruz). It is also known to affect deer and would thus likely include the deer of Guam, Rota and Pohnpei (Wiles et al. 1999).

Rocky Mountain spotted fever (RMSF) is a severe and often life threatening tick-transmitted disease caused by the bacterium "*Rickettsia rickettsii*" which "can be lethal even in previously healthy and young patients" (Raoult & Roux 1997, Levy 2008). First described at the end of the nineteenth century in its namesake mountains, it is now known well outside of the United States (Parola et al. 2005).

Some people who were on Guam and/or Wake were reported to be sick with Rocky Mountain spotted fever (CDC 1975). They may have contracted the disease elsewhere, however Micronesia's most ubiquitous tick species, the brown dog tick (*Rhipicephalus sanguineus*) is a known vector of this rickettsial infection (Demma et al.2005, Parola et al. 2005, Levy 2008). There are also other types of rickettsial infections within the spotted fever grouping (Eremeeva & Dasch 2011).

Arboviruses

Arboviruses, short for "arthropod-borne viruses," are viruses that are maintained within arthropods (i.e., insects, arachnids) and by feeding on the blood of susceptible vertebrates, transmitted to onto those hosts (CDC 2005).

Among the multitude of tick-borne arboviruses are Midway virus and Johnston Atoll virus, which were initially described from locales relatively close to Micronesia, as their names imply (Amerson & Shelton 1976,Takahashi et al. 1982). Both were found on the seabird soft tick (*Carios capensis*), which has been repeatedly documented from the more remote areas of Micronesia.

The southern ocean seabird tick, *Amblyomma loculosum*, has been found to carry an arbovirus, an aride virus, that adversely impacted the Seychelle's rosette terns (*Sterna dougalii*). Hoogstraal et al. (1976) expressed concern that the "relatively frequent association of *A. loculosum* with sick or dying birds, and with humans, and the presence of Aride and possibly other arboiviruses [sic] with this tick, point to the need for biological and epidemiological investigations to determine the role of this species in public health and in wildlife health."

West Nile virus is most often associated with mosquitoes but ticks can also carry this virus (Hoogstraal et al. 1976). The seabird soft tick (*Carios capensis*) can harbor the virus and can be a vector in the migratory ruddy turnstone (*Arenaria interpres*) (Spurr & Sandlant 2004). This bird is very common throughout Micronesia (Pratt et al. 1987, Wiles 2005).

Some Other Tick-borne Diseases

There are several tick-borne diseases that are unlikely to turn up in Micronesia, but possibly could, especially with the high level of international travel and changes of residences to and from Micronesia. Some of these are tick-borne encephalitis, *Aegyptianella*, tick paralysis, tick-borne relapsing fever, Soldado virus, Uukeniemi virus, heartwater disease, and various species of *Borrelia*, including Lyme borreliosis or Lyme disease.

Some notable differences with Lyme disease, however, are the relatively high incidence in places having interchange with Micronesia and that it is emergent worldwide (Parola & Raoult 2001, USAF 2006). Records show a few cases have been found in Micronesia. (Orloski et al. 2000, Dei 2005, Brown 2011, Guam Epidemiology Newsletter 2011), and one tick implicated as a vector, the scrub tick *Haemaphysalis longicornis* is in Micronesia (Saville 1999, AFPMB 2002, Chu et al. 2008). There is also the matter of people suffering the long-term effects of "late disseminated stage" Lyme disease, returning or moving to Micronesia (CDC 2011).

Could Ticks be Involved in the "Guam Disease"?

As far as could be found, the involvement of tick-borne disease has never been ruled out in one of the greatest medical mysteries of the region, the so-called "Guam Disease" or "Lydigo-Bodig." An unusual outbreak of form of Amyotrophic Lateral Sclerosis (ALS) and Parkinson's disease with dementia (PDC) peaked on Guam in the 1950s, when it was "much higher than anywhere else in the world," or in other estimates, "nearly 100 times higher than any other place in the world." More recently, it has gradually declined to barely noticeable level (Reed & Brody 1975, Plato et al. 2003, Chen 2004).

Some reports have attributed Lydigo-Bodig to a hereditary factor. But other evidence favored the idea of cultural change or an environmental cause (Reed & Brody 1975, Haddock & Chen 2003, Chen 2004, Steele 2005). According to Plato et al. (2003): "Environmental factors underlying ALS and PDC could have changed so much in the past 50 years to affect disease rates. Post World War II and particularly in the late 1960s, there have been rapid and radical socioeconomic, ethnographic and ecological changes on Guam brought about mainly by modernization and westernization."

Various theories as to etiology have been put forth. Much investigation was done to the cause being related to the consumption of cycad seeds (*Cycas circinalis*), but conclusive evidence was not found (Sacks 1996, Chen 2004, Colfer et al. 2006, Miller 2006).

Another theory has been biomagnification of cycad toxins within the consumed flesh of local flying foxes (or fruit bats), *Pteropus mariannus* and *P. tokudae* speculating that the extirpation and extinction of these mammal species would account for the decline in the incidences of "Guam Disease" (Chen 2004). Other ideas relate to "excesses and deficiencies of elements" (Miller & Sanzolone 2003, Denton et al. 2009).

The emergence of many diseases around the world has also brought to light that when ecosystems are extremely stressed to the point of total upheaval, diseases are likely to occur. When an environment is "degraded" it is "susceptible to the appearance of opportunistic species" including microorganisms. Certainly, very few places in the world have suffered the environmental ravages Guam has experienced, especially in recent decades (Jaffe 1984, Epstein 1997).

Ticks are considered to be "edge dwellers" often are found in "transitional vegetations" where trails are near forested areas or where ecosystems meet (USAF 2006). Maps in Reed & Brody (1975) show many of the cases of ALS/PD found in the villages of Umatac and Merizo appear to lie within such "transitional" environments.

The people who suffered from this disease were described as, among other things, having "more contact with animals" and "more exposed to the natural environment" than others on Guam (Reed & Brody 1975). Furthermore, persons nowadays who have adopted a lifestyle of air-conditioned dwellings and driving cars to shopping malls would have a far less amount of tick exposure than those who decades past who farmed and ranched, using a family carabao as their means of transportation.

Most of the tick-borne diseases that affect humans and domestic animals are bacterial and hence treated with antibiotics (Parola & Raoult 2001). These medications were only discovered in the late 1920s and did not come into common use until some time later.

In a table of Chen & Yase's book on ALS in the Pacific (1984), among "Etiological Hypotheses of Motor Neuron Disease," the several "single environmental agents-living organisms," was the possibility of being it "ticke-borne"[sic]. But of course, it would be overly simplistic to take such a hint to mean that Lydigo-bodig could easily be demonstrated to be a tick-borne disease. It certainly is its own complex disease with its own characteristic "tau tangles" and other distinctive features (Perez-Tur 1999, Winton et al. 2006). Many very capable researchers have tried for decades to find the cause of this baffling outbreak. However, many tick-borne diseases have neurological manifestations (Halperin & Heyes 1992, AFPMB 2002, NINDS 2007).

CONCLUSIONS

As more research into ticks and the pathogens they carry continues around the world, it would seem appropriate that such research also be considered for Micronesia. Ticks may be unappealing subjects to consider in many a person's opinion, and hence they are an oft-ignored segment of the biota, including that of Micronesia. The process of collecting them from hard to capture hosts is more challenging than with many other animals. Nevertheless, their potential for the spread of diseases should make ticks worthy of much more attention than they have recently received.

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