Systematic & Applied Acarology (2010) 15, 163–183. ISSN 1362-1971

Electronic polytomous and dichotomous keys to the genera and species of hard ticks (Acari: Ixodidae) present in New Zealand

SCOTT HARDWICK
AgResearch, Lincoln Research Centre, Private Bag 4749, Christchurch 8140, New Zealand
Email: scott.hardwick@agresearch.co.nz

Abstract

New Zealand has a relatively small tick fauna, with nine described and one undescribed species belonging to the genera *Ornithodoros, Amblyomma, Haemaphysalis* and *Ixodes.* Although exotic hard ticks (Ixodidae) are intercepted in New Zealand on a regular basis, the country has largely remained free of these organisms and the significant diseases that they can vector. However, professionals in the biosecurity, health and agricultural industries in New Zealand have little access to user-friendly identification tools that would enable them to accurately identify the ticks that are already established in the country or to allow recognition of newly arrived exotics. The lack of access to these materials has the potential to lead to delays in the identification of exotic tick species. This is of concern as 40-60% of exotic ticks submitted for identification by biosecurity staff in New Zealand are intercepted post border. This article presents dichotomous and polytomous keys to the eight species of hard tick that occur in New Zealand. These keys have been digitised using Lucid® and Phoenix® software and are deployed at http://keys.lucidcentral.org/keys/v3/hard_ticks/Ixodidae genera.html in a form that allows use by non-experts. By enabling non-experts to carry out basic identifications, it is hoped that professionals in the health and agricultural industries in New Zealand can play a greater role in surveillance for exotic ticks.

Key words: Ixodidae, dichotomous, polytomous, Lucid®, Phoenix®, biosecurity, New Zealand

Introduction

The worldwide decline in taxonomic expertise (Godfray 2002, Walter & Winterton 2007, Wheeler 2004) is inhibiting prevention and management of biological invasions (Lodge *et al.* 2006). Protocols for diagnosing pests and diseases underpin essentially all quarantine activities, and low-quality, inaccessible or absent taxonomic keys are major impediments to effective border biosecurity and pest management (IPPC 2006, Lodge *et al.* 2006). For a taxonomic specialist, identifying a specimen may only require a brief check of critical characters (Walter & Winterton 2007). However, less specialised diagnosticians dealing with unfamiliar species in quarantine situations require extremely well-designed taxonomic tools to obtain correct identifications. Therein lies the problem, as traditional dichotomous keys are "compiled by those who do not need them for those who cannot use them" (Lobanov 2003), resulting in tools that can be inadequate for quarantine requirements (Lodge *et al.* 2006, Walter & Winterton 2007).

One way to alleviate the shortage of taxonomic expertise is to capitalise on new, rapidly evolving technologies, such as polytomous (matrix based) electronic interactive keys (Agnarsson & Kuntner 2007, Chesmore 2002, Lodge *et al.* 2006, Norton 2002, 2005, Walter & Winterton 2007). While paper-based dichotomous keys are simple, portable, and do not require associated technologies such as software and computers to be used, they have particularly limited utility, both when specimens are damaged and when diagnosticians have difficulty recognising particular characters. Reaching a conclusion with a dichotomous key depends on the user being able to progress stepwise through couplets or less commonly a greater number, e.g. triplets, of questions in a manner

predetermined by the key's author. However, damaged structures and incorrect interpretations of characters can render couplets unanswerable. Polytomous keys allow users to bypass characters that are unrecognisable, hidden, damaged or missing and choose those that are most easily observed or recognised on the specimen. Although paper-based polytomous keys can be difficult to use (Walter & Winterton 2007), this can be overcome by presenting them in electronic format using custom, e.g. Walker *et al.* 2005, or commercial software such as Delta (Dallwitz 2007, 2009, http://delta-intakey.com) and Lucid® (Norton 2002, 2005, http://Lucidcentral.com). Further advantages of electronic keys over paper-based keys are that they can be easily corrected or updated and made readily available via the World Wide Web, and that genetic data and media files can be easily incorporated. Disadvantages associated with the use of electronic keys are their cost, reliance on the user having access to a computer on which the appropriate software is loaded, and the ability to utilise electronic resources in field situations. Whilst the ongoing and rapid development of software and handheld computing devices is likely to overcome the aforementioned problems, it is likely that there will be a need for both paper and electronic versions of keys for the foreseeable future.

Here, I describe the application of computer software to develop a key to hard tick species (Acari: Ixodidae) that are significant to New Zealand quarantine activities. The advantages offered by polytomous over dichotomous keys are particularly relevant to ticks because most specimens submitted for identification are collected by nonspecialists and are often crushed, have missing structures, or are contaminated with debris.

Ticks are blood-feeding external parasites of birds, mammals, reptiles and amphibians that can act both as reservoirs and as vectors for a range of diseases caused by bacteria, viruses and rickettsiae (Varma 1993). New Zealand's tick fauna consists of eight hard tick (Acari: Ixodidae) species, all of which are formally described, and two soft tick (Acari: Argasidae) species, one of which is undescribed (Dumbleton 1953, 1963, Heath 1977). The hard tick *Haemaphysalis longicornis* Neumann is the only non-indigenous tick species in New Zealand and was likely introduced from Japan via Australia (Hoogstraal, *et al.* 1968). It feeds on a range of mammalian and avian species and is of economic importance, both in New Zealand (McKenna 1996) and elsewhere (Hoogstraal *et al.* 1968). It is also the only tick that is commonly encountered by humans in New Zealand (McKenna 1996). Four hard ticks (*Ixodes auritulus* Neumann, *I. eudyptidis* Maskell, *I. kerguelenensis* André & Colas-Belcour, and *I. uriae* White), and one soft tick (*Ornithodoros capensis* Neumann) are primarily parasites of seabirds (Dumbleton 1953, 1961, Roberts 1970). *Ixodes eudyptidis* is limited to coastal regions of New Zealand and southern Australia (Heath 1977, Roberts 1970), while the others have widespread distributions in the Northern and Southern Hemispheres (Amerson 1968, Arthur 1960a, Cooley & Kohls 1945, Dumbleton 1973, Heath 1977, Hoogstraal 1985, Roberts 1970). Of the remaining four species, *I. anatis* Chilton, *I. jacksoni* Hoogstraal and *Amblyomma* (formerly *Aponomma*) *sphenodonti* (Dumbleton) are endemic to New Zealand and are associated with kiwi, *Apteryx* spp. (Struthioniformes: Apterygidae), cormorant, *Stictocarbo punctatus* (Sparrman) (Pelecaniformes: Phalacrocoracidae) and tuatara, *Sphenodon punctatus* Gray (Rhynchocephalia: Sphenodontidae), respectively (Heath 1977). The fourth is an undescribed soft tick collected from the native bat *Mystacina tuberculata* Gray (Chiroptera: Mystacinidae) (Heath 1977).

Unlike many other countries, New Zealand is currently free of most ticks and tick-borne diseases that impact animal production and human health (Heath 2002a, b). The sole exception is *Theileria orientalis*, which is present in the North Island and is vectored by *H. longicornis* (Heath 2002b, James, *et al.* 1984). However, should additional tick species or tick-borne diseases become established in New Zealand, this situation could change. Between 1955 and 2009, the total border interceptions and post-border detections (hereafter referred to as "quarantine detections") of exotic hard ticks made by New Zealand quarantine authorities was 122 (Heath 2001, pers. comm. 2009,

Loth 2005), including 17 species from the genera *Amblyomma*, *Bothriocroton*, *Dermacentor*, *Haemaphysalis*, *Ixodes* and *Rhipicephalus* (Heath 2001, 2009, Loth 2005). To date, there have been no quarantine detections of exotic soft ticks in New Zealand (Heath 2001, pers. comm. 2009, Loth 2005). Approximately 40% of tick quarantine detections are from animals, typically dogs, imported into New Zealand (Loth 2005). A similar proportion is from humans and their clothing, whilst the remainder arrive in luggage, containers or via other routes not involving mammals (Loth 2005). Quarantine detections from humans, luggage and other objects are of particular concern as these all occur post-border and rely on the public bringing specimens to the attention of the appropriate authorities (Heath pers. comm. 2009).

In New Zealand, quarantine authorities, health professionals, members of the agricultural industries and ecologists currently have very limited tools for accurately identifying tick specimens and may resort to the dubious assumption that any specimen they encounter is *H. longicornis*. This situation has prompted the Ministry of Agriculture and Forestry Biosecurity New Zealand (MAFBNZ) to call for better tick taxonomic tools (MAFBNZ pers. comm. 2008). Developing electronic keys to ticks is also a top priority of the Quadrilateral Scientific Collaboration in Plant Biosecurity (http://www.quadscoop.org/), involving quarantine agencies from Australia, Canada, New Zealand, and the United States.

This contribution describes two keys that enable New Zealand quarantine authorities, health professionals, members of the agricultural industries and ecologists to determine whether a tick specimen submitted for identification is a species already established in New Zealand or a potential exotic. I provide electronic and paper-based dichotomous and polytomous keys that enable non-experts to identify: i) nymphs and adults of the three genera and eight species of Ixodidae present in New Zealand, ii) adults of all 12 extant genera of Ixodidae in the world, and iii) nymphs of eight of the 12 extant genera of Ixodidae in the world. Genera excluded from the nymphal key were those containing species with very restricted geographical distributions and host ranges that are unlikely to be encountered during New Zealand quarantine activities.

Methods

The taxa included in my keys are listed in Table 1. Dichotomous (Table 2) and polytomous keys (Tables 3 & 4) to identify adults and nymphs of Ixodidae to genus were constructed while examining specimens of *Amblyomma*, *Amblyomma* (formerly *Aponomma*), *Rhipicephalus* (formerly *Boophilus*), *Bothriocroton*, *Dermacentor*, *Ixodes*, *Hyalomma*, and *Rhipicephalus*, and with reference to the following literature: Arthur 1960a, b, Arthur & Chaudhuri 1965, Barker & Murrell 2004, Beati *et al.* 2008, Belozerov *et al.* 2001, Guglielmone *et al.* 2009, 2010, Hoogstraal *et al.* 1970, Horak *et al.* 2002, Kaufman 1972, Keirans *et al.* 1994, Klompen *et al.* 2002, Matthysse & Colbo 1987, Nuttall & Warburton 1911, 1915, Roberts 1970, Sonenshine 1991, Varma 1993, Volzit 2002, Volzit & Keirans 2003, 2007, Walker *et al.* 2000 and Walker *et al.* 2003.

To develop the key to New Zealand species, I referred to previously published keys and taxonomic descriptions contained in Arthur (1963), Chilton (1904), Dumbleton (1943, 1953, 1958, 1961, 1963, 1973), Hoogstraal (1967), Hoogstraal *et al.* (1968), McKenna (1996) and Roberts (1970), and I examined representative male, female and nymphal specimens of all species in New Zealand except *I. jacksoni*. This allowed a range of discriminating features to be identified and included. The keys were digitised using Phoenix® and Lucid® software (http://Lucidcentral.com).

The polytomous key was constructed using LucidBuilder software. LucidBuilder enables the user to develop a data matrix based on character states scored as being common, rare, uncertain (not known), common and misinterpreted, rare and misinterpreted, not scoped or absent. Character states

are scored by placing a tick mark in the appropriate cell of the data matrix as illustrated in Table 5. It is also possible for the software to assign more than one state to an entity. For example, males of the genus *Ixodes* almost always have 7 plates on the ventral surface. However, males of *I. jacksoni* are an exception to this in that their ventral plates are obsolete (Hoogstraal *et al.* 1967). In this situation the character state can be scored as both commonly having 7 ventral plates and rarely with the ventral plates being obsolete (Table 5).

TABLE 1. List of ixodid taxa included in the dichotomous and polytomous keys in Tables 2–4.

Genus	**Species present in New Zealand**	**Lifestages included in keys**
Amblyomma–with eyes		N[1], A[2]
Amblyomma–without eyes[3] (former *Aponomma*)	*Am.* (*Ap.*) *sphenodonti*	N, A
Anomalohimalaya		A
Bothriocroton[3]		N, A
Cosmiomma		A
Dermacentor		N, A
Haemaphysalis	*H. longicornis*	N, A
Hyalomma		N, A
Ixodes	*I. anatis*	N, A
	I. auritulus	N, A
	I. eudyptidis	N, A
	I. jacksoni	N, A
	I. kerguelenensis	N, A
	I. uriae	N, A
Margaropus		A
Nosomma		A
Rhipicentor		A
Rhipicephalus		N, A
Rhipicephalus (*Boophilus*)		N, A

[1]Nymph; [2]Adult (male and female); [3]in the nymphal key eyeless *Amblyomma* (former *Aponomma*) and *Bothriocroton* are not distinguished from each other.

TABLE 2. Dichotomous key to the ixodid genera and species known to occur in New Zealand.

1	Scutum absent in all life stages; capitulum ventral, visible dorsally in larvae, but not in nymphs and adults, prominent basis capituli absent (sexes differing on only the form of the genital orifice) . . . . . Argasidae
	Scutum always present; capitulum anterior, visible dorsally and with a prominent basis capituli . . . . . Ixodidae 2
2(1)	Scutum covers 1/3-1/2 of the body; genital aperture and porose areas present or absent 3
	Scutum covers whole body; genital aperture fully developed and porose areas absent . . . . . Male Ixodidae 34

3(2) Porose areas and genital aperture absent . . . . . Nymph Ixodidae 4
Porose areas and genital aperture present . . . . . Female Ixodidae 16

Nymphs

4(3) Anal groove passes around front of anus . . . . . *Ixodes*
(Six *Ixodes* species present in New Zealand) 5
Anal groove is present or obsolete (difficult to see or absent), but always embracing the posterior of the anus 10

5(4) All coxae unarmed (without spurs). 6
At least some coxae armed 7

6(5) Coxa I contiguous (touches) with basis capituli (even when engorged) . . . . . *I. uriae*
Coxa I not contiguous with basis capituli. . . . . *I. jacksoni*

7(5) First segment of palp with an internal forwardly directed spur 8
Internal forwardly directed spur on first segment of palp absent 9

8(7) Palpal segment 1 with both an internal forwardly directed spur and a distinct mesodorsal spur. . . . . *I. kerguelenensis*
Palpal segment 1 with only an internal forwardly directed spur . . . . . *I. auritulus zealandicus*

9(7) Basis capituli with auriculae ventrally (associated with seabirds) . . . . . *I. eudyptidis*
Basis capituli without auriculae ventrally (associated with kiwi and waterfowl other than sea birds) . . . . . *I. anatis*

10(4) Festoons present 11
Festoons absent . . . . . *Rhipicephalus* (*Boophilus*)
(Species from this subgenus not present in New Zealand)

11(10) Eyes present 12
Eyes absent 15

12(11) Palps short in appearance; basis capituli hexagonal . . . . . *Rhipicephalus*
(Species from this genus not present in New Zealand)
Palps long or short in appearance; basis capituli triangular, quadrangular or rectangular 13

13(12) Palps long to elongated and constricted proximally; segment 2 of palps about three times longer than segment 3 . . . . . *Amblyomma*
(*Amblyomma* with eyes: no *Amblyomma* with eyes in New Zealand)
Palps short or long to elongated but not constricted proximally 14

14(13) Eyes bulging; palps long to elongate; segment 2 of palps approximately three times as long as segment 3 . . . . . *Hyalomma*
(Species from this genus not present in New Zealand)
Eyes flat; palps short and broad or long in appearance; article 2 of palps usually not approximately three times as long as article 3 . . . . . *Dermacentor*
(Species from this genus not present in New Zealand)

15(11) Palps short and broad with palpal segment 2 often being extended laterally; basis capituli rectangular. . . . . *Haemaphysalis*
(One species from this genus present in New Zealand) . . . . . *H. longicornis*[1]
Palps elongate in appearance and about three or more times longer than broad . . . . . *Bothriocroton* and former *Aponomma* (now *Amblyomma*)
(One species from the eyeless *Amblyomma* present in New Zealand) . . . . . *Am.* (*Ap.*) *sphenodonti*[1, 2]

Females

16(3) Anal groove encircles the anus closely then passes back as a single long postanal groove that reaches the posterior margin (scutum ornate) . . . . . *Cosmiomma*
(The single species in this genus, *C. hippopotamensis*, not present in New Zealand)
Anal groove not as above 17

17(16) Anal groove present and extends around front of anus; festoons absent; eyes absent and scutum inornate . . . . . *Ixodes*
(Six *Ixodes* species present in New Zealand) 18
Anal groove distinct or indistinct (obsolete) and never extending around front of anus; festoons present or absent; eyes present or absent; scutum ornate or inornate 23

18(17) All coxae unarmed (without spurs). 19
One or more of the coxae armed (with spurs) 20
19(18) Third palpal segment greatly swollen mesad at apex; porose areas large and oval in shape; anal grooves obvious and easy to see. . . . . *I. uriae*
Third palpal segment only moderately swollen at apex; porose areas large and sub-triangular in shape; anal grooves obscure and difficult to see . . . . . *I. jacksoni*
20(18) Scutum broader than long; coxal armature limited to a single external spur on coxa I; second palpal segment approximately twice as long as third; dentition of hypostome 2/2. . . . . *I. anatis*
Scutum longer than broad; spurs present on all coxae; dentition of hypostome 4/4 21
21(20) First segment of palp with an internal forwardly directed spur; basis capituli with cornua and retrograde auriculae; porose areas oval 22
First palpal segment without anterior spur; basis capituli without cornua, auriculae with transverse posterior margin; porose areas sub-triangular or pear shaped, widest internally (occasionally touching) . . . . . *I. eudyptidis*
22(21) Palpal article 1 with both an anterior spur and a distinct mesodorsal spur. . . . . *I. kerguelenensis*
Palpal article 1 with only an anterior spur . . . . . *I. auritulus zealandicus*
23(17) Eyes present 24
Eyes absent 31
24(23) Festoons present 25
Festoons absent. 30
25(24) Palps much longer than the basis capituli, segment 2 obviously longer than broad 26
Palps short in appearance (about as long as basis capituli) 28
26(25) Scutum with ornamentation 27
Scutum without ornamentation. . . . . *Hyalomma*
(Species from this genus not present in New Zealand)
27(26) Segment 3 of palps with a dorsal and ventral flange . . . . . *Nosomma*
(The single species in this genus, *N. monstrosum*, not present in New Zealand)
Segment 3 of palps without a dorsal and ventral flange. . . . . *Amblyomma*
(*Amblyomma* with eyes: No *Amblyomma* with eyes in New Zealand)
28(25) Scutum usually ornate and basis capituli rectangular in shape. . . . . *Dermacentor*
(Species from this genus not present in New Zealand)
Scutum usually inornate and basis capituli hexagonal in shape 29
29(28) Coxa IV with two short pointed spurs . . . . . *Rhipicentor*
(Species from this genus not present in New Zealand)
Coxa IV without two short pointed spurs. . . . . *Rhipicephalus*
(Species from this genus not present in New Zealand)
30(24) Palps extremely short and ridged laterally and dorsally. . . . . *Rhipicephalus* (*Boophilus*)
(Species from this subgenus not present in New Zealand)
Palps short, but not extremely short, and not ridged laterally or dorsally . . . . . *Margaropus*
(Species from this genus not present in New Zealand)
31(23) Palps much longer than wide 32
Palps short and broad with a conical appearance, segment 2 extending laterally . . . . . *Haemaphysalis*
(One species from this genus present in New Zealand) . . . . . *H. longicornis*[1]
32(31) Palps long and conical in appearance but not extending laterally; basis capituli being hexagonal in shape . . . . . *Anomalohimalaya*
(Species from this genus not present in New Zealand)
Palps long and narrow in appearance; basis capituli often sub-rectangular or sub-triangular, but never hexagonal in shape 33
33(32) Dentition on hypostome 2/2 or if 3/3 the internal file much smaller than the external; scutum inornate or weakly ornate; hosts include varanid lizards, but also wombat (*Vombatus* and *Lasiorhinus* species), and echidna (*Tachyglossus aculeatus*); distribution Australia and New Guinea . . . . . *Bothriocroton*
(Species from this genus not present in New Zealand)
Hypostomal dentition generally 3/3 or higher, internal row of teeth usually not smaller than external rows; iridescent ornamentation often present on scutum; hosts exclusively reptiles. . . . . *Aponomma* (now *Amblyomma*)
(One species from the eyeless *Amblyomma* present in New Zealand) . . . . . *Am.* (*Ap.*) *sphenodonti*[1, 2]

Males

34(2) Anal groove present and extends around front of anus; festoons absent; seven ventral plates normally present and scutum is inornate . . . . . *Ixodes*
(Six *Ixodes* species present in New Zealand) 35
Anal groove distinct or indistinct (obsolete) and never extending around front of anus; festoons present or absent; eyes present or absent; scutum ornate or inornate; ventral plates various but never seven in number 40

35(34) Ventral plates obsolete (indistinct) and tarsi with paired apicoventral projections . . . . . *Ixodes jacksoni*
Ventral plates easily seen and tarsi without paired apicoventral projections 36

36(35) Posterior margin of body with five brushes of setae (may appear as a fringe of hairs); all coxae without spurs and third segment of palp pointed and upturned . . . . . *I. uriae*
Posterior margin of body without brushes of setae; third segment of palp not pointed and upturned . 37

37(36) Pre-genital plate transverse, jugular plates absent . . . . . *I. anatis*
Pre-genital plate sub-pentagonal, jugular plates present 38

38(37) Dentition of hypostome 2/2, toothed area short . . . . . *I. eudyptidis*
Dentition of hypostome greater than 2/2, toothed area long 39

39(38) Dentition of hypostome 4/4, toothed area long; second palpal segment gradually narrowed basally; anal grooves slightly diverging . . . . . *I. auritulus zealandicus*
Dentition of hypostome 4/4–6/6, toothed area long; second palpal segment gradually narrowing basally; lateral margin of anal grooves constricted medially . . . . . *I. kerguelenensis*

40(34) Eyes present (may be difficult to see in some *Boophilus*, *Amblyomma* and *Dermacentor* (*Anocentor*) *nitens*) 41
Eyes absent 49

41(40) Spiracular plate partially ornamented and with irregular ridges . . . . . *Cosmiomma*
(The single species in this genus, *C. hippopotamensis*, not present in New Zealand)
Spiracular plate not as above 42

42(41) Palps much longer than basis capituli (palpal segment 2 much longer than broad) 43
Palps about as long as basis capituli (palpal segment 2 is about as long as wide) 45

43(42) Palps broad, ornate and with a dorsal flange on segment 3 . . . . . *Nosomma*
(The single species in this genus, *N. monstrosum*, not present in New Zealand)
Palps not as above 44

44(43) Scutum inornate; adanal and more often than not subanal plates present; festoons irregular and partially coalesced . . . . . *Hyalomma*
(Species from this genus not present in New Zealand)
Scutum usually ornate; male without adanal and subanal plates; festoons regular, not coalesced . . . . . *Amblyomma*
(*Amblyomma* with eyes: No *Amblyomma* with eyes in New Zealand)

45(42) Festoons present 46
Festoons absent 48

46(45) Basis capituli rectangular in shape; scutum usually ornate . . . . . *Dermacentor*
(Species from this genus not present in New Zealand)
Basis capituli hexagonal; scutum usually inornate 47

47(46) Scutum usually inornate (4 ornate species); adanal and accessory plates present; coxa IV without two long spurs . . . . . *Rhipicephalus*
(Species from this genus not present in New Zealand)
Scutum inornate; adanal and accessory plates absent; 2 long spurs present on coxa IV . . . . *Rhipicentor*
(Species from this genus not present in New Zealand)

48(45) Palps extremely short and ridged dorsally and laterally; leg IV normal . . . . *Rhipicephalus* (*Boophilus*)
(Species from this subgenus not present in New Zealand)
Palps short (not extremely short), but not ridged dorsally or laterally; leg IV greatly enlarged and beady in appearance . . . . . *Margaropus*
(Species from this genus not present in New Zealand)

49(41) Palps longer than wide (elongate in appearance) 50
Palps short and broad in appearance, segment 2 usually extending laterally (festoons present) . . . . . *Haemaphysalis*
(One species from this genus present in New Zealand) . . . . . *H. longicornis*[1]

50(49) Palps elongate and sub-cylindrical in appearance (at least 3 times as long as wide), segment 2 of palps being especially long 51
Palps elongate and conical in appearance (segment 2 at least twice as long as broad and not extended laterally); basis capituli quadrangular . . . . . *Anomalohimalaya*
(Species from this genus not present in New Zealand)

51(50) Dentition on hypostome 2/2 or if 3/3 the internal file much smaller than the external; scutum inornate or weakly ornate; hosts include varanid lizards, but also wombat (*Vombatus* and *Lasiorhinus* species), and echidna (*Tachyglossus aculeatus*); distribution Australia and New Guinea . . . . . *Bothriocroton*
(Species from this genus not present in New Zealand)
Hypostomal dentition generally 3/3 or higher, internal row of teeth usually not smaller than external rows; iridescent ornamentation often present on scutum; hosts exclusively reptiles . . . . . *Aponomma* (now *Amblyomma*)
(One species from the eyeless *Amblyomma* present in New Zealand) . . . . . *Am.* (*Ap.*) *sphenodonti*[1, 2]

---

[1] Embedded images and fact sheets contained within the electronic keys are designed to help the user progress through the key and confirm whether the specimen being examined occurs in New Zealand, e.g. if the specimen is identified as belonging to genus *Haemaphysalis* the user can access a fact sheet that contains a detailed description and images of *H. longicornis*.

[2] *Am.* (*Ap.*) *sphenodonti* is inornate with hypostomal dentition of 3/3 distally and 2/2 proximally, the 2 outer files consisting of stout denticles while those on the inner file are very fine.

Dependent and not scoped scoring is included in the data matrix to streamline or create a folding key. When a character state that has been scored using a positive dependency is selected, further questions are unfolded and presented to the user. In the polytomous key the following dependencies are used: character states scutum (present) and capitulum visible dorsally (yes) unfolds the character "number of legs"; character state number of legs (8) unfolds the character "size of scutum"; character state size of scutum (scutum covers the whole body) unfolds the eight characters (T–AA) associated with determining which genus a male ixodid belongs to; character state size of scutum (scutum covers 1/2-1/3 of body) unfolds the characters "porose areas" and "genital aperture"; character states porose areas (absent) and genital aperture (absent) unfold the five characters (G–K) associated with determining which genus an ixodid nymph belongs to; and the character states porose areas (present) and genital aperture (present) unfold the six characters (AL–AR) associated with determining which genus an ixodid female belongs to (Table 3). Not scoped scores were also used in the construction of the polytomous key. This type of scoring enables the coding of characters that are useful and applicable only for a subset of the entities in the key. Entities contained in the subset are coded for these characters in a normal fashion, but all the other entities are assigned the not scoped score for these characters. The characters associated with a subset of entities will only be presented to the user or unfolded when all other entities in the key have been eliminated. In the polytomous key outlined in this contribution, not scoped scoring is used to unfold the key and present the user with characters that discriminate between: the nymphs of the *Ixodes* species present in New Zealand (subset 1, characters L–S); the males of eyeless *Amblyomma* and *Bothriocroton* (subset 2, character AB); males of the *Ixodes* species present in New Zealand (subset 3, characters AC–AK); the females of eyeless *Amblyomma* and *Bothriocroton* (subset 4, character AR); the females of *Rhipicentor* and *Rhipicephalus* (subset 5, character AS); and the females of the *Ixodes* species present in New Zealand (subset 6, characters AT–BA) (Table 3).

I conducted initial testing of the keys on adult and nymphal specimens of *Amblyomma* (eyed and eyeless), *Bothriocroton*, *Dermacentor*, *Haemaphysalis*, *Hyalomma*, *Ixodes* and *Rhipicephalus* using a blind testing protocol. The keys were then reviewed by a tick taxonomist, a quarantine diagnostician who had limited experience of tick taxonomy, and a laboratory technician who had no previous experience at identifying ticks.

TABLE 3. Characters and states used in the polytomous key to ixodid genera and species known to occur in New Zealand.

Character		Score	State[†]
*Hard tick (*Ixodidae*) or soft tick (*Argasidae*)*			
A	Scutum	1	absent
		2	present[A]
B	Capitulum visible dorsally	1	no
		2	yes[A]
Ixodidae*: life stage*			
C	Number of legs[a]	1	6
		2	8[B]
D	Size of scutum[b]	1	scutum covers whole body[C]
		2	scutum covers 1/3–1/2 of body[D]
E	Porose areas[d]	1	absent[E]
		2	present[F]
F	Genital aperture[d]	1	absent[E]
		2	present[F]
Nymphs Ixodidae *genera*[e]			
G	Anal groove	1	obsolete (absent)
		2	embraces the posterior (rear) of the anus
		3	embraces the anterior (front) of the anus
H	Festoons	1	absent
		2	present
I	Eyes	1	absent
		2	present and flat
		3	present and bulging in appearance or orbited
J	Basis capituli (dorsal shape)	1	dorsally, basis capituli hexagonal in shape
		2	dorsally, basis capituli rectangular–sub rectangular in shape
		3	dorsally, basis capituli triangular–sub triangular in shape
K	Palps (length, shape and ornamentation)	1	very short and ridged dorsally and laterally
		2	short and broad (but article 2 not laterally extended)
		3	short and broad with article 2 being extended laterally giving the palps a conical shape
		4	long and broad
		5	elongate with article 2 being at least twice as long as article 3 but not constricted proximally
		6	elongate with article 2 being about three times longer than article 3; palp constricted proximally

Character		Score	State[†]
Key to nymphs of the Ixodes *species present in New Zealand* *(Subset 1)*‡			
L	Segment 1 of the palps (number of spurs)	1	with no spurs
		2	with only an internal forwardly directed spur
		3	with both an internal forwardly directed spur and a mesodorsal spur
M	Coxa I	1	not contiguous (touching) the basis capituli
		2	contiguous (touching) the basis capituli
N	Coxal spurs (1)	1	no spurs present on any coxae
		2	spurs present on one or more coxae
O	Coxal spurs (2)	1	coxa I with an external spur; coxae II–IV with no spurs
		2	coxae I–III with both internal and external spurs, coxa IV with external spur only (coxa IV may have a mild spur-like salience on internal surface)
		3	coxa I with an internal and external spur, coxae II–III with an external spur only
P	Cornua	1	absent
		2	present
Q	Scutum	1	widest well before mid-length
		2	widest about mid-length
R	Hypostomal dentition	1	hypostomal dentition mainly 2/2 (may have a row of 3/3 apically)
		2	hypostomal dentition mainly 3/3 then 2/2 (may have a row of 4/4 apically)
S	Auriculae (presence, form)	1	absent
		2	present and button, ridge or ledge shaped
		3	present as retrograde spurs (horn-like)
Males Ixodidae *genera*[c]			
T	Anal groove (presence, form)	1	obsolete (absent)
		2	embraces the posterior (rear) of the anus
		3	embraces the anterior (front) of the anus
U	Eyes (presence)	1	absent
		2	present
V	Festoons (presence, form)	1	absent
		2	festoons present and regular in appearance
		3	festoons present but partially coalesced
W	Scutum (ornamentation)	1	absent
		2	present
X	Ventral plates (presence, number)	1	absent (small plaques may be present)
		2	with adanal plates only
		3	with adanal and accessory plates only
		4	with adanal, sub-anal and accessory plates present

Character		Score	State†
		5	with 7 plates: pregenital, median, anal, epimeral (2) and adanal (2) plates
Y	Palps (shape or form)	1	extremely short, shorter than hypostome and ridged dorsally and laterally
		2	short and broad, as long as or longer than hypostome, not conical in appearance
		3	short and broad and ornamented; article 3 with a dorsal and ventral flange
		4	short, about as long as the hypostome, usually about twice as long as broad, clavate in appearance; segment 1 being extended ventrointernally
		5	short with article 2 being at least as broad as long and often extended laterally, general appearance is conical in shape
		6	long to elongated in appearance (not conical in appearance and article 3 without a dorsal and ventral flange)
Z	Basis capituli (dorsal shape)	1	quadrangular
		2	square or rectangular
		3	triangular
		4	hexagonal
		5	sub-pentagonal
AA	Leg IV (form)	1	not massive and beady
		2	massive and beady
AB	Eyeless *Amblyomma* or *Bothriocroton*: hypostomal dentition; ornamentation of scutum, hosts and origin (Subset 2)	1	Dentition 2/2 or if 3/3 the internal file much smaller than the external; scutum inornate or weakly ornate; hosts include varanid lizards, wombat, and echidna; distribution Australia and New Guinea
		2	Dentition 3/3 or higher, internal row of teeth usually not smaller than external rows; iridescent ornamentation often present on scutum; hosts exclusively reptiles
Key to males of the Ixodes *species present in New Zealand (Subset 3)*			
AC	Ventral plates (presence)	1	obsolete
		2	present and easily seen
AD	Third segment of the palp (shape or form when viewed laterally)	1	pointed and upturned when viewed laterally
		2	not pointed and upturned when viewed laterally
AE	Pregenital plate (presence, shape)	1	absent
		2	present, transverse in shape
		3	present, sub-pentagonal in shape
AF	Jugular plates (presence)	1	absent
		2	present
AG	Apicoventral surface of the tarsi (presence of paired projections)	1	absent
		2	present

Character		Score	State[†]
AH	Coxal spurs (presence)	1	no spurs present on any coxae
		2	spurs present on one or more coxae
AI	Rear margin of the body (presence of brushes or a fringe of setae)	1	absent
		2	present
AJ	Hypostome dentition	1	2/2 or less
		2	4/4
		3	4/4–6/6 or 5/5–6/6
AK	Anal groove (shape of the lateral margins)	1	parallel
		2	straight and converging slightly
		3	straight and diverging slightly
		4	constricted laterally
		5	curved and converging slightly
Females Ixodidae *genera*[F]			
AL	Anal groove (presence, form)	1	obsolete
		2	embraces the posterior (rear) of the anus
		3	embraces the anterior (front) of the anus
		4	surrounds the anus closely then passes back as a single median groove
AM	Eyes (presence)	1	absent
		2	present
AN	Festoons (presence)	1	absent
		2	present
AO	Scutum (ornamentation)	1	absent
		2	present
AP	Palps	1	extremely short, shorter than hypostome and ridged dorsally and laterally
		2	short and broad, as long as or longer than hypostome; article 3 without a dorsal and ventral flange
		3	short and broad and ornamented; article 3 with a dorsal and ventral flange
		4	short with article 2 being at least as broad as long and often extended laterally; general appearance is conical in shape
		5	long and conical in appearance; segment 1 being extended ventrointernally
		6	long and broad in appearance (not conical in appearance)
		7	long to elongated in appearance, but not conical or broad in appearance
AQ	Basis capituli (dorsal shape)	1	square or rectangular
		2	triangular
		3	hexagonal
		4	sub-pentagonal

Character		Score	State†
AR	Eyeless *Amblyomma* or *Bothriocroton*: hypostomal dentition; ornamentation of scutum, hosts and origin (Subset 4)	1	Dentition 2/2 or if 3/3 the internal file much smaller than the external; scutum inornate or weakly ornate; hosts include varanid lizards, wombat, and echidna; distribution Australia and New Guinea
		2	Dentition generally 3/3 or higher, internal row of teeth usually not smaller than external rows; iridescent ornamentation often present on scutum; hosts exclusively reptiles
AS	*Rhipicentor* or *Rhipicephalus*-coxa IV (presence of two short spurs) (Subset 5)	1	absent
		2	present
Key to f*emales of the* Ixodes *species present in New Zealand* (Subset 6)			
AT	Third segment of the palps (form)	1	not swollen mesad at apex
		2	slightly swollen mesad at apex (slight but obvious bump)
		3	greatly swollen mesad at apex (very obvious bump)
AU	Segment 1 of the palps (presence and number of spurs)	1	absent
		2	with only a internal forwardly directed spur
		3	with a internal forwardly directed spur and a mesodorsal spur
AV	Porose areas (form)	1	circular
		2	oval with the longer axis being lateral
		3	pear or sub-triangular shaped (widest internally)
AW	Cornua (presence)	1	absent
		2	present
AX	Scutum (form)	1	broader than long
		2	longer than broad
AY	Hypostome dentition	1	mainly 2/2
		2	mainly 4/4 (may reduce to 2/2 on the later 1/3 of the hypostome)
AZ	Auriculae (presence, form)	1	absent
		2	present and button, ridge or ledge shaped
		3	present as retrograde spurs (horn-like)
BA	Coxal spurs (presence, form)	1	all coxae without spurs
		2	armature limited to a single external spur on coxa I
		3	internal spur on coxa I only, external spur on all coxae
		4	internal spur on coxae I–III (internal spur on coxa III may be reduced to a salience), external spur on all coxae

† In the polytomous Lucid key a state followed by an uppercase character controls the appearance (unfolding) of the character marked by the corresponding lowercase character, e.g. the state scutum present^{A} controls the appearance of the character number of legs^{a}.

.....notes continued next page

‡ Subsets (1–6) of questions are associated with 'not scoped scoring', e.g. in the Lucid key only the *Ixodes* nymphs are scored using the characters and states contained in subset 1. All other entities are scored using the not scoped option in LucidBuilder. This results in the questions in subset 1 unfolding and being presented to the user when the only entities remaining in the key are *Ixodes* nymphs.

Results and Discussion

I rectified an error in an earlier key whereby the second dichotomous pairing of Dumbleton's 1963 key incorrectly stated that female *I. anatis* has spurs on the first three coxae. In contrast, the specimens of *I. anatis* that I examined were consistent with earlier descriptions of female *I. anatis* because a single spur was present on the first coxa, while coxae II–III were without spurs (Chilton 1904, Dumbleton 1953).

Tables 2–4 present the dichotomous key (Table 2), and the features, states (Table 3) and data matrix (Table 4) used in the polytomous key (Table 4) to the ixodid taxa listed in Table 1. On paper, the dichotomous key (Table 2) is easier to use than the polytomous key (Tables 3 and 4), but the reverse is true when it is presented electronically. The electronic key to New Zealand Ixodidae is available directly from the author on a compact disk or from http://keys.lucidcentral.org/keys/v3/hard_ticks/Ixodidae genera.html. It contains the dichotomous and polytomous keys and has been designed to enable a nonexpert to identify New Zealand Ixodidae. Upon starting, users select either the dichotomous or the polytomous key. If the dichotomous option is selected, then Phoenix software (Norton 2003, CBIT) and the associated dichotomous key to New Zealand Ixodidae are initiated (Table 2). If the polytomous key is selected, characters and their associated states (Table 3) are presented to enable the specimen to be identified to family, life stage, genus and finally species. Users are not required to follow any particular sequence of questions within families, life stages, genera and species. In both the dichotomous and polytomous keys, all features referred to either in couplet questions or as character states are illustrated with line drawings, micrographs, or both. Once identification has been reached, users can access embedded fact sheets that contain detailed descriptions, images, or both for the male, female and nymph. Notes on the distribution and ecology of each species, and how to distinguish it from similar species are also provided. This additional information assists in confirming the identification.

During initial testing of both keys using species exotic to New Zealand, an experienced tick taxonomist correctly identified all 15 adult and 10 nymphal specimens to genus level. When presented with adults and nymphs of *H. longicornis* and four of the *Ixodes* species that are known to occur in New Zealand, all specimens again were correctly identified. A quarantine diagnostician correctly identified 10 adults and 10 nymphs to genus. An inexperienced technician was able to identify 15 of the 10 adults and 10 nymphs to genus. Both the quarantine diagnostician and inexperienced technician were able identify the nymphs and adults of *H. longicornis*. The latter result is important as this is the species that professionals in the health and agricultural industries in New Zealand are most likely to encounter. All the testers and in particular the quarantine diagnostician and inexperienced technician commented that the images and fact sheets contained within the key helped them to confidently identify the specimen they were examining. The inexperienced technician also commented that the key was interesting because until they were exposed to it they had always assumed that New Zealand had only one species of tick. However, all reviewers commented that they would like to see a glossary and front page included in the key. These are currently being developed and will be added to later versions.

TABLE 4A: Polytomous key to nymphs of all Ixodidae genera and to the Ixodidae species known to occur in New Zealand.

				Ixodidae Nymphs													
Character	*Argasidae*	*Ixodidae*	***Larva***	*Amblyomma* (with eyes)[1,5]	*Amblyomma* (without eyes)[2]	*Bothriocroton*[15]	*Dermacentor*[1,5]	*Haemaphysalis*[3,5]	*Hyalomma*[1]	*Ixodes*[4,5]	*Ixodes anatis*[4]	*Ixodes auritulus zealandicus*[4]	*Ixodes eudyptidis*[4]	*Ixodes jacksoni*[4]	*Ixodes kerguelenensis*[4]	*Ixodes uriae*[4]	*Rhipicephalus*[1,5]	*Rhipicephalus (Boophilus)*[1]
A	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
B	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
C	-	-	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
E	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
G	-	-	-	2	2	2	2	2	2	3	3	3	3	3	3	3	2	1
H	-	-	-	2	2	2	2	2	2	1	1	1	1	1	1	1	2	1
I	-	-	-	2/3	1	1	2	1	2/3	1	1	1	1	1	1	1	2	2
J	-	-	-	2/3	2/3	2/3	2/3	2	2/3	2	2	2	2	2	2	2	1	1
K	-	-	-	6	6	6	2/5	3	5	4	4	4	4	4	4	4	2	1
L	-	-	-	-	-	-	-	-	-		1	2	1	1	3	1	-	-
M	-	-	-	-	-	-	-	-	-		1	1	1	1	1	2	-	-
N	-	-	-	-	-	-	-	-	-		2	2	2	1	2	1	-	-
O	-	-	-	-	-	-	-	-	-		1	2	3	-	2	-	-	-
P	-	-	-	-	-	-	-	-	-		1	2	1	1	2	1	-	-
Q	-	-	-	-	-	-	-	-	-		1	2	1	1	1	1	-	-
R	-	-	-	-	-	-	-	-	-		1	2	2	1	2	1	-	-
S	-	-	-	-	-	-	-	-	-		1	3	2	1	2	1	-	-

[1] Species belonging to this genus not present in New Zealand
[2] One species of eyeless *Amblyomma* present in New Zealand, *Am.* (*Ap.*) *sphenodonti*
[3] One species of *Haemaphysalis* present in New Zealand, (*H. longicornis*)
[4] Present in New Zealand
[5] Members of this genus have previously been intercepted at New Zealand's borders

TABLE 4B: Polytomous key to males of all Ixodidae genera and to the Ixodidae species known to occur in New Zealand.

				Ixodidae Males																			
Character	*Argasidae*	*Ixodidae*	***Larva***	*Amblyomma* (with eyes)[1]	*Amblyomma* (without eyes)[2]	*Anomalohimalaya*[1]	*Bothriocroton*[1,5]	*Cosmiomma*[1]	*Dermacentor*[1,5]	*Haemaphysalis*[3,5]	*Hyalomma*[1]	*Ixodes*[4,5]	*Ixodes anatis*[4]	*Ixodes auritulus zealandicus*[4]	*Ixodes eudyptidis*[4]	*Ixodes jacksoni*[4]	*Ixodes kerguelenensis*[4]	*Ixodes uriae*[4]	*Margaropus*[1]	*Nosomma*[1]	*Rhipicentor*[1]	*Rhipicephalus*[1,5]	*Rhipicephalus (Boophilus)*[1]
A	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
B	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
C	-	-	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D	-	-	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
E	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
F	-	-	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
T	-	-	-	2	2	2	2	1	2	2	2	3	3	3	3	3	3	3	1	2	2	2	1
U	-	-	-	2	1	2	1	2	2	1	2	1	1	1	1	1	1	1	2	2	2	2	2
V	-	-	-	2	2	2	2	2	2	2/3	1	1	1	1	1	1	1	1	1	2	2	2	1
W	-	-	-	2	1/2	1	1/2	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1
X	-	-	-	1	1	1	1	2	1	1	4	5/1	5	5	5	1	5	5	2	4	1	3	3
Y	-	-	-	6	6	4	6	6	2	5	6	2	2	2	2	2	2	2	2	3	2	2	1
Z	-	-	-	2/3	2/3	1	5	3	2	2	2	2	2	2	2	2	2	2	4	2	4	4	4
AA	-	-	-	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1
AB	-	-	-	-	2	-	1		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AC	-	-	-	-	-	-	-	-	-	-	-		2	2	2	1	2	2	-	-	-	-	-
AD	-	-	-	-	-	-	-	-	-	-	-		2	2	2	2	2	1	-	-	-	-	-
AE	-	-	-	-	-	-	-	-	-	-	-		2	3	3	1	3	1	-	-	-	-	-
AF	-	-	-	-	-	-	-	-	-	-	-		1	2	2	1	2	2	-	-	-	-	-
AG	-	-	-	-	-	-	-	-	-	-	-		1	1	1	2	1	1	-	-	-	-	-
AH	-	-	-	-	-	-	-	-	-	-	-		2	2	2	1	2	1	-	-	-	-	-
AI	-	-	-	-	-	-	-	-	-	-	-		1	1	1	1	1	2	-	-	-	-	-
AJ	-	-	-	-	-	-	-	-	-	-	-		1	2	1	1	3	1	-	-	-	-	-
AK	-	-	-	-	-	-	-	-	-	-	-		5	3	2	4	4	1	-	-	-	-	-

[1] Species belonging to this genus not present in New Zealand
[2] One species of eyeless *Amblyomma* present in New Zealand, *Am.* (*Ap.*) *sphenodonti*
[3] One species of *Haemaphysalis* present in New Zealand, (*H. longicornis*)
[4] Present in New Zealand
[5] Members of this genus have previously been intercepted at New Zealand's borders

TABLE 4C: Polytomous key to females of all Ixodidae genera and to the Ixodidae species known to occur in New Zealand.

				Ixodidae Males																		
Character	*Argasidae*	*Ixodidae*	***Larva***	*Amblyomma* (with eyes)[1]	*Amblyomma* (without eyes)[2]	*Anomalohimalaya*[1]	*Bothriocroton*[1,5]	*Cosmiomma*[1]	*Dermacentor*[1,5]	*Haemaphysalis*[3,5]	*Hyalomma*[1]	*Ixodes*[4,5]	*Ixodes anatis*[4]	*Ixodes auritulus zealandicus*[4]	*Ixodes eudyptidis*[4]	*Ixodes jacksoni*[4]	*Ixodes kerguelenensis*[4]	*Ixodes uriae*[4]	*Margaropus*[1]	*Nosomma*[1]	*Rhipicentor*[1]	*Rhipicephalus*[1,5]	*Rhipicephalus* (*Boophilus*)[1]
A	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
B	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
C	-	-	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
D	-	-	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
E	-	-	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
F	-	-	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
AL	-	-	-	2	2	2	2	4	2	2	2	3	3	3	3	3	3	3	1	2	2	2	1
AM	-	-	-	2	1	1	1	2	2	1	2	1	1	1	1	1	1	1	2	2	2	2	2
AN	-	-	-	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	2	2	2	1
AO	-	-	-	2	1/2	1	1/2	2	2	1	1	1	1	1	1	1	1	1	1	2	1	1	1
AP	-	-	-	7	7	5	7	7	2	4	7	6	6	6	6	6	6	6	2	3	2	2	1
AQ	-	-	-	1/2	1/2	3	4	2	1	1	1	1/2	1	1	1	1	1	1	3	1	3	3	3
AR	-	-	-	-	2	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1	-
AT	-	-	-	-	-	-	-	-	-	-	-		1	1	1	2	1	3	-	-	-	-	-
AU	-	-	-	-	-	-	-	-	-	-	-		1	2	1	1	3	1	-	-	-	-	-
AV	-	-	-	-	-	-	-	-	-	-	-		1	1/2	2/3	3	2	2	-	-	-	-	-
AW	-	-	-	-	-	-	-	-	-	-	-		1	2	1	1	2	1	-	-	-	-	-
AX	-	-	-	-	-	-	-	-	-	-	-		1	2	2	2	2	2	-	-	-	-	-
AY	-	-	-	-	-	-	-	-	-	-	-		1	2	2	1	2	1	-	-	-	-	-
AZ	-	-	-	-	-	-	-	-	-	-	-		1	3	2	1	2	1	-	-	-	-	-
BA	-	-	-	-	-	-	-	-	-	-	-		2	4	3	1	4	1	-	-	-	-	-

[1]Species belonging to this genus not present in New Zealand
[2]One species of eyeless *Amblyomma* present in New Zealand, *Am.* (*Ap.*) *sphenodonti*
[3]One species of *Haemaphysalis* present in New Zealand, (*H. longicornis*)
[4]Present in New Zealand
[5]Members of this genus have previously been intercepted at New Zealand's borders

TABLE 5. LucidBuilder data matrix for polytomous key to genera of male Ixodidae.

Character	State	*Amblyomma* (with eyes)	*Amblyomma* (without eyes)	*Anomalohimalaya*	*Bothriocroton*	*Cosmiomma*	*Dermacentor*	*Haemaphysalis*	*Hyalomma*	*Ixodes*	*Ixodes anatis*	*Ixodes auritulus zealandicus*	*Ixodes eudyptidis*	*Ixodes jacksoni*	*Ixodes kerguelenensis*	*Ixodes uriae*	*Margaropus*	*Nosomma*	*Rhipicentor*	*Rhipicephalus*	*Rhipicephalus* (*Boophilus*)
Anal groove	1					✓											✓				✓
	2	✓	✓	✓	✓		✓	✓	✓									✓	✓	✓	
	3									✓	✓	✓	✓	✓	✓	✓					
Eyes	1		✓	✓	✓			✓		✓	✓	✓	✓	✓	✓	✓					
	2	✓				✓	✓		✓								✓	✓	✓	✓	✓
Festoons	1									✓	✓	✓	✓	✓	✓	✓	✓				✓
	2	✓	✓	✓	✓	✓	✓	✓										✓	✓	✓	
	3								✓												
Scutum ornamentation	1	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	2	✓	✓		✓	✓	✓											✓		✓	
Ventral plates (presence and number)	1	✓	✓	✓	✓		✓	✓		✓				✓					✓		
	2					✓											✓				
	3																			✓	✓
	4								✓									✓			
	5									✓	✓	✓	✓		✓	✓					
Palps (shape or form)	1																				✓
	2						✓			✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
	3																	✓			
	4			✓																	
	5							✓													
	6	✓	✓		✓	✓			✓												
Basis capituli (dorsal shape)	1			✓																	
	2	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			
	3	✓	✓		✓	✓															
	4																✓		✓	✓	✓
	5		✓																		
Leg IV (form)	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
	2																✓				
Eyeless *Amblyomma* or *Bothriocroton*: hypostomal dentition; ornamentation of scutum, hosts and origin	1			*	✓	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	2	✓	✓	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

(✓= Common score, ✓= rare score, *=not scoped score and a blank cell indicates an absent score).

QUADS (http://www.quadscoop.org/) has indicated that, for optimal utility, electronic identification tools need to be extended to cover more than one faunal region. I am currently developing another electronic key that includes Australasian Ixodidae, Ixodidae that have previously been intercepted at New Zealand's border, those ixodid genera that contain a small number of species (eyeless *Amblyomma* (former *Aponomma*), *Anomalohimalaya*, *Bothriocroton*, *Dermacentor*, *Margaropus*, *Rhipicephalus* (former *Boophilus*), and *Rhipicentor*), the monotypic genera *Cosmiomma* and *Nosomma*, and the subgenera of *Ixodes*. In the future, there is scope to expand the key to include all known ixodid taxa plus genetic data such as nucleotide sequences and high resolution melt curves (Winder *et al.* in press).

Acknowledgements

The author thanks Dr. A.C.G. Heath (AgResearch, New Zealand), Associate Professor G. J. Hickling (University of Tennessee, USA), and Dr. R.G. Robbins (AFPMB, Walter Reed Army Medical Center, USA) for providing specimens. Dr. Heath and Dr. Sherly George (MAFBNZ) kindly reviewed and commented on early versions of the key. Thanks also to Dr. Craig Phillips (AgResearch, New Zealand) and Dr. Cor Vink (AgResearch, New Zealand) for reviewing earlier versions of the manuscript; the former was instrumental in helping to secure financial support. This study was funded by New Zealand's Foundation for Research, Science & Technology through contract C02X0501, the Better Border Biosecurity (B3) programme (www.b3nz.org).

References

Agnarsson, I. & Kuntner, M. (2007) Taxonomy in a changing world: Seeking solutions for a science in crisis. *Systematic Biology*, 56, 531–539.

Amerson, A.B. (1968) Tick distribution in the central Pacific as influenced by sea bird movement. *Journal of Medical Entomology*, 5, 332–329.

Arthur, D.R. (1960a) A review of some ticks (Acarina: Ixodidae) of sea birds. Part II. The taxonomic problem associated with *Ixodes auritulus-pervcavatus* group of species. *Parasitology*, 50, 199–226.

Arthur, D.R. (1960b) *Ticks: a monograph of the Ixodoidea. Part V. On the genera* Dermacentor, Anocentor, Cosmiomma, Boophilus and Margaropus. London, Cambridge: University Press. 251pp.

Arthur, D.R. (1963) *British ticks.* London, Butterworths & Co. Ltd. 218pp.

Arthur, D.R. & Chaudhuri, R.P. (1965) A revision of *Nosomma monstrosum* (Nuttall and Warburton, 1908) Ixodoidea: Ixodidae. *Parasitology*, 55, 391–400.

Barker, S.C. & Murrell, A. (2004) Systematics and evolution of ticks with a list of valid genus and species names. *Parasitology*, 2004, S15–S36.

Beati, L., Keirans, J.E., Durden, L.A., & Opiang, M.D. (2008) *Bothriocroton oudemansi* (Neumann, 1910) n. comb. (Acari: Ixodida: Ixodidae), an ectoparasite of the western long-beaked echidna in Papua New Guinea: redescription of the male and first description of the female and nymph. *Systematic Parasitology*, 69, 185–200.

Belozerov, V.N., Voltzit, O.V., Kok, D.J. & Fourie, L.J. (2001) Morphology of *Margaropus winthemi* (Acari: Ixodidae) based on scanning electron microscope study with comparative morphometric and phylogenetic analysis. *Acarina*, 9, 253–270.

Chesmore, E.D. (2002) Electronics and computing applications in entomology. *Antenna (London)*, 26, 241–245.

Chilton, C. (1904) A species of *Ixodes* parasitic on the grey duck. *Transactions of the New Zealand Institute*, 36, 201–202.

Cooley, R.A. & Kohls, G.M. (1945) The genus *Ixodes* in North America. *National Institute of Health Bulletin*, 184, 1–246.

Dallwitz, M.J. (2007) A Comparison of Interactive Identification Programs. http://delta-intkey.com/www/

comparison.htm
Dallwitz, M.J. (2009) Programs for Interactive Identification and Information Retrieval. http://delta-intkey.com/www/idprogs.htm.
Dumbleton, L.J. (1943) A new tick from the tuatara (*Sphenodon punctatus*). *New Zealand Journal of Science and Technology*, 24, 185b-190b.
Dumbleton, L.J. (1953) The ticks (Ixodoidea) of the New Zealand sub-region. *New Zealand Cape Expedition Series Bulletin*, 14, 1–28.
Dumbleton, L.J. (1958) The occurrence of an argasid tick in New Zealand. *New Zealand Journal of Science*, 1, 570-578.
Dumbleton, L.J. (1961) The ticks (Acarina: Ixodoidea) of sea birds in New Zealand waters. *New Zealand Journal of Science*, 4, 760–769.
Dumbleton, L.J. (1963) A synopsis of the ticks (Acarina: Ixodoidea) of New Zealand. *Tuatara*, 11, 72–78.
Dumbleton, L.J. (1973) Additions to the New Zealand tick fauna. *Tuatara*, 20, 65–74.
Godfray, H.C.J. (2002) Challenges for taxonomy. *Nature*, 417, 17–19.
Guglielmone, A.A., Robbins, R.G., Apanaskevich, D.A., Petney, T.N., Estrada-Peña, A. & Horak, I.G. (2009) Comments on controversial tick (Acari: Ixodida) species names described or resurrected from 2003 to 2008. *Experimental & Applied Acarology*, 48, 311–327.
Guglielmone, A.A., Robbins, R.G., Apanaskevich, D.A., Petney, T.N., Estrada-Peña, A., Horak, I.G. & Barker, S.C. (2010) The Argasidae, Ixodidae and Nuttalliellidae (Acari: Ixodida) of the world: a list of valid species names. *Zootaxa*, 2528, 1–28.
Heath, A.C.G. (1977) Zoogeography of the New Zealand tick fauna. *Tuatara*, 23, 29–39.
Heath, A.C.G. (2001) Exotic tick interceptions 1980–2000. *Surveillance*, 28, 13–15.
Heath, A.C.G. (2002a) Recently introduced exotic animals and their parasites: what risk to New Zealand's biosecurity? *Surveillance*, 29, 15–17.
Heath, A.C.G. (2002b) Vector competence of *Haemaphysalis longicornis* with particular reference to blood parasites. *Surveillance*, 29, 12–14.
Hoogstraal, H. (1967) *Ixodes jacksoni* n. sp. (Ixodoidea: Ixodidae), a nest parasite of the spotted cormorant, *Phalacrocorax punctatus* (Sparrman) in New Zealand. *Journal of Medical Entomology*, 4, 37–41.
Hoogstraal, H., Roberts, F.H.S., Kohls, G.M. & Tipton, V.J. (1968) Review of *Haemaphysalis* (*Kaiseriana*) *longicornis* Neumann (resurrected) of Australia, New Zealand, New Caledonia, Fiji, Japan, Korea, and northeastern China and USSR, and its parthenogenetic and bisexual populations (Ixodoidea, Ixodidae). *Journal of Parasitology*, 54, 1197–1213.
Hoogstraal, H., Kaiser, M.N. & Mitchell, R.M. (1970) *Anomalohimalaya lama*, new genus and new species (Ixodoidea: Ixodidae), a tick parasitizing rodents, shrews, and hares in the Tibetan Highland of Nepal. *Annals of the Entomological Scociety of America*, 63, 1576–1586.
Hoogstraal, H. (1985) Argasid and nuttalliellid ticks as parasites and vectors. *Advances in Parasitology*, 24, 135–238.
Horak, I.G., Camicas, J.L. & Keirans, J.E. (2002) The Argasidae, Ixodidae and Nuttalliellidae (Acari: Ixodida): a world list of valid tick names. *Experimental and Applied Acarology*, 28, 27–54.
IPPC. (2006) Diagnostic protocols for regulated pests. International Standards for Phytosanitary Measures (ISPM) No. 27 FAO Rome. 11p.
James, M.P., Saunders, B.W., Guy, L.A., Brookbanks, E.O., Charleston, W.A.G. & Uilenberg, G. (1984) *Theileria orientalis*, a blood parasite of cattle. First report in New Zealand. *New Zealand Veterinary Journal*, 32, 154–156.
Kaufman, T.S. (1972) A *revision of the genus* Aponomma*, Neumann 1899 (Acarina, Ixodidae).* Ph.D. Dissertation, University of Maryland. 389 pp.
Keirans, J.E., King, D.R. & Sharrad, R.D. (1994) *Aponomma* (*Bothriocroton*) *glebopalma*, n. subgen., n. sp., and *Amblyomma glauerti* n. sp. (Acari: Ixodida: Ixodidae), parasites of monitor lizards (Varanidae) in Australia. *Journal of Medical Entomology*, 31, 132–147.
Klompen, H., Dobson, S.J. & Barker, S.C. 2002. A new subfamily, Bothriocrotoninae n. subfam., for the genus *Bothriocroton* Keirans, King & Sharrad 1994 n. status (Ixodida: Ixodidae), and synonymy of *Aponomma* Neumann, 1899 with *Amblyomma* Koch, 1844. *Systematic Parasitology*, 53, 101–107.
Lobanov, A. (2003) Keys to beetles and biological diagnostics. http://www.zin.ru/ANIMALIA/Coleoptera/eng/syst8.htm
Lodge, D.M., Williams, S., MacIsaac, H.J., Hayes, K.R., Leung, B., Reichard, S., Mack, R.N., Moyle, P.B., Smith, M., Andow, D.A., Carlton, J.T. & McMichael, A. (2006) Biological invasions: recommendations

for U.S. policy and management. *Ecological Applications*, 16, 2035–2054.
Loth, L. (2005) Review of exotic tick interceptions in New Zealand since 1980. *Surveillance*, 32, 7–9.
Matthysse, J.G. & Colbo, M.H. (1987) *The ixodid ticks of Uganda, together with species pertinent to Uganda because of their present known distribution.* College Park, Maryland, Entomological Society of America. 426pp.
McKenna, P.B. (1996) The tick fauna of New Zealand. *Surveillance*, 23, 27.
Norton, G. (2002) Multi-media/internet keys and the taxonomic crisis. *Antenna (London)*, 26, 245–248.
Norton, G. (2003) Identification software for tackling biological invasions. *Proceedings of International Seminar on Biological Invasions. NIAES and FFTC.* pp. 139–153.
Norton, G. (2005) II. Invasive species: the role of Lucid identification keys. *Extension Bulletin - Food & Fertilizer Technology Center*, 561, 7–10.
Nuttall, G.H.F. & Warburton, C. (1911) Part II. Ixodidae. In: *Ticks. A mongraph of the Ixodoidea* London, Cambridge University Press. pp. 105–348.
Nuttall, G.H.F. & Warburton, C. (1915) *Ticks. A monograph of the Ixodoidea. Part III. The genus* Haemaphysalis. London, Cambridge University Press. 349–550 pp.
Roberts, F.H.S. (1970) *Australian ticks*. Melbourne, Commonwealth Scientific and Industrial Research Organisation. 267pp.
Sonenshine, D.E. (1991) *Biology of ticks*. New York, Oxford University Press. 447pp.
Varma, M.G.R. (1993) Ticks and Mites (Acari) In: Lane, R. P. & Crosskey, R. W. (Eds.) *Medical insects and arachnids*. London, Chapman and Hall. pp. 597–658.
Volzit, O.V. Keirans, J.E. (2002) A review of Asian *Amblyomma* species (Acari, Ixodida, Ixodidae). *Acarina*, 10, 95–136.
Volzit, O.V. & Keirans, J.E. (2003) A review of African *Amblyomma* species (Acari, Ixodida, Ixodidae). *Acarina*, 11, 135–214.
Volzit (2007) A review of Neotropical *Amblyomma* species (Acari: Ixodidae). *Acarina*, 15, 3–134.
Walker, A.R., Bouattour, A., Camicas, J.-L., Estrada Peña, A., Horak, I.G., Latif, A.A., Pegram, R.G. & Preston, P.M. (2003) *Ticks of Domestic Animals in Africa: a Guide to Identification of Species*. Bioscience Reports. 227pp.
Walker, A.R., Matthews, J. & Preston, P.M. (2005) The development of electronic keys for the identification of ticks. *International Journal of Tropical Insect Science*, 25, 2–5.
Walker, J.B., Keirans, J.E. & Horak, I.G. (2000) *The genus* Rhipicephalus *(Acari, Ixodidae). A guide to the brown ticks of the world.* Cambridge, Cambridge University Press. 643pp.
Walter, D.E. & Winterton, S. (2007) Keys and the crisis in taxonomy: extinction or reinvention? *Annual Review of Entomology*, 52, 193–208.
Wheeler, Q.D. (2004) Taxonomic triage and the poverty of phylogeny. (Special issue: Taxonomy for the twenty-first century.). *Philosophical Transactions of the Royal Society of London*, 359, 571–583.
Winder, L., Phillips, C.B., Richards, N., Ochoa-Coronal, F., Hardwick, S. & Vink, C. (2010) DNA melting analysis - a useful tool for the identification of biosecurity risks. *Methods in Ecology and Evolution*, In Press.

Accepted by R.G. Robbins 30 Sept. 2010; published 10 Dec. 2010