Tuhinga 23: 29–37

A new species of soft tick (Ixodoidea: Argasidae) from the New Zealand lesser short-tailed bat, *Mystacina tuberculata* Gray

Allen C.G. Heath

AgResearch Ltd Wallaceville, National Centre for Biosecurity and Infectious Disease, PO Box 40 063, Upper Hutt, New Zealand
(allen.heath@agresearch.co.nz)

ABSTRACT: *Carios quadridentatus*, a new species of argasid tick associated with the New Zealand lesser short-tailed bat, is described and illustrated from larval material. This is the second species of soft tick found in New Zealand, bringing the total number of tick species breeding in New Zealand to 11. The taxonomic history of bat ticks is discussed, together with the affinities of the new species with the Australian bat-tick fauna.

KEYWORDS: Argasidae, *Carios*, soft tick, lesser short-tailed bat, New Zealand, new species.

Introduction

The ectoparasite fauna of New Zealand's two rare and extant endemic bat species is diverse, but incompletely known. The long-tailed bat (*Chalinolobus tuberculatus* Forster, 1844) is host to a flea (Jordan 1947) and an ornithonyssine mite, but possibly also to a trombiculid mite and a spinturnicid, both still undescribed (O'Donnell 2005). The less common lesser short-tailed bat (*Mystacina tuberculata* Gray, 1843) hosts more ectoparasite species than its sympatric (Lloyd 2005), with a sarcoptid mite (Fain 1963), a myobiid mite (Fain 1972; Uchikawa 1988), a laelapid mite (Heath *et al.* 1987a) and two demodecid mites (Desch 1989). Fain (1972: 153), in his description of *Mystacobia hirsuta* (Myobiidae), gives the locality as 'Isles Stewart (Archipel Salomon), Pacifique, 1932'; this was an error for Solomon Island, off Stewart Island, both also known by the alternative names Rerewhakaupoko and Rakiura, respectively. The sarcoptid mite, *Chirophagoides mystacopis* Fain, 1963 was collected from the same locality (Fain 1963), although no date is given for the latter species. The error was possibly carried over from Fain (1968: 160, 184, table 7), where the plural 'Solomon Is' was used, although 'Nouvelle Zélande' is referred to only on p. 160. In the present study, to this eclectic mix of ectoparasites of the lesser short-tailed bat an argasid tick is added, which has until now remained unnamed and undescribed.

Desch (1989) described two species of *Demodex*, but his assertion that the follicle mites, the bat fly *Mystacinobia zelandica* Holloway, 1976 and the myobiid mite *Mystacobia hirsuta* Fain, 1972 were the only known specific parasites of *Mystacina tuberculata* is incorrect in a number of respects. Unaccountably, the sarcoptid and laelapid mites mentioned above were both overlooked by Desch (1989). Furthermore, the bat fly is not parasitic, merely using bats both phoretically and commensally (Allaby 1985), living in the guano and roost surroundings (Holloway 1976).

The lesser short-tailed bat is listed as a Category A species, of highest conservation priority, although it is 'Not critically endangered or endangered but is facing a high risk of extinction in the medium term future' (Lloyd 2001: 75), but its parasites are not commonly available. The small number of acarine samples that has been collected, with the exception of those species referred to above, consists almost entirely of the mesostigmatid mite *Chirolaelaps mystacinae* Heath, Bishop & Daniel, 1987 (Heath *et al.* 1987a; other material held by the author). In contrast, Daniel (1979) refers to observations on 600 live bats over a three-year period at one colony, without any 'parasitic flies, blood-sucking bugs and fleas' being found (see also notes under 'Materials and methods'). The mites on which Heath *et al.* (1987a) based their description were obtained from a roost used by captive bats at Wellington Zoological Gardens, with additional paratypes from Omahuta Kauri Sanctuary and Featherston in the North Island, and Codfish Island, Big South Cape Island and Stewart Island in the south. The localities are the names that appear on the slide labels for the paratypes. Current convention offers the discretionary use of the alternative names Whenuahou (Codfish Island), Taukihepa (Big South Cape Island) and Rakiura (Stewart Island). That mite also occurs at the locality from which the ticks described here were obtained (Rangataua, near Ohakune, North Island). These localities cover the range of the three subspecies of *Mystacina tuberculata* as defined by Hill & Daniel (1985) and the six lineages proposed by Lloyd (2003).

The first indication that there was an argasid tick parasitic on *Mystacina tuberculata* appeared as a personal communication from G.W. Ramsay in Heath (1977) with a brief reference to 'an as yet unnamed argasid from North Auckland'. This information was repeated by Daniel (1979), but with more collection details, as follows:

> Larval ticks have frequently been observed embedded in the skin of *Mystacina* handled at the Omahuta colony – a maximum of four was found on one adult bat and two on one naked 2-week old bat. This tick is an undescribed species of genus *Argas* (*Carios*), and appears to have affinities with *A.* (*C.*) *australiensis*, *A.* (*C.*) *daviesi*, *A.* (*C.*) *dewae*, and *A.* (*C.*) *macrodermae*, which are parasitic on six Australian species of bat.

In a checklist of the New Zealand tick fauna, Heath *et al.* (2011) refer to these reports, commenting that there had been no formal published description of the tick in intervening years, and furthermore that the specimen(s) could not be located (G. Hall, pers. comm. 3 May 2011). Following the author's recent discovery of three specimens of Argasidae larvae among material collected from *Mystacina tuberculata* in the central North Island in 1997, a description is here presented of the eleventh species in New Zealand's somewhat sparse tick fauna, and only the second in the Argasidae (Heath *et al.* 2011). It has been assumed that the tick described here is the same species originally mentioned in Heath (1977) and Daniel (1979). This report illustrates, describes and names the tick, although it might be thought premature to prepare a description on the larva alone, given that no other life stages, and especially adults, are available for description. However, there are precedents for describing bat argasids from larvae alone, with 14 other species so named (Labruna & Venzal 2009).

Larval characteristics are sufficiently diagnostic to the extent that keys for larvae have been provided by Kohls *et al.* (1965), Sonenshine *et al.* (1966) and Jones & Clifford (1972). Furthermore, differentiation using adults of *Alectorobius* species (the now outmoded subgenus to which bat argasids were originally assigned, and which contained around 75% of bat-infesting soft ticks) is complicated in many cases, so the larval stage is indicated for species identification (Hoogstraal & Kohls 1962; Kohls *et al.* 1965; Labruna & Venzal 2009).

Because the new species appears to be rare in New Zealand (being found in only two collections to date, assuming the now lost material is of the same species), it may be, arguably, the only species of bat argasid in the country. This makes a strong case for naming this new species from limited larval material with the aim of stimulating further collections. Apart from the single previous record reported both in Heath (1977) and Daniel (1979), there have been no indications that other workers (e.g. Dwyer 1962) have collected or seen ticks on the bats they have handled. Furthermore, there are unlikely to be opportunities to obtain a full series of all life stages of the tick to complete a description, as this would require radical sampling and perhaps destruction of a colony roost, or at least severe disturbance – operations that most likely would not be permitted with such an endangered mammal, despite evidence showing that it is colonising exotic pine plantations (Borkin & Parsons 2010). If the new species has a biology similar to that known for others in the group to which it apparently has affinities (see 'Discussion'), then the larvae usually feed for 17–19 days, whereas adults and nymphs become replete in 20–50 minutes (Hoogstraal 1985) and spend the remainder of their lives in guano or crevices in the roost. This behaviour makes it much more likely for larvae to be found than other stages when bats are examined.

Taxonomic history

The nomenclatorial history of the Argasidae is convoluted, and even to the present there is lack of consensus for some taxa, with the bat-infesting argasids not excepted. Estrada-Peña *et al.* (2010) provide the most recent summary of attempts by other authors to systematise the taxa, although they themselves do not attempt a classification.

In summary: the first reported argasid tick associated with bats was named *Carios vespertilionis* Latreille, 1802 (later placed in the genus *Argas* by Hoogstraal (1958)), a widespread European species ranging also into North Africa. Other bat ticks were placed in *Ornithodoros*, subgenus *Alectorobius* (see Kohls *et al.* 1965; Jones & Clifford 1972), specifically for predominately Neotropical species associated with bats. Ticks of the Oriental-Australian group discussed in the present paper were included in the subgenus *Argas* (*Carios*) (see Sonenshine *et al.* 1966; Hoogstraal 1985).

The subgenus *Carios* was erected mainly on host predilection, but defined also on the basis of adult morphology (Hoogstraal 1958). There are differing descriptions of what constitutes the morphology of the Haller's organ in the larvae of species within this taxon (Hoogstraal & Kohls 1962; Hoogstraal 1985), which is confusing. In an attempt to provide direction and clarity, Klompen & Oliver (1993) undertook a phylogenetic analysis based on 83 characters across all life stages, partly because mainly post-larval stages had been used previously to establish taxonomic relationships; they, followed by Horak *et al.* (2002), placed nearly all bat-associated species in *Carios*, but as a genus with no subgenera recognised. Finally, Guglielmone *et al.* (2010) reverted all bat-associated argasids to the genus *Argas*, with no subgenera. Subgenera will be used here only where they can be referred directly to the various authors cited.

On balance, despite the lack of consensus among contemporary workers, the inclusion of most bat-associated argasids in *Carios* as a genus seems justified, and that is the rationale followed for the species described here, principally because there appears to be no good reason to diverge either from the conclusions of Klompen & Oliver (1993), or the names proposed by Horak *et al.* (2002). This is contrary to the most recent species list of Guglielmone *et al.* (2010), but they also state (p. 2) that 'most species of Argasidae can be assigned to more than one genus'. The recent use of *Carios* as a genus for new species of bat argasids from Brazil (Labruna & Venzal 2009, although these authors were not in agreement on their choice of genus) and Uruguay (Barros-Battesti *et al.* 2011) supports the action taken in this paper. Other tick taxonomists, along with Estrada-Peña *et al.* (2010), are awaiting the expected clarification provided by some future molecular genetics studies.

Materials and methods

In all, 65 *Mystacina tuberculata* from a colony of 3000–4000 individuals in Rangataua State Forest (39°23'S, 175°33'E) near Ohakune, North Island, New Zealand, were examined in December 1997 and a collection of ectoparasites made from five adult bats (B. Lloyd, pers. comm. 5 April 2011). The material (received by the author in 2006) was mounted at that time and put aside without detailed examination. A recent re-examination of the material has shown that three larvae of an argasid tick are present.

Dr Lloyd (pers. comm. 5 April 2011) reported:

> I checked all bats for obvious ectoparasites etc. There were bat flies on a significant proportion, but I only noted ticks on 5 of the 65 bats that I handled. Four with ticks were adult females the other a male. Unfortunately, I haven't made notes of where on the bats the ticks were found. At various times I have noted that they were found on: rump, wing, groin, chin and fur.

Dr Lloyd usually refers to all Acari as either 'mites', 'ticks' or 'ectos', although with the exception of the three argasid larvae described here, only various life stages of the laelapid mite *C. mystacinae* were present in the source material. It appears from the collection data (see below) that at least two, and possibly three, bats were the source of the tick larvae.

The tubes containing the specimens of engorged Argasidae larvae, were labelled as follows: '(1) 27 Dec '97, Rangataua, ecto of S-t bat'; '(2) Ecto M. tuberculata 30 Dec '97, Rangataua'; and '(3) 27 Dec '97 Rangataua Ecto of S-t bat'. Each larva was mounted individually on a microscope slide in Hoyer's solution, after clearing in lactic acid and rinsing in ethanol. None of the larvae has complete mouthparts; only one has an intact hypostome; another, just half of the chelicerae; the third has neither intact hypostome nor chelicerae. Drawings have been done using a drawing tube and measurements made with a slide micrometer. Anatomical terms and morphological measurements follow Sonenshine *et al.* (1962), Kaiser & Hoogstraal (1974), Evans & Till (1979) and Labruna & Venzal (2009). Measurements are in millimetres.

Systematics
Order Ixodida Leach, 1815
Superfamily Ixodoidea Dugès, 1834
Family Argasidae Canestrini, 1890

Genus *Carios* Latreille, 1796

***Carios quadridentatus* new species**
(Figs 1 and 2)

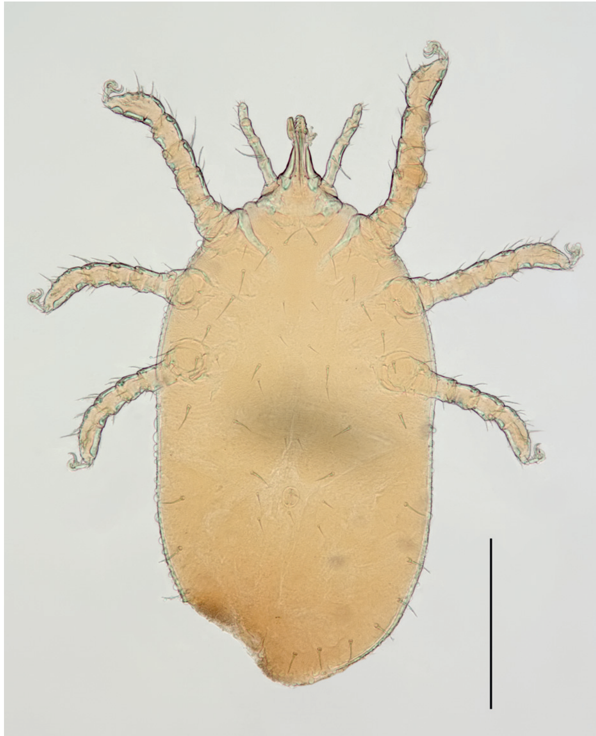

Fig. 1 *Carios quadridentatus* new species, holotype larva: habitus. Scale bar 0.5 mm.

DESCRIPTION:

Body length (three partly engorged specimens), excluding capitulum, measured from first (anterior) post-hypostomal seta (PH1) (Figs 2A,B): Range 1.163–1.465; mean 1.310.

Body width (at level of coxae III): Range 0.845–0.876; mean 0.855.

Body outline: Oval. Paired apodemes (*sensu* Evans 1992) extending into mid-line to about level with base of first pair of dorso-central setae and arising just anterior to leg I coxae; traces of apodemes at level of coxae II.

Dorsal plate (Fig. 2F): Generally oval with an irregular outline and tapering anteriorly; posterior border slightly concave. Individual 'cells' are apparent; circular in outline, giving a 'snakeskin' appearance. 0.227–0.241 long, mean 0.235; 0.0818–0.100 wide, mean 0.0939, at the anterior end; 0.141–0.154 wide, mean 0.147, at the base.

Setae, dorsum (Figs 2A,C): Total 15 pairs; 12 pairs dorso-lateral, three pairs central. Setae lightly serrate (*sensu* Evans 1992) in distal half; antero-lateral and postero-lateral setae each 0.0591–0.864 long, mean (of nine) 0.06337.

Setae, ventrum (Figs 2B,D): Short, and number seven pairs (including two on anal plate), together with an unpaired postero-median seta; and two on each coxa (total 21). Setae barely serrate in distal half; 0.0364–0.0545 long; mean (of nine) 0.0439.

Capitulum (Fig. 2H): Basis capituli outline roughly triangular, *c.* 1.4 times as broad as long, measured to insertion of PH2 (posterior post-hypostomal seta); anterior sheath transparent, fusing with ventral portion of hypostome shaft.

Palpi (Fig. 2H): Palpal length formula 1:1.7:1.6:1.7; based on segment IV, 0.041 (all three specimens); segment III, 0.0636–0.0772, mean 0.0681; segment II, 0.0636–0.0682, mean 0.0650; segment I, 0.0636–0.0772, mean 0.0712. Palpal setal counts: article I, 0; article II, 4; article III, 4; article IV, 9.

Hypostome (Figs 2E,H): Arising from a flared anterior extension of the basal 'collar' of the capitulum, extending to a level of *c.* distal end of palpal segment III; *c.* 2 times as long as broad; measuring 0.091 (from tip to origin); apex bluntly pointed; corona with four minute rounded denticles; dental formula 2/2 in four files, each of four denticles. Post-hypostomal (Fig. 2H), PH1 (anterior), *c.* 0.007 long, 0.0272 between bases (all three larvae); PH2 (posterior) *c.* 0.009 long, 0.0682–0.1 between bases, mean 0.0879. Distance between pairs of PH1 and PH2 setae (measured from the mid-point of a line joining the bases of each pair), 0.06.

Legs: Moderately short, 0.4 times body length; leg I slightly stouter than legs II and III; coxae not contiguous.

Setal pattern (antero-lateral-antero-dorsal/antero-ventral, postero-dorsal/postero-ventral-postero-lateral; see Evans & Till 1979): Trochanters I–III, 1–0/1 0/1–1 (one extra postero-ventral on trochanter II of one larva, and one extra antero-ventral seta on trochanter II of another); femur I, 2–2/2 0/1–1; femur II variable, 2–2/2 1/0–1, 2–2/2 0/1–1, 2–2/1 1/1–1; femur III variable, 2–2/1 0/1–1, 1–2/1 2/1–0, 2–2/1 0/1–1; genua I–III, 1–1/1 0/1–1; tibiae I–III, 1–1/1 1/1–1.

Tarsus I (Fig. 2G): Setal formula apical 1, apico-ventral 1, antero-lateral 1, disto-median 1, paracapsular 2 (plus two very small adjacent setae), postero-median 1, baso-dorsal 1

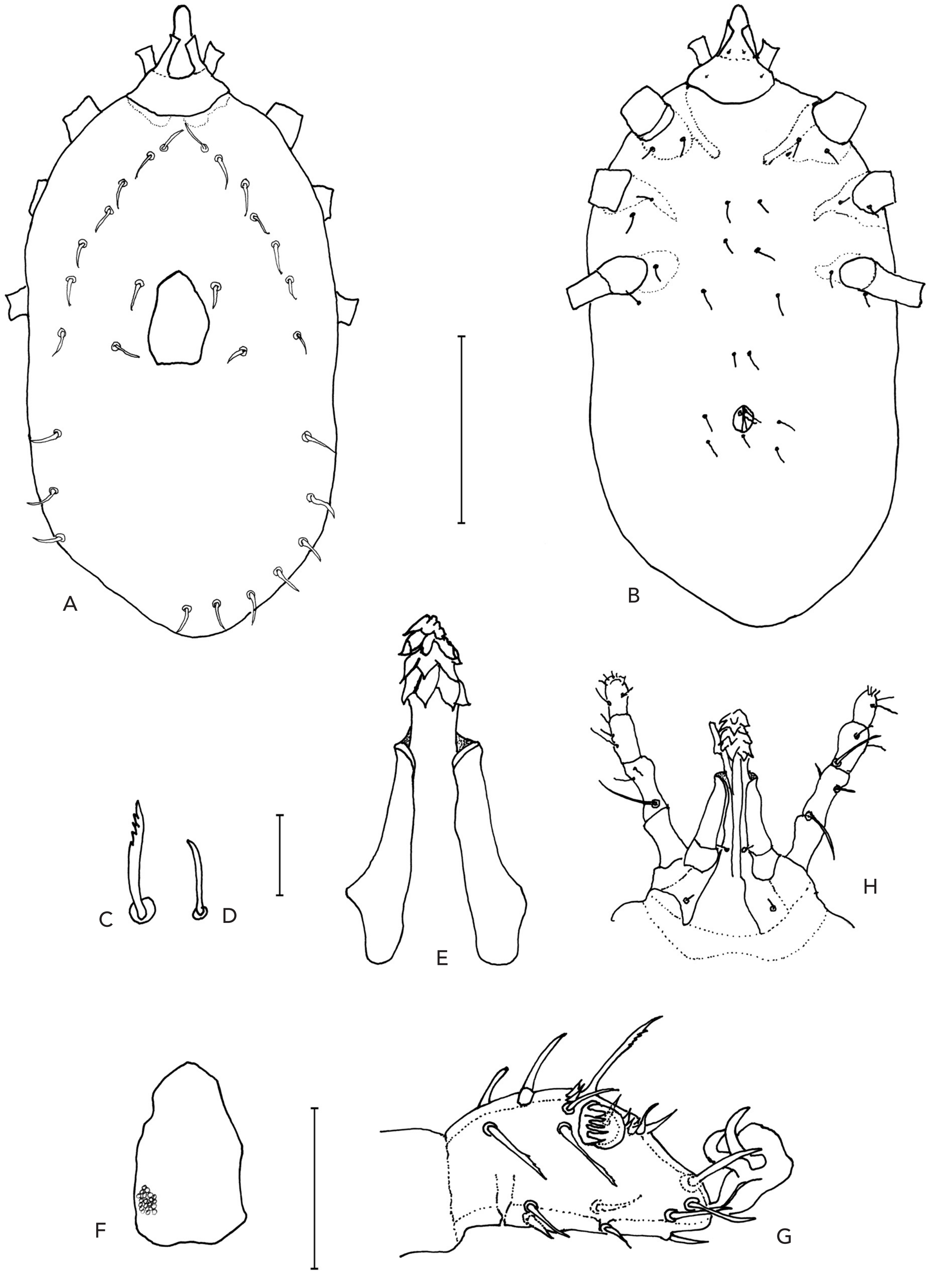

Fig. 2 *Carios quadridentatus* new species, holotype larva: A, B, dorsal and ventral views; C, D, dorsal and ventral setae; E, hypostome, ventral view; F, dorsal plate; G, tarsus I; H, capitulum, ventral view. Scale bars A, B, 0.5 mm; C, D, E, 0.05 mm; F, G, H, 0.1 mm.

pair, baso-ventral 1 pair, mid-ventral 1 pair, pre-mid-ventral 1 pair (17 in total); Haller's organ an open pit, with a few anteriorly directed projections with eight internal sensillae visible, five on 'rim' and three minute setae on an internal disc; anterior pit setae number five, two long, two intermediate and one short; mild serration on larger seta. Large excretory pore opening out onto ventral surface just proximal to baso-ventral setae, and another, smaller pore between insertions of mid-ventral setae.

TYPE MATERIAL: **Holotype** partly engorged larva, ex adult lesser short-tailed bat, Rangataua State Forest, Ohakune, New Zealand, 27 December 1997, B.D. Lloyd (AA.000202). Exact label details as written by collector are: '(1) 27 Dec '97, Rangataua, ecto of S-t bat'. **Paratypes** two partly engorged larvae, ex adult lesser short-tailed bats, Rangataua State Forest, Ohakune, New Zealand, 30 December 1997 and 27 December 1997, B.D. Lloyd (AA.000203). Exact label details as written by collector are: '(2) Ecto M. tuberculata 30 Dec '97, Rangataua' and '(3) 27 Dec '97 Rangataua Ecto of S-t bat'. Types deposited in the Museum of New Zealand Te Papa Tongarewa, Wellington.

ETYMOLOGY: The species epithet *quadridentatus* (Latin = four teeth) refers to the number of hypostomal teeth in each file, a unique feature in the genus.

Discussion

There are around 190 species in the family Argasidae, about 60 of which infest bats (Hoogstraal 1985; Estrada-Peña *et al.* 2010), but those from the Australasian (sometimes termed Australian) and Oriental biogeographical regions appear to provide the best basis for comparison with the species described here. In fact, possible affinities with the Australian fauna have already been proposed (G.W. Ramsay *in* Daniel 1979).

The ancestral mystacinid bats are thought to have dispersed from Australia to New Zealand at some point during Gondwana's break-up phase. Although the superfamily Noctilionoidea, to which the Mystacinidae belong, are now restricted to Central and South America and New Zealand (Lloyd 2001), an Australian rather than American origin for New Zealand bats is more likely, partly on the basis of fossil mystacinids in Australia, partly because the argasid tick described here has morphological affinities with Australian species, and partly because dispersal of bats from Australia to New Zealand seems more plausible than direct dispersal from Central or South America (Lloyd 2001).

A link with the South American tick fauna was also considered, but there is little supporting evidence. Hoogstraal (1985) did not recognise any South American affinity when he combined a group of argasids from insectivorous bats in the *Argas* (*Carios*) taxon: six species in all, with four from Australia (see below), together with *A.* (*C.*) *vespertilionis* from the Ethiopian and Palearctic regions and parts of India, and the smaller *A.* (*C.*) *pusillus* Kohls, 1950 from Malaysia and the Philippines. In an earlier study (Hoogstraal & Kohls 1962), larvae of *A.* (*C.*) *vespertilionis* were found to differ only in minute details from larvae collected from Australian and New Guinea bats, and although the larvae in question were not referable to *A.* (*C.*) *vespertilionis*, neither could they be assigned with certainty to either *A.* (*C.*) *australiensis* Kohls & Hoogstraal, 1962 or *A.* (*C.*) *pusillus*. Where the supposed larva of *A.* (*C.*) *australiensis* is referred to later (see text and Table 1), an interrogation mark (?) is used to indicate the uncertainty mentioned above.

A further reason for rejecting a Neotropical affinity for the new species was evident when using the key to larvae of Argasidae of the western hemisphere (Kohls *et al.* 1965), as well as the revised key to same group (Jones & Clifford 1972). The specimens in the present study keyed out to '*Ornithodoros* (*Alectorobius*) *yumatensis*', now known as *Carios yumatensis* (Cooley & Kohls, 1941) (see Horak *et al.* 2002), a bat tick from southern USA and Mexico with eight pairs of ventral setae, excluding coxal setae and an unpaired postero-median seta. The number of ventral setae, dentition and size of that North American species, as well as other lesser features, readily separate it from the specimens in the present study.

In contrast, when using Sonenshine *et al.*'s (1966) key to the larvae of Ornithodorinae of the eastern hemisphere, the new species keyed out to '*Argas* (*Carios*) *australiensis* – *A.* (*C.*) *pusillus* – *A.* (*C.*) *vespertilionis* group', although there were no couplets for species separation. Subsequently, three further species were described in *Argas* (*Carios*) from Australia: *A.* (*C.*) *daviesi* Kaiser & Hoogstraal, 1973; *A.* (*C.*) *dewae* Kaiser & Hoogstraal, 1974; and *A.* (*C.*) *macrodermae* Hoogstraal *et al.*, 1977.

Some morphological features (see below and Table 1) place *Carios quadridentatus* closer to both *C. dewae* and *C. daviesi* than to the other Australian species. The latter species is from a cave in Western Australia inhabited by bats, while the former was taken by Kaiser & Hoogstraal (1974) from a number of species of bats from southeast Australia and Tasmania, including Gould's wattled bat *Chalinolobus gouldii*.

Table 1 Comparative principal morphological characteristics of a selection of bat argasids from the Oriental and Australasian regions. Taxa as in Horak *et al.* (2002).

	Carios vespertilionis	*Carios dewae*	*Carios australiensis*(?)	*Carios daviesi*	*Carios macrodermae*	*Carios pusillus*	*Carios quadridentatus*
Dorsal setae (n)	36–38	*c.* 42	26–28	32	22–24	24–30	30
Ventral setae (n)	12–14	17	20	20	28	12–14	21
Capitulum W:L	2×	1.6×	2.3×*	1.6×*	3.3×	No data**	1.4×
Hypostomal teeth	12	12–14	8	11–12	8–10	12	4
Palpal setae	No data	0,4,4,*c.* 9	No data	0,4,4, *c.* 8	0,5,5,8–9	No data	0,4,4,9

* Measured from illustrations in Hoogstraal & Kohls (1962) and Kaiser & Hoogstraal (1973).

** No measurements available, but clearly broader than long from the rather inadequate illustration (see Kohls 1950).

Note that New Zealand's long-tailed bat, *Ch. tuberculatus*, originated in Australia (Lloyd 2001). Some authors (e.g. Kohls *et al.* 1965; Sonenshine *et al.* 1966) deem the setal formula on tarsus I as diagnostic, but no counts are available for the Australian species for comparison. However, as far as can be seen from figures (Kaiser & Hoogstraal 1973, 1974), the tarsal setae of *C. dewae* are more similar in position and number to those of *C. quadridentatus* than those of *C. daviesi*, although the serrations on the large tarsal seta of *C. quadridentatus* are considerably fewer and less prominent than shown for *C. dewae* (see Kaiser & Hoogstraal 1974).

The body length of the new species falls within the range of *Carios dewae* and *C. australiensis* (?) as measured on partly fed larvae, but *C. pusillus* is much smaller, at just 0.41 mm long. The other Australian species were not comparable because measurements had been made on unfed larvae. Among the Australian species, the shape of the dorsal plate of *C. dewae* is closest to that of *C. quadridentatus.*

The leg:body length ratio of *Carios dewae* is similar to that of *C. quadridentatus* (other species have longer legs), but the latter differs from the Australian species in number of dorsal and ventral setae, a slightly narrower capitulum and, more significantly, reduced hypostomal dentition. The new species has two files of teeth (denticles) on each side of the hypostome (i.e. 2/2 dentition), with only four teeth in each. See Table 1 for comparisons with other relevant species.

The paucity of hypostomal denticles is not a unique feature among Argasidae, because there are eight species in the eastern group of the genus *Ornithodoros* (Sonenshine *et al.* 1966) that have 2/2 dentition, and with two to five denticles in either file. This is, however, the only significant morphological feature that associates them with the new species; also, most members of the eastern group are parasites principally of burrow-inhabiting mammals in Africa, the Middle East, the former USSR and the Far East.

Conclusions

A new species of bat tick is described here that has affinities with Australian bat argasids, and probably evolved from that fauna, but is distinct from it. *Carios quadridentatus* differs from all other bat-infesting species placed in *Argas* or *Carios* principally by the number of dorsal and ventral setae, and by its hypostomal formula. However, it shares the same palpal seta formula, and bears a close similarity in the morphology of the dorsal plate and the relative narrowness of the capitulum, with two species from the Australian region: *C. dewae* and *C. daviesi.*

There was some circumstantial evidence that a mesostigmatid mite had affected the health of captive lesser short-tailed bats in New Zealand (Heath *et al.* 1987b), although later observations have not necessarily supported that finding (Ruffell & Parsons 2009). The effects of other acarine parasites such as *Chirophagoides mystacopis* are unknown, although sarcoptid mites can cause severe mange (Mullen & O'Connor 2009). It is worth considering also that ticks in general are good vectors of disease, and at least two species of bat argasids have been implicated as vectors of viruses with zoonotic implications (Hoogstraal 1985). The potential for impairing the health of their chiropteran hosts is not known, except that some host resistance through acquired immunity might be expected. An opportunistic survey of 54 lesser short-tailed bats in New Zealand found them largely free of disease (Duignan *et al.* 2003), and although no potential arthropod vectors were found, the authors listed numerous micro-organisms that infect bats worldwide and that can also be zoonotic. This suggests that there can be no complacency where New Zealand's rare bats and ticks are concerned.

Acknowledgements

Brian Lloyd is thanked profoundly for providing the material from which this paper originated, and Ricardo Palma (Museum of New Zealand Te Papa Tongarewa (Te Papa), Wellington, New Zealand) is thanked for helpful comments on an earlier draft of the manuscript. Two anonymous referees are also thanked for their strongly supportive comments. Grateful thanks go also to Grace Hall (Landcare Research New Zealand Ltd, Auckland, New Zealand) for her assiduous, but ultimately unsuccessful, search for apparently lost bat-argasid specimens in the New Zealand Arthropod Collection; and to Phil Mckenna (Gribbles Veterinary Pathology Limited, Palmerston North, New Zealand) for allowing access to his parasite database. I am very grateful to Jean-Claude Stahl (Te Papa) for preparing Fig. 1, and Raymond Coory (Te Papa) for scanning and improving aspects of the format of Fig. 2. This work was partly funded by the New Zealand Foundation for Research, Science and Technology through the Better Border Biosecurity (B3) programme.

References

Allaby, M. (*ed.*) (1985). *The Oxford dictionary of natural history.* Oxford: Oxford University Press. 688 pp.

Barros-Battesti, D.M., Landulfo, G.A., Onofrio, V.C., Faccini, J.L.H., Marcili, A., Nieri-Bastos, F.A., Venzal, J.M. and Labruna, M.B. (2011). *Carios mimon* (Acari: Argasidae): description of adults and redescription of larva. *Experimental and Applied Acarology* 54: 93–104.

Borkin, K.M. and Parsons, S. (2010). Plantation forests are used by the lesser short-tailed bat, *Mystacina tuberculata rhyacobia. New Zealand Journal of Zoology* 37: 13–17.

Cooley, R.A. and Kohls, G.M. (1941). Further new species of *Ornithodoros* from bats (Acarina: Argasidae). *United States Public Health Report* 56: 910–914.

Daniel, M.J. (1979). The New Zealand short-tailed bat, *Mystacina tuberculata*; a review of present knowledge. *New Zealand Journal of Zoology* 6: 357–370.

Desch, C.E. (1989). Two new species of *Demodex* (Acari: Demodicidae) from the New Zealand short-tailed bat, *Mystacina tuberculata* Gray, 1843 (Chiroptera: Mystacinidae). *New Zealand Journal of Zoology* 16: 221–230.

Duignan, P., Horner, G. and O'Keefe, J. (2003). Infectious and emerging diseases of bats, and health status of bats in New Zealand. *Surveillance* 30: 15–18.

Dwyer, P.D. (1962). Studies on the two New Zealand bats. *Zoology Publications from Victoria University of Wellington* 28. 28 pp.

Estrada-Peña, A., Mangold, A.J., Nava, S., Venzal, J.M., Labruna, M. and Guglielmone, A.A. (2010). A review of the systematics of the tick family Argasidae (Ixodida). *Acarologia* 50: 317–333.

Evans, G.O. (1992). *Principles of acarology.* Wallingford: CAB International. 563 pp.

Evans, G.O. and Till, W.M. (1979) Mesostigmatic mites of Britain and Ireland (Chelicerata: Acari-Parasitiformes). An introduction to their external morphology and classification. *Transactions of the Zoological Society of London* 35: 139–270.

Fain, A. (1963). Les acariens psoriques parasites des chauves-souris. XXV *Chirophagoides mystacopis* n.g., n.sp. (Sarcoptidae: Sarcoptiformes). *Bulletin et Annales de la Société Royale d'Entomologie de Belgique* 99*:* 159–167.

Fain, A. (1968). Etude de la variabilité de *Sarcoptes scabiei* avec une révision des Sarcoptidae. *Acta Zoologica et Pathologica Antverpiensia* 47: 1–196.

Fain, A. (1972). Diagnoses de nouveaux Myobiidae (Acarina: Trombidiformes). *Revue de Zoologie et de Botanique Africaines* 86: 148–157.

Guglielmone, A.A., Robbins, R.G., Apanaskevich, D.A., Petney, T.N., Estrada-Peña, A., Horak, I.G., Shao, R. and Barker, S.C. (2010). The Argasidae, Ixodidae and Nuttalliellidae (Acari: Ixodida) of the world: a list of valid names. *Zootaxa* 2528: 1–28.

Heath, A.C.G. (1977). Zoogeography of the New Zealand tick fauna. *Tuatara* 23: 26–39.

Heath, A.C.G., Bishop, D.M. and Daniel, M.J. (1987a). A new laelapine genus and species (Acari: Laelapidae) from the short-tailed bat *Mystacina tuberculata*, in New Zealand. *Journal of the Royal Society of New Zealand* 17: 31–39.

Heath, A.C.G., Julian, A.F., Daniel, M.J. and Bishop, D.M. (1987b). Mite infestation (Acari: Laelapidae) of New

Zealand short-tailed bats, *Mystacina tuberculata,* in captivity. *Journal of the Royal Society of New Zealand* 17: 41–47.

Heath, A.C.G., Palma, R.L., Cane, R.P. and Hardwick, S. (2011). Checklist of New Zealand ticks (Acari: Ixodidae, Argasidae). *Zootaxa* 2995: 55–63.

Hill, J.E. and Daniel, M.J. (1985). Systematics of the New Zealand short-tailed bat *Mystacina* Gray, 1843 (Chiroptera: Mystacinidae). *Bulletin of the British Museum of Natural History (Zoology)* 48: 279–300.

Holloway, B.A. (1976). A new bat-fly family from New Zealand (Diptera: Mystacinobiidae). *New Zealand Journal of Zoology* 3: 279–301.

Hoogstraal, H. (1958). Bat ticks of the genus *Argas* (Ixodoidea, Argasidae). 3. The subgenus *Carios*, a redescription of *A.* (*C.*) *vespertilionis* (Latreille, 1802), and variation within an Egyptian population. *Annals of the Entomological Society of America* 51: 19–26.

Hoogstraal, H. (1985). Argasid and nuttalliellid ticks as parasites and vectors. *Advances in Parasitology* 24: 135–238.

Hoogstraal, H. and Kohls, G.M. (1962). Bat ticks of the genus *Argas* (Ixododea: Argasidae). 5. Description of larvae from Australian and New Guinea *Carios*-group populations. *Proceedings of the Linnean Society of New South Wales* 82: 275–280.

Hoogstraal, H., Moorhouse, D.E., Wolf, G. and Wassef, H.Y. (1977). Bat ticks of the genus *Argas* (Ixodoidea: Argasidae). *A.* (*Carios*) *macrodermae*, new species, from Queensland, Australia. *Annals of the Entomological Society of America* 70: 861–870.

Horak, I.G., Camicas, J.-L. and 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.

Jones, E.K. and Clifford, C.M. (1972). The systematics of the subfamily Ornithodorinae (Acarina: Argasidae). V. A revised key to larval Argasidae of the western hemisphere and description of seven new species of *Ornithodoros. Annals of the Entomological Society of America* 65: 730–740.

Jordan, K.H.E. (1947). On a new genus and species of bat-fleas from the Pelorus Islands and New Zealand. *Transactions of the Royal Society of New Zealand* 76: 208–210.

Kaiser, M.N. and Hoogstraal, H. (1973). Bat ticks of the genus *Argas* (Ixodoidea: Argasidae). 9. *A.* (*Carios*) *daviesi*, new species, from Western Australia. *Annals of the Entomological Society of America* 66: 423–428.

Kaiser, M.N. and Hoogstraal, H. (1974). Bat ticks of the genus *Argas* (Ixodoidea: Argasidae). 10. *A.* (*Carios*) *dewae*, new species, from southeastern Australia and Tasmania. *Annals of the Entomological Society of America* 67: 231–257.

Klompen, J.S.H. and Oliver, J.H. (1993). Systematic relationships in the soft ticks (Acari: Ixodida: Argasidae). *Systematic Entomology* 18: 313–331.

Kohls, G.M. (1950). Ticks (Ixodoidea) of the Philippines. *National Institutes of Health Bulletin* 192. 28 pp.

Kohls, G.M. and Hoogstraal, H. (1962). Bat ticks of the genus *Argas* (Ixodoidea: Argasidae) 4. *A.* (*Carios*) *australiensis* n. sp. from Australia. *Annals of the Entomological Society of America* 55: 555–559.

Kohls, G.M., Sonenshine, D.E. and Clifford, C. (1965). The systematics of the subfamily Ornithodorinae (Acarina: Argasidae). II. Identification of the larvae of the western hemisphere and descriptions of three new species. *Annals of the Entomological Society of America* 58: 331–336.

Labruna, M.B. and Venzal, J.M. (2009). *Carios fonsecai* sp. nov. (Acari, Argasidae), a bat tick from the central-western region of Brazil. *Acta Parasitologica* 54: 355–363.

Lloyd, B.D. (2001). Advances in New Zealand mammalogy 1990–2000: short-tailed bats. *Journal of the Royal Society of New Zealand* 31: 59–81.

Lloyd, B.D. (2003). Intraspecific phylogeny of the New Zealand short-tailed bat *Mystacina tuberculata* inferred from multiple mitochondrial gene sequences. *Systematic Biology* 52: 460–476.

Lloyd, B.D. (2005). Lesser short-tailed bat. Pp. 110–126. *In*: King, C.M. (*ed.*) *The handbook of New Zealand mammals*. 2nd edn. Melbourne: Oxford University Press. 610 pp.

Mullen, G.R. and O'Connor, B.M. (2009). Mites (Acari). Pp. 433–492. *In*: Mullen, G.R. and Durden, L.A. (*eds*) *Medical and veterinary entomology*. 2nd edn. Amsterdam: Academic Press and Elsevier. 637 pp.

O'Donnell, C.F.J. (2005). New Zealand long-tailed bat. Pp. 98–109. *In*: King, C.M. (*ed.*) *The handbook of New Zealand mammals*. 2nd edn. Melbourne: Oxford University Press. 610 pp.

Ruffell, J. and Parsons, S. (2009). Assessment of the short-term success of a translocation of lesser short-tailed bats *Mystacina tuberculata. Endangered Species Research* 8: 33–39.

Sonenshine, D.E., Clifford, C.M. and Kohls, G.M. (1962). The identification of larvae of the genus *Argas* (Acarina: Argasidae). *Acarologia* 4: 193–214.

Sonenshine, D.E., Clifford, C.M. and Kohls, G.M. (1966). The systematics of the subfamily Ornithodorinae (Acarina: Argasidae). III. Identification of the larvae of the eastern hemisphere. *Annals of the Entomological Society of America* 59: 92–122.

Uchikawa, K. (1988). Myobiidae (Acarina, Trombidiformes) associated with minor families of Chiroptera (Mammalia) and a discussion of phylogeny of chiropteran myobiid genera. *Journal of Parasitology* 74: 159–176.