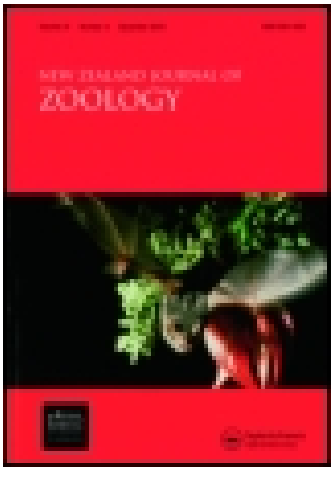

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RESEARCH ARTICLE

On four poorly known harvestmen from New Zealand (Arachnida: Opiliones: Cyphophthalmi: Eupnoi: Dyspnoi: Laniatores)

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Despite the unique and interesting nature of New Zealand's Opiliones fauna, little work on these animals has been published since the studies of Forster, whose last harvestman publication appeared nearly half a century ago. Since then, most groups of New Zealand Opiliones have been neglected. Here we provide field observations and live photographs of four poorly known species, one for each of the four Opiliones suborders. We also redescribe *Rakaia collaris* Roewer, 1942, a species of Cyphophthalmi described on the basis of a single female specimen, and considered a nomen dubium in previous studies. The objective of this study is to highlight the incredible New Zealand opiliofauna and to raise interest in this group of terrestrial arthropods commonly used for biogeographical and evolutionary studies.

Keywords: *Acropsopilio neozealandiae*; Aotearoa; Arthropoda; *Mangatangi parvum*; *Rakaia collaris*; scanning electron microscopy; *Synthetonychia proxima*

Introduction

The harvestman fauna of New Zealand is among the most diverse and interesting of any world region of comparable size, with all species but two synanthropic forms (Gruber & Hunt 1973; Sirvid et al. 2010)—the phalangiid *Phalangium opilio* Linnaeus, 1758 and the sclerosomatid *Nelima doriae* (Canestrini, 1871)—being endemic (Forster 1947, 1954). The New Zealand fauna was, along with that of some European regions, the best studied in the world, thanks to the work of Forster, who published numerous studies including two Cyphophthalmi revisions (Forster 1948a, 1952), an article on the New Zealand Monoscutidae (Forster 1944), and his seminal Laniatores monograph (Forster 1954), with subsequent additions (Forster 1964, 1965). However, after his last Opiliones publication on the cave Laniatores (Forster 1965), no harvestman species was described in New Zealand for the remainder of the twentieth century (Sirvid et al. 2010). In fact, it was 38 years until the next New Zealand species description, in the suborder Cyphophthalmi (Boyer & Giribet 2003). As of today, the New Zealand fauna includes representatives of two synanthropic and five native families, including Pettalidae (Cyphophthalmi); Monoscutidae Neopilionidae (Eupnoi); Acropsopilionidae (Dyspnoi); and Synthetonychidae and Triaenonychidae (Laniatores). With the exception of Synthetonychidae, all native families include members distributed on other Gondwanan landmasses. Synthetonychidae remains a family-level endemic of New Zealand, and the family is of further importance due to its phylogenetic placement—as the sister group to all remaining Laniatores (Sharma & Giribet 2011), the largest of the four Opiliones suborders.

Since Forster's revisionary work on Cyphophthalmi, only a single species has been described

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(Boyer & Giribet 2003). Nonetheless, the suborder has received substantial attention, undergoing major taxonomic revision (Boyer & Giribet 2007), with the addition of the genus *Aoraki* Boyer & Giribet, 2007. Additional evolutionary studies of the New Zealand Cyphophthalmi (Boyer et al. 2007a; Boyer et al. 2007b; Boyer & Giribet 2009; Giribet et al. 2012) have identified further undescribed species of New Zealand Cyphophthalmi, which await taxonomic formalisation.

The New Zealand Eupnoi have also received recent attention from Taylor, who has focused on Neopilionidae, synonymising Monoscutidae and Megalopsalidinae, describing four new species, three new genera, and proposing numerous synonymies during the process of revising the taxonomy of the group (Taylor 2004; Taylor 2008; Taylor 2012, 2013). Several outstanding taxonomic issues remain in this family, especially due to the scarcity of published molecular work in a group with numerous cases of sympatry, extreme sexual dimorphism and male polymorphism.

Dyspnoi is represented in New Zealand by a single species in the family Acropsopilionidae, *Acropsopilio neozealandiae* (Forster, 1948a). Other than a distributional report (McCartney et al. 2007), little has been published on this animal. Originally placed in an uncertain position between Eupnoi and Dyspnoi (Silvestri 1904), *Acropsopilio* Silvestri, 1904 later became the type genus of Acropsopilionidae Roewer, 1923, and was assigned to Dyspnoi by Roewer (1923). Shear (1975) made Acropsopilionidae a subfamily (Acropsopilioninae) of Caddidae Banks, 1893, and since then it has been considered a member of the suborder Eupnoi. However, a recent molecular phylogenetic analysis of Caddidae showed the family to be polyphyletic. The genus *Caddo* Banks, 1892 constitutes the sister group of the remaining Eupnoi, as proposed in recent phylogenetic work on Opiliones (e.g. Martens et al. 1981; Shultz & Regier 2001; Giribet et al. 2010), while the members of Acropsopilioninae are the sister group to the remaining Dyspnoi (Groh & Giribet 2014). We therefore adopt this view here, with Acropsopilionidae recognised as a family of Dyspnoi, as originally proposed by Roewer (1923).

Finally, the largest suborder, Laniatores, and the clade with the largest number of New Zealand species and genera, has received virtually no attention since Forster's last work (Forster 1965), with the exception of an unpublished thesis (Vélez 2011). In addition, virtually nothing has been published on the endemic family Synthetonychidae since its original description by Forster (1954).

It is therefore our aim to make available new field information and live photographs of four poorly known species of New Zealand Opiliones, one for each of the four suborders: *Rakaia collaris* Roewer, 1942 (Cyphophthalmi), *Mangatangi parvum* Taylor, 2013 (Eupnoi), *Acropsopilio neozealandiae* (Forster, 1948b) (Dyspnoi) and *Synthetonychia* cf. *proxima* Forster, 1954 (Laniatores). We hope that this work will shed light on this important but still obscure group of arachnids and contribute to advancing our knowledge of the New Zealand Opiliones. This will hopefully serve to increase awareness for this group of key evolutionary and ecological importance (Giribet & Boyer 2010; Sharma & Giribet 2011).

Methods

Live specimens were photographed in the field with a Canon EOS 5D body, Canon Macro Photo Lens MP-E 65 mm (1 to 5 ×), a Macro Ring Lite MR-14EX, and equipped with a Canon Receiver GP-E2 GPS, to record the exact locality of each specimen.

Rakaia collaris specimens for scanning electron microscopy were cleansed and sonicated in an Ultrasonic cleaner Branson 200 for 1–2 min, examined under a compound microscope, and sonicated again following the same procedure if debris remained on the cuticle. Specimens were then dissected in ethanol under a stereomicroscope, air dried and mounted onto a carbon bi-adhesive tape on an aluminium stub. The samples were coated with platinum–palladium. The coated specimens were then imaged in an FEI Quanta 200 scanning electron microscope under an accelerating voltage of 5 kV.

All reported specimens and associated data, including GPS coordinates, are housed in the Department of Invertebrate Zoology in the Museum of Comparative Zoology (MCZ), Harvard University.

The MCZ prefix IZ refers to specimens housed in the Department of Invertebrate Zoology. Specimens were collected under DOC Permission Record Numbers NMINV 02/9 (2002) and 38002-RES (2014). Additional data and images of the specimens can be found in the MCZ online database MCZbase (http://mczbase.mcz.harvard.edu/).

Suborder Cyphophthalmi

Family Pettalidae

Genus *Rakaia* Hirst, 1925

***Rakaia collaris* Roewer, 1942**. (Figs. 1–3)

This species was described by Roewer (1942) based on a single female specimen reported to have been collected in Akaroa. His original description and illustrations are presented in Fig. 1A. A translation of his original description is provided here:

> Corona analis as in *Purcellia* (Tabl. 20, Fig. 4c); Front end of carapace 'projecting forward[1]', with a protruding cucullus,[2] the frontal edge of which is concave (different from *Rakaia antipodiana* Hirst) (Tabl. 20, Fig. 4a, b). Palpal tarsus shorter than tibia. Fourth coxa as wide as I–III together; Femur of legs I to IV straight. Claws of tarsus I–IV simple, not combed. Tarsus I without scopula. Everything else consistent with *Rakaia antipodiana* Hirst. Length of body 3 mm; Coloration uniform dark brown.

Unfortunately, little information is contained in this description, which refers to a female individual. Females often lack the characters traditionally used to diagnose species of Cyphophthalmi, so Giribet (2000) considered this species a nomen dubium. Boyer & Giribet (2009) included a Cyphophthalmi species from Banks Peninsula in their study. Collected from native forest at the private Hinewai Nature Reserve and Wildlife Sanctuary, Boyer & Giribet (2009) labelled it '*Rakaia* sp. Hinewai', and noted its relationship to other Otago and Canterbury species in the genus. Nine specimens were collected in *Fuscospora fusca* (Hooker f.) Heenan & Smissen leaf litter in Hinewai in February 2003 (MCZ IZ-134574; DNA100958; GPS coordinates: −43.8087° 173.0214°), with six additional male specimens having been collected in January 2014 (MCZ IZ-29209; GPS coordinates: −43.8088° 173.0214°) in the same location. Subsequent collecting in additional localities in Banks Peninsula yielded no additional specimens, and we now consider that the species from Hinewai corresponds to *R. collaris*. We provide the first description of the male. For further details on the anatomy of Cyphophthalmi, see recent cladistics analyses of the suborder and of the family Pettalidae (Giribet & Boyer 2002; de Bivort & Giribet 2010; Giribet et al. 2012).

Male description

Total length 2.09 mm (specimen from Fig. 1C) to 2.30 (specimen from Fig. 1D), greatest width 1.19 mm (Fig. 1D), in the second opisthosomal segment, nearly as wide in the prosoma, behind the ozophores; height 0.69 µm (Fig. 1C); length–width ratio 1.95 (specimen from Fig. 1D). Body reddish-brown (Fig. 1B). Anterior margin of dorsal scutum projecting forward, concave, without conspicuous lateral projections; prosoma roundly triangular. Eyes absent, lenses absent. Ozophores in lateral position (Figs 1B, 1C) with circular opening (Fig. 2B); ornamentation uniform (Fig. 2B). Transverse prosomal sulcus present but inconspicuous. Transverse opisthosomal sulci visible. Mid-dorsal, longitudinal opisthosomal sulcus present but inconspicuous. Coxae IV wide, with lateral margins visible beyond the lateral prosomal margin in the dorsal view. Dorsal scutum flat (Fig. 1C); maximum height at opisthosomal area.

Coxae of legs I, II and III free. Ventral prosomal complex with coxae I not meeting at the midline, instead separated by the palpal endites. Coxae II and IV meeting at the midline, but not coxae III, which are separated by the sternum (Fig. 2A); margin between coxae II and III and margin between coxae III and IV both reaching the midline (Fig. 2A) near each other. Anterior margin of coxae II endites enlarged, curving laterally and posteriorly. Endites of coxae III running along the margin between coxae II and III; coxae IV endites running parallel to coxae IV midline suture for 200 µm long, a distance much longer than the length of the gonostome (Fig. 2A). Coxal endites forming smooth sternal plate with greatest width between coxae I and II. Pores of

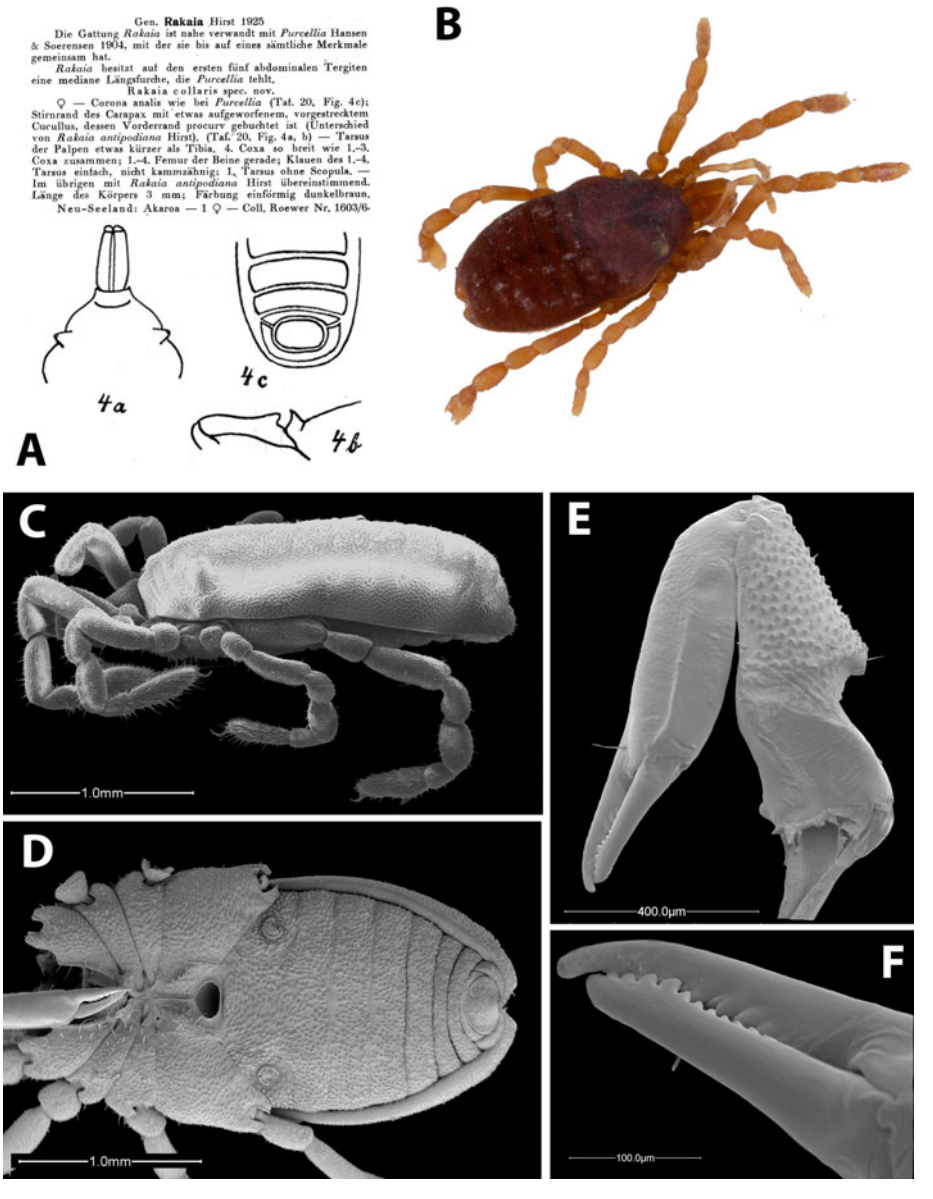

Figure 1 *Rakaia collaris* Roewer, 1942. **A**, Original description and images from Roewer (1942); **B**, live male specimen from Hinewai, photographed 22 January 2014 (MCZ IZ-29209); **C**, lateral view of male from Hinewai (MCZ IZ-134574); **D**, ventral view of male (MCZ IZ-134574); **E–F**, left chelicera, retrolateral view (MCZ IZ-134574).

coxal glands visible at inner margins between coxae III and IV. Sternum present. Coxae IV endites without projections. Gonostome roundly semi-triangular, 174 µm long and 122 µm wide, delimited by coxae IV everywhere except in the posterior margin. Lateral walls formed by very slightly elevated endites of coxae IV (Fig. 2A). Coxae IV with ornamented ridges flanking gonostome and coxae IV endites.

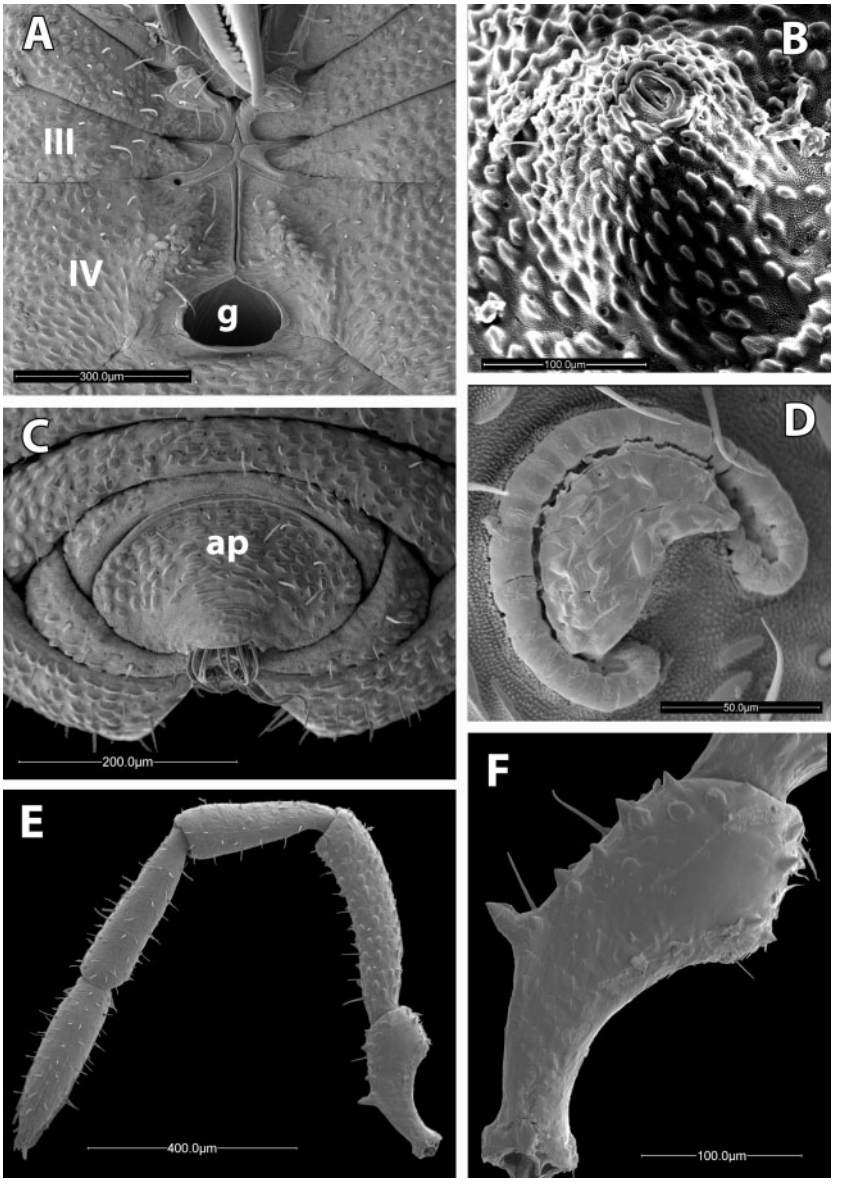

Figure 2 *Rakaia collaris* Roewer, 1942 (male specimen MCZ IZ-134574). **A**, Sternal region (g; gonostome; III: coxa III; IV: coxa IV); **B**, ozophore; **C**, anal region, ventral view (ap: anal plate); **D**, spiracle; **E**, left palp, retrolateral view; **F**, trochanter of left palp.

Spiracles C-shaped, open to the lateral posterior, with maximum diameter of 97 µm (Fig. 2D). Sternal opisthosomal glands absent. Sternite 8 and posterior margin of sternite 7 curved anteriorly through the midline. Sternites 8 and 9 and tergite IX free, not forming a corona analis (Figs 1D, 2C). Tergite IX slightly bilobed, with a single central opening of the anal gland oriented ventrally; tergite VIII largely bilobed, lacking opening of the anal glands. Anal plate measuring

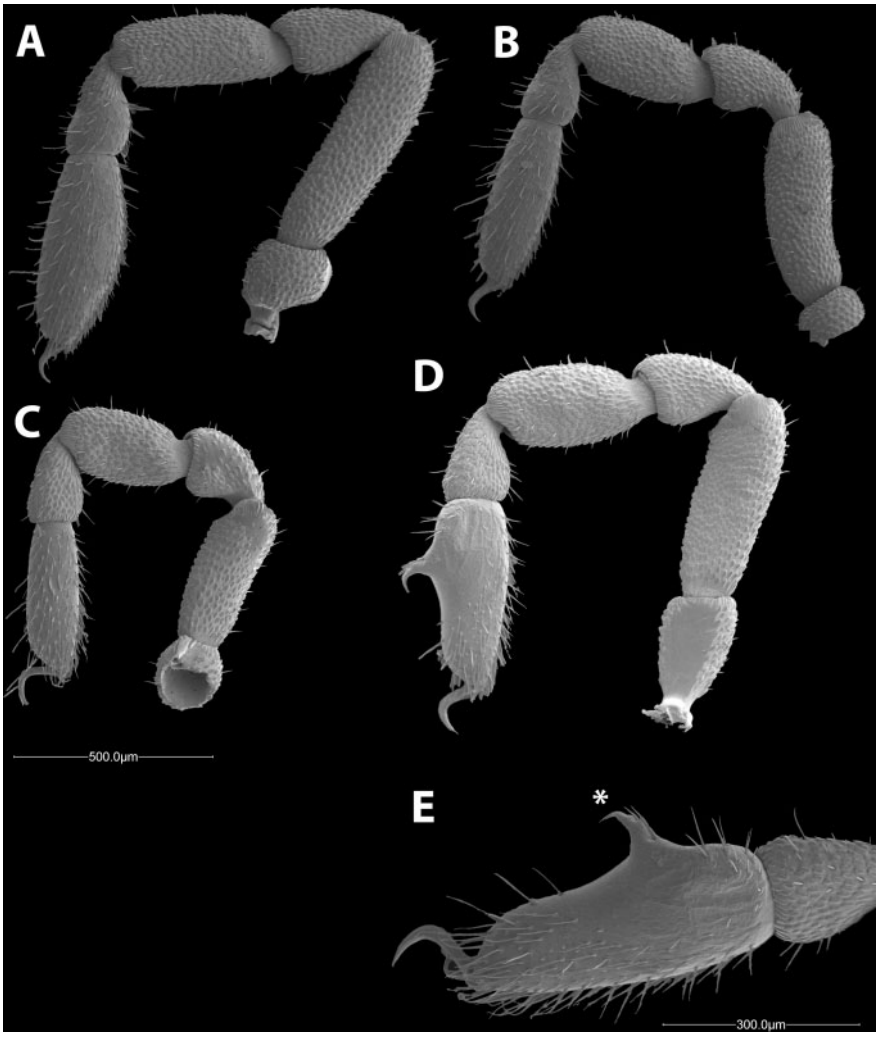

Figure 3 *Rakaia collaris* Roewer, 1942 (retrolateral views of left legs of male MCZ IZ-134574). **A**, Leg I; **B**, leg II; **C**, leg III; **D**, leg IV; **E**, detail of tarsus IV with adenostyle (asterisk).

285 × 158 µm, with a broad scopula originating in the central posterior edge of the anal plate (Fig. 2C). Cuticle with tubercular–microgranulate morphology (Murphree 1988) in all ventral areas including coxae and anal plate, except on coxal and palpal endites, and the margin of ventral surface between the sternites and tergites.

Chelicerae (Fig. 1E) relatively short, robust, with few setae. Proximal article 688 µm long, 300 µm wide, with microgranulation on all surfaces and a dorsal crest. Second article 873 µm long, without conspicuous ornamentation, sub-cylindrical, its widest portion near middle of article but closer to articulation with mobile digit, bearing a longitudinal apodeme on the lateral side. Moveable finger 290 µm long, 70 µm wide (Fig. 1F). Dentition on mobile digit non-uniform, with seven or eight small denticles on the proximal portion of the digit and five larger distal denticles. Fixed digit with multiple bicuspidate uniform denticles.

Palp (Fig. 2E) with club-shaped trochanter, narrowing posteriorly, bearing a conspicuous

ventral process (Fig. 2F). Trochanter and femur ornamented. Dimensions of palpal articles (in μm) from trochanter to tarsus of male are: 266/398/313/341/334; palpal claw 40 μm.

Legs (Fig. 3) with all claws smooth, long and hook-like, without lateral ornamentation (Fig. 3, 3E). Surfaces of all trochanters, femurs, patellae, tibiae and metatarsi of legs III and IV entirely ornamented. Metatarsi of legs I and II ornamented proximally and smooth distally. All tarsi appearing smooth. Tarsus of leg I with a distoventral concentration of setae, but perhaps not forming a distinct solea (Fig. 3A). Tarsus IV undivided (Fig. 3E), carrying a lamelliform adenostyle bearing a pair of posterior setae (Fig. 3E); distal margin at 40% of tarsal length. Leg measurements are provided in Table 1.

Table 1 Leg measurements (in μm).

	Tr	Fe	Pt	Ti	Me	Ta
Leg I	163	605	325	400	239	493
Leg II	?	455	268	317	205	422
Leg III	?	387	219	332	207	380
Leg IV	290	528	273	386	216	481

Fe, femur; Me, metatarsus; Pt, patella; Ta, tarsus; Ti, tibia; Tr, trochanter. Spermatopositor and ovipositor organ not studied.

Suborder Eupnoi

Family Monoscutidae

Genus *Mangatangi* Taylor, 2013

***Mangatangi parvum* Taylor, 2013**. (Figs 4A, 4B)

This species was recently described by Taylor (2013) from museum material collected in 1977 (one male, one female) in the Hunua Ranges, and by a male collected by Forster in Cuvier Island (date not specified). It is a small species never illustrated alive and unrecorded for nearly four decades. During a recent trip to Lake Waikareiti, in Te Urewera National Park, we photographed live specimens and collected material of this species (MCZ IZ-29238; GPS coordinates: −38.7253° 177.1649°). We provide the first photographs of live specimens for this species. All specimens were seen at dusk or during the night, when the members of this family become active.

Suborder Dyspnoi

Family Acropsopilionidae

Genus *Acropsopilio* Silvestri, *1904*

***Acropsopilio neozealandiae* (Forster, 1948b)**. (Figs 4C, 4D)

This minute New Zealand harvestman species has been considered an elusive species until recently, when flight-intercept-pitfall traps were used to collect it (McCartney et al. 2007). We have also collected multiple specimens during a series of field trips to New Zealand using methods for direct examination of sifted leaf litter, expanding upon the known distribution of the species. This includes the following localities:

Woods Mill Track, Kaimai Mamaku Forest Park, North Is. (MCZ IZ-64843; GPS coordinates: −38.0252° 175.9772°).

Mt. Bovis Track via Bullock Creek Rd., Paparoa National Park, South Is. (MCZ IZ-64837; GPS coordinates: −42.1012° 171.4149°).

Klondyke Corner, Arthur's Pass National Park, Bealey, South Is. (MCZ IZ-64842; GPS coordinates: −43.0016° 171.5896°).

Te Urewera National Park, Hawke's Bay, North Is. (MCZ IZ-30457; GPS coordinates: −38.6474° 176.9079°).

East Matukituki Valley, Mount Aspiring National Park, Otago (specimen photographed; no MCZ voucher; GPS coordinates: −44.4873° 168.7871°).

These localities add new distribution points to those recorded by McCartney et al. (2007). We furthermore provide what we believe to be the first live photographs of this elusive species.

Acropsopilio neozealandiae is perhaps not as rare as previously thought, but its broad distribution contrasts with those of virtually all other Opiliones, which are much more restricted (Forster 1947, 1954; Boyer & Giribet 2009). Similar broad distributions across all major islands in New Zealand are found in other soil animals, including the centipedes *Craterostigmus crabilli* Edgecombe & Giribet, 2008 (Edgecombe & Giribet 2008; Giribet et al. 2009) and *Anopsobius neozelanicus* Silvestri, 1909, although in the latter case, this could be a complex of cryptic species, as it has been shown also for the New Zealand *Peripatopsis* (Trewick 1998, 2000).

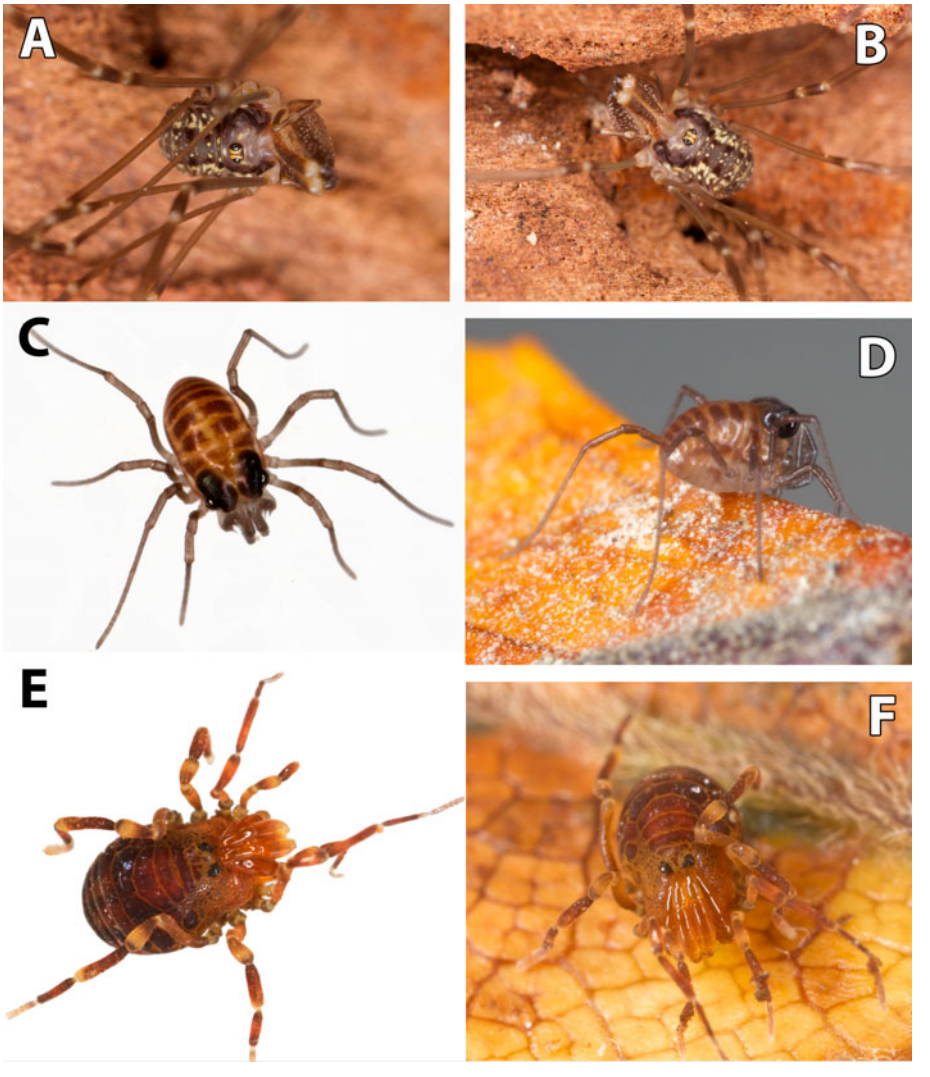

Figure 4 **A, B**, *Mangatangi parvum* Taylor, 2013 (MCZ IZ-29238) from Te Urewera National Park, photographed 12 January 2014. **C, D**, *Acropsopilio neozealandiae* (Forster, 1948) (MCZ IZ- 30457) from Te Urewera National Park, photographed 12 January 2014. **E, F**, *Synthetonychia* cf. *proxima* Forster, 1954 (MCZ IZ-137212) from Westland-Tai Poutini National Park, photographed 19 January 2014.

Suborder Laniatores

Family Synthetonychidae

Genus *Synthetonychia* Forster, 1954

Synthetonychia cf. proxima Forster, 1954. (Figs 4E, 4F)

The monogeneric family Synthetonychidae was erected by Forster (1954) for a group of species endemic to New Zealand. With the exception of a study of the male genitalia (Martens 1986) and recent molecular phylogenetic work (Giribet et al. 2010; Sharma & Giribet 2011) placing Synthetonychidae as the sister group to the remaining Laniatores, no new information has been published on this endemic family of New Zealand Opiliones, and to our knowledge, no images of living specimens had been previously published, and only recently images of the types hosted at Te Papa Tongarewa have

become available online. Despite being of an equivalent phylogenetic importance to that of the tuatara or the coelacanth for understanding the evolution of the largest Opiliones suborder, no new specimens have been reported since the original description of the family, the genus and its 14 species (Forster 1954). We present data and live photographs of a specimen collected by sifting leaf litter samples along the Alex Knob Track, in Franz Josef (MCZ IZ-137212; GPS coordinates: −43.4096° 170.1778°). Although two species have been described based on specimens from Franz Josef, *Synthetonychia glacialis* Forster, 1954 and *Synthetonychia sinuosa* Forster, 1954, our specimen matches the description of *S. proxima*, a species based on type material from Queen Charlotte Sounds. However, this specimen was entirely consumed in an RNA extraction and no voucher, other than the photographs and its transcriptome, remain.

After finding this specimen we spent c. 4 hours sifting litter and moss in the same site without finding additional specimens. In addition, we unsuccessfully sifted leaf litter and moss for synthetonychiids in c. 50 additional localities without a single specimen, confirming the rarity of the members of this Laniatores family. A few additional records for this family are also available in MCZbase.

Final conclusions

Despite hosting one of the most interesting world faunas of Opiliones and the enormous body of work laid down mostly by Forster, the harvestman fauna of New Zealand remains understudied, and was largely neglected for nearly 40 years. Recent taxonomic work on Neopilionidae (Taylor 2004, 2008, 2011, 2013) and evolutionary work on Cyphophthalmi (Boyer et al. 2007a, b; Boyer & Giribet 2007, 2009; Giribet et al. 2012) have shown the interest of this unique New Zealand fauna and should encourage further use of Opiliones as study systems. The potential of Laniatores to become evolutionary models to study evolutionary processes in New Zealand is also high (Giribet & Boyer 2010), but remains largely unexplored with a few exceptions (Vélez 2011), despite the singularity and key evolutionary position of Synthetonychidae (Giribet et al. 2010; Sharma & Giribet 2011) or the interesting but largely unexplored phylogenetic and biogeographical patterns of triaenonychids and acropsopilionids (Giribet & Kury 2007; Mendes & Kury 2008; Groh & Giribet 2014). The 'rare' species highlighted here suggest that advancement of our knowledge of the New Zealand opiliofauna will require careful and long-term fieldwork, as well as detailed and meticulous taxonomic effort.

Acknowledgements

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Notes

1. Roewer used the word *aufgeworfenem*, a German word that would translate into English as 'piled up'
2. Nowadays the 'cucullus' refers exclusively to the specific plate that covers the mouthparts in the arachnid order Ricinulei.

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