THE ADULT AND JUVENILE STAGES OF TWO PREDATORY MITES, *RHAGIDIA GERLACHEI* AND *TUBEROSTOMA LEECHI*, IN THE MARITIME ANTARCTIC

MARION EDWARDS *and* MICHAEL B. USHER*

Department of Biology, University of York, York YO1 5DD, UK

ABSTRACT. Two species of rhagidiid mite are known from the maritime Antarctic. Although the adults of *Rhagidia gerlachei* and *Tuberostoma leechi* can be separated by morphological characters, their juvenile life stages have not previously been described.

Multivariate statistical techniques are used to separate the two taxa of all life stages even when there are no apparent differences in chaetotaxy (e.g. the larvae). Discriminant function equations, based on measurements of three characters, enable larvae, protonymphs and deutonymphs to be assigned to species. All of the juvenile stages of *R. gerlachei* are described, drawing attention to the differences between the corresponding stages of both species. The leg chaetotaxy is described in detail.

Identification of all life stages of these two taxa has enabled a more detailed study of the species' distribution in the maritime Antarctic to be undertaken. *R. gerlachei* has an extensive distribution along the Antarctic Peninsula and its offshore islands, whereas *T. leechi* is restricted to the South Shetland Islands and the north-western fringe of the Antarctic Peninsula.

INTRODUCTION

Only two species of predatory mites in the family Rhagidiidae (Acari, Prostigmata), *Rhagidia gerlachei* (Trouessart) and *Tuberostoma leechi* (Strandtmann), have been described from the maritime Antarctic. *R. gerlachei* was originally described as a subspecies of *Norneria gigas* by Trouessart (1903), but Trägårdh (1907) and all subsequent authors have used the generic name *Rhagidia* Thorell, which has priority over *Norneria* Canestrini. Trägårdh (1907) and Berlese (1917) considered the taxon to be of specific status, although Thor and Willman (1941) reverted to subspecific status, using the name *Rhagidia gigas gerlachei*. Subsequent publications have retained specific status for this taxon. *Tuberostoma leechi* was originally described in the genus *Rhagidia* by Strandtmann (in Womersley and Strandtmann, 1963), but it was transferred to the newly erected genus *Tuberostoma* by Zacharda (1980).

Although the adult stages of both taxa have been described in detail (Womersley and Strandtmann, 1963; Zacharda, 1980), neither the leg chaetotaxy nor the juvenile life-stages have been described. Strandtmann (1970) listed nine characters for separating the adults. Three of his four 'objective' characters relate either to the genital setae or to the leg chaetotaxy, both of which change through ontogeny. Of his five 'subjective' characters, one relates specifically to the males, and the remainder tend to be less distinct or indistinct in the juvenile life-stages. The aims of this study were, therefore, to describe the juvenile stages and to investigate the changes in leg chaetotaxy through ontogeny. Discriminant function analyses have been used as an aid to separating the juvenile stages of the two species.

MATERIAL STUDIED

The majority of the material used in this study was collected by R. G. Booth and M. B. Usher from an extensive geographical range in the maritime Antarctic during

* All correspondence relating to this paper should be addressed to Michael B. Usher.

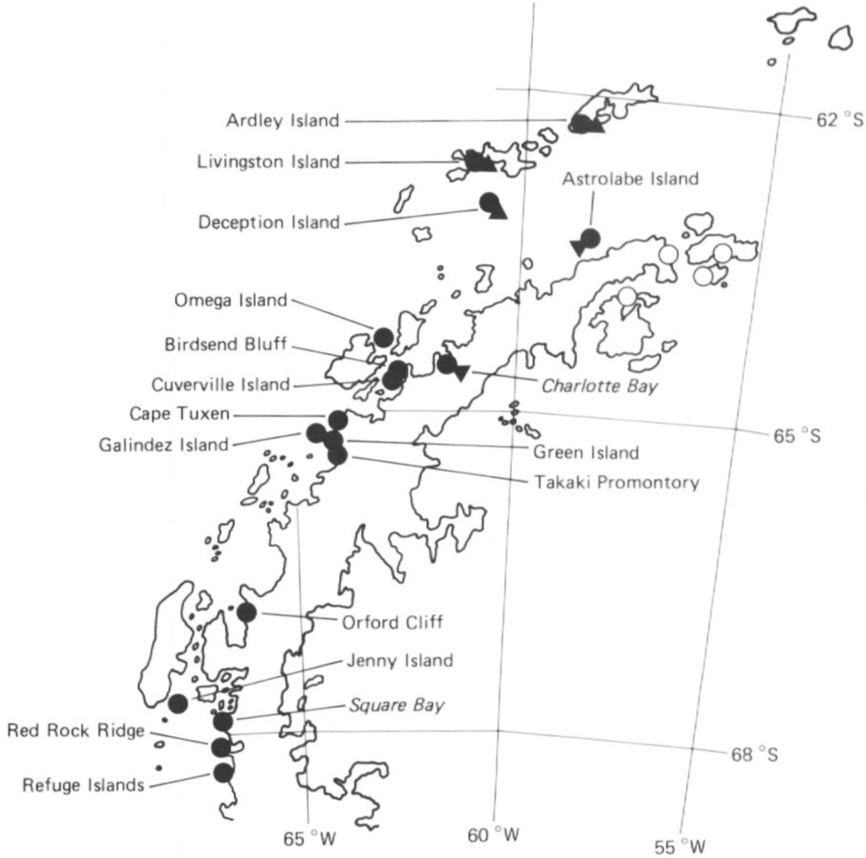

Fig. 1. Sketch map of the Antarctic Peninsula to show the distribution of *Rhagidia gerlachei* and *Tuberostoma leechi*. ●, Individuals of *R. gerlachei* and, ▲, of *T. leechi* which were included in the numerical analyses; ▼, localities where *T. leechi* was recorded but not included in the numerical analysis. ○, Four localities at the north of the Antarctic Peninsula where samples were collected and neither species was found (Joinville, Dundee and James Ross Islands, and Hope Bay).

the 1980–81 and 1981–82 austral summers. The northernmost samples were from Ardley Island (62° 12′ S, 58° 54′ W), and the southernmost from the Refuge Islands (68° 21′ S, 67° 08′ W) (Fig. 1). Neither *Rhagidia* nor *Tuberostoma* is found in the South Orkney Islands, and specimens from South Georgia have not been examined. Owing to the comparatively large size of these mites, many of the individuals were obtained by hand collection, although a few (particularly juveniles) were extracted from samples of vegetation (see Usher and Booth, 1984).

Specimens were preserved in 70% ethanol. Adults and tritonymphs were cleared in 50% lactic acid, and the younger life-stages in 30% lactic acid, prior to being mounted permanently in Heinze PVA mountant (Evans and Till, 1979). Observations were made under phase-contrast microscopy and measurements were made using a calibrated eye-piece graticule.

A larger number of adults has been examined, both by the authors and by R. G. Booth and M. Zacharda. Their studies indicated that there were only two species of rhagidiid mites in the maritime Antarctic. From several thousand mites available, a total of 85 individuals were selected for the numerical analysis. These represented the different life-stages (larva, protonymph, deutonymph, tritonymph, and both male and female adults). Three criteria were used in selecting these individuals. The first was to obtain an even spread of the individuals from the widest possible geographical range. The second was to include approximately equal numbers of each of the life-stages (counting males and females as two stages). The third was to include equal numbers of each taxon. Although the first criterion was approximately fulfilled, the second and third criteria were not fulfilled owing to a shortage of some material (e.g. there were apparently no tritonymphs of *T. leechi* in the samples).

Multivariate Study of Taxa

It was found that the life-stages, except for protonymphs and larvae, could be identified to species by the number of setae on trochanter II, two in *R. gerlachei* and only one in *T. leechi*. This character was used as an independent validation of the numerical separation of species, which was based on a discriminant function analysis (Pitkin, 1980; Usher and Edwards, 1986). The twelve characters that were selected for the discriminant functions are listed in Table I and illustrated in Fig. 2. They were selected because they could be measured easily and reliably in all of the life-stages (except for the outer apical seta of the hypostome which is absent in the larva). The list in Table I contains characters used by Zacharda (1980) for separting the genera, some of the quantitative characters used by Strandtmann (1970) for separating the taxa, but no characters relating to the legs, which are frequently lost or obscured during mounting.

The discriminant function analysis was performed using a GENSTAT program in which the χ^2 value indicates the strength of the discrimination achieved. The initial discriminant function analysis was performed using all 12 characters for the male and female data, both individually and combined. Subsequently, several discriminant function analyses were performed, each with a single character eliminated: the character set with the highest χ^2 value was used for the next series of analyses when a further character could be eliminated. Such a step-wise elimination of characters was continued until seven characters remained (characters *c*, *d*, *hl*, *hw*, *ia*, *oa* and *ai* of Table I), after which there was no further increase in χ^2 when the number of characters in the male data was reduced (though there was a very small increase with the female data). The resulting equation for the combined male and female data was

$$y = 1.72 - 0.02c + 0.07d - 0.14hl + 0.01hw + 0.06ia + 0.16oa + 0.13ai. \qquad (1)$$

Using this equation, the scores (y-values) for the male of *R. gerlachei* ranged from 3.20 to 6.05 and for the females from 1.80 to 5.74. For *T. leechi* the corresponding values for the males were from -3.52 to -5.52 and for the females from -2.65 to -5.68. The sign of the y value can therefore be used to discriminate between the two species.

Using equation (1) it was possible to calculate scores for the deutonymphs, which cannot be sexed (the tritonymphs had to be omitted due to the absence of *T. leechi*). The scores ranged from 1.14 to 4.10 for *R. gerlachei* and from -2.50 to -4.17 for *T. leechi*. These individuals were all known to be correctly classified by the discriminant function in equation (1) since they were checked by the number of setae on trochanter II, a character that was not included in the discriminant function. The equation derived from the adult data could therefore be used to discriminate the deutonymphs correctly.

Using the 7 characters in equation (1), a further discriminant function analysis was

Table I. The 12 characters used in the discriminant function analyses of *Rhagidia gerlachei* (*R*) and *Tuberostoma leechi* (*T*). All characters are measurements of length, in μm, as shown in Fig. 2. Trichobothria are shown in Fig. 5(*a–c*). The ranges give the maximum and minimum values observed for each character. T, D, P and L refer to the tritonymph, deutonymph, protonymph and larva respectively and *n* indicates the number of individuals measured.

	♂		♀		T	D		P		L	
	R	*T*	*R*	*T*	*R*	*R*	*T*	*R*	*T*	*R*	*T*
n	12	8	11	11	10	11	4	6	2	5	5
Chelicera											
Length (*c*)	238–288	258–295	237–313	268–352	168–231	135–156	155–187	103–119	135–144	108–112	107–117
Moveable digit (*d*)	88–131	73–101	97–138	95–114	69–94	57–65	50–60	38–46	43–46	35–38	36–38
Basal seta (*b*)	18–30	27–34	17–34	27–32	15–24	9–15	17–20	10–16	14–18	14–15	12–16
Basal–apical setal insertion points (*ba*)	22–34	19–25	22–39	20–27	15–30	14–20	10–17	13–22	14–15	10–12	10–12
Hypostome											
Length (*hl*)	117–151	151–178	118–164	161–194	90–124	74–89	91–117	55–72	69–76	23–62	61–68
Width (*hw*)	118–144	114–139	114–141	124–161	87–117	69–84	67–82	56–62	62–70	51–54	53–56
Apical setae											
Inner (*ia*)	55–75	40–59	54–74	50–60	35–55	27–37	25–30	21–26	22–26	18–19	16–18
Outer (*oa*)	60–77	40–54	47–78	44–57	37–70	34–44	20–27	21–27	18–22	—	—
Inner insertion point – apex (*ai*)	37–49	37–57	37–57	48–58	25–38	21–34	25–34	18–24	22–23	18–25	20–25
Basal setae											
Inner (*ib*)	50–65	50–62	45–67	60–70	29–47	24–32	25–32	18–22	19–23	15–19	15–18
Outer (*ob*)	72–96	64–77	64–91	75–84	44–70	37–47	35–44	26–31	28–31	23–26	23–26
Trichobothria (*tr*)	80–102	67–82	80–114	69–84	67–84	57–85	40–49	50–61	44	30–31	30–38

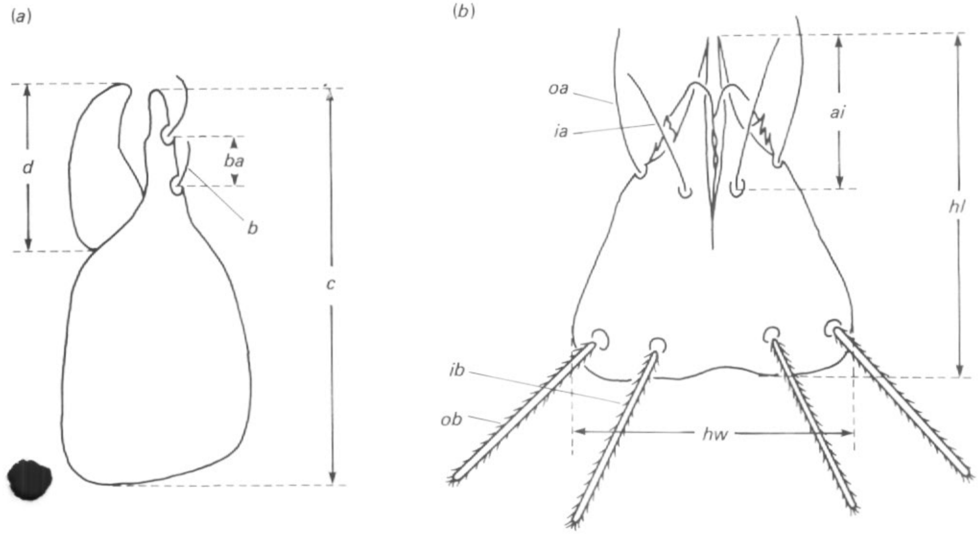

Fig. 2. A diagrammatic representation of the characters used in the formulation of the discriminant function equations, equations (1)–(4) inclusive. The ranges of the lengths for both *Rhagidia gerlachei* and *Tuberostoma leechi* are given in Table I.

performed on the deutonymph data, and this function was then used to separate the protonymphs whose scores formed two distinct clusters. Validation of the correct assignment of protonymphs was possible by counting the number of setae on tibia I. This process of 'mapping' from the discriminant function of one life-stage to the preceding stage was continued from the protonymph data to the larvae. Where the classification of an individual was uncertain after mapping, the individual was omitted from the subsequent discriminant function analysis and its score calculated using the new discriminant function based on data from all of the other individuals in its life stage.

Having thus separated the two species in the deutonymphal, protonymphal and larval stages, a step-wise elimination of characters was continued, reducing the number of characters from seven until there was no further increase in the value of χ^2. This gave the following three discriminant function equations, each based on three characters:

$$y_d = 2.10 - 0.15c + 0.20hw + 0.25oa, \quad (2)$$

$$y_p = 34.12 - 1.63c + 3.20d + 0.50hw, \quad (3)$$

$$y_l = 48.71 - 0.34c - 1.00d + 1.42ia, \quad (4)$$

where the subscripts *d*, *p* and *l* represent deutonymphs, protonymphs and larvae respectively and the character symbols are listed in Table I. Calculation of the scores for the individuals of the three developmental stages showed that two distinct clusters of points were formed (Fig. 3), negative scores being associated with *T. leechi* and positive scores with *R. gerlachei*.

Description of Juvenile Life-stages

The following description applies to both species, except for the tritonymph of *T. leechi*, which has not been seen. Differences between the two taxa relate principally

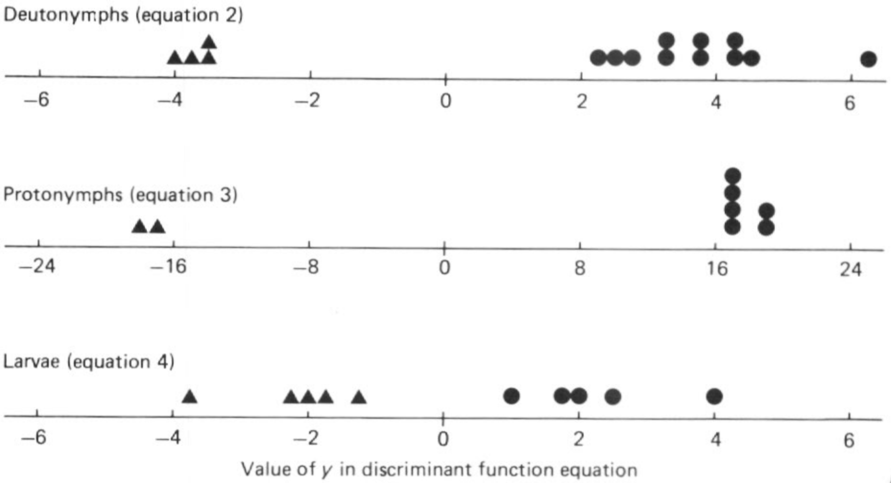

Fig. 3. Values of the discriminant function score, *y*, from equations (2), (3) and (4) for the deutonymphs, protonymphs and larvae respectively. *Rhagidia gerlachei* (●) has positive scores and *Tuberostoma leechi* (▲) has negative scores.

to the leg chaetotaxy and solenidiotaxy, and are indicated where appropriate. The only 'objective' difference recorded by Strandtmann (1970) which could be expected to be constant through all life-stages is the presence of basal clawlets on the tarsal claws of *T. leechi*. However, examination showed that, although this character is constant in the adults, the clawlets are difficult to distinguish in the juvenile life-stages. The character has therefore not been used in the following descriptions or in the discriminant functions. The terminology in the descriptions below follows Zacharda (1980), and size ranges of the characters used in the numerical analysis are given in Table I. The ano-genital regions of the juvenile stages are shown in Fig. 4, and the trichobothria and leg chaetotaxy in Fig. 5.

Idiosoma

Chaetotaxy constant through ontogeny. Prodorsum, epivertex prominent bearing *iv*; *ev* external to *tr*; *sc* strong, almost twice length of *ev*. Opisthosoma with 12 pairs of setae, *ih*, *d1*, *d2* approximately equal; *eh* about twice length of *ih*; *el* and *es* equal to *d2* in larva, *il* and *is* longer than *el* and *es*. Lumbar and sacral setae showi[ng] proportionally greater increase in length through ontogeny. Four pairs lyrifissures, *ly1–ly3* located between *ih*, *d1*, *d2* and *il* respectively; *ly4* lateral and slightly anterior to *al*.

Pedipalps

Structure and solenidiotaxy constant. Chaetotaxy of femur (two setae) and genu (three setae) constant. Tibiotarsus with spiniform solenidion, with 10 setae in tritonymph and deutonymph, with 9 setae in protonymph and larva (one ventral seta absent).

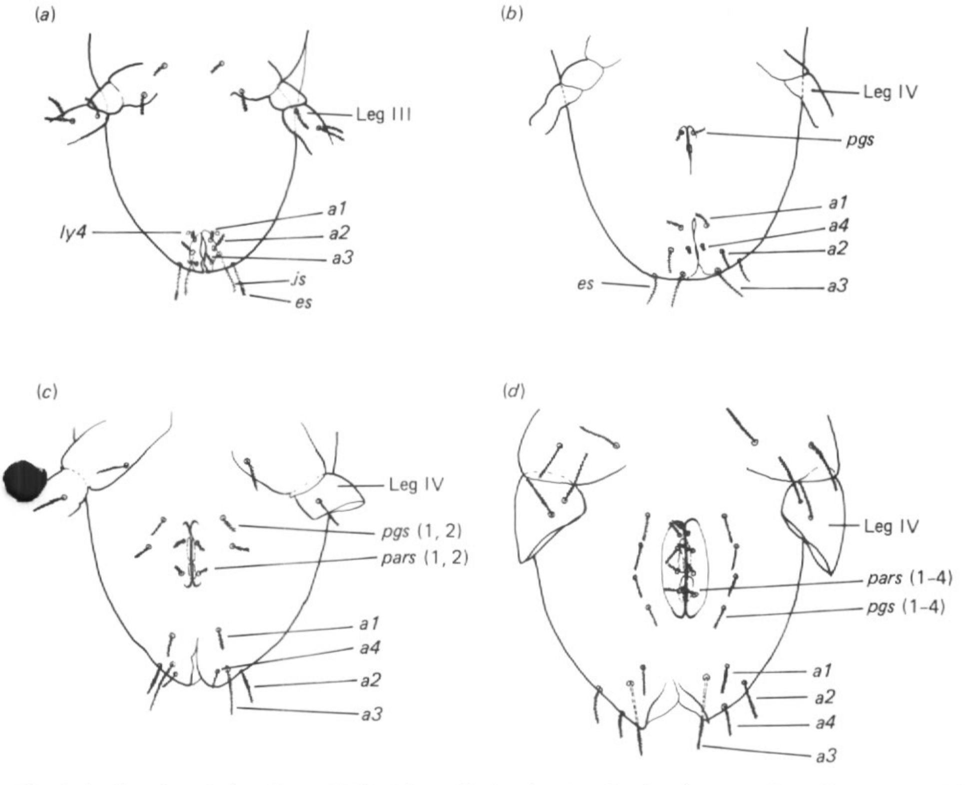

Fig. 4. Anal and genital regions of *Rhagidia gerlachei* showing the development through ontogeny. (*a*) Larva, (*b*) protonymph, (*c*) deutonymph and (*d*) tritonymph. The genital setae have been indicated by *pgs* (progenital setae) and *pars* (paragenital setae). Other nomenclature follows Zacharda (1980).

Solenidiotaxy

Tibiae I and II of *R. gerlachei* with dorso-apical rhagidial seta and dorso-basal spiniform solenidion. Genua I and II with ventro-apical spiniform solenidion. Tibia III with mid-dorsal spiniform solenidion. Genu III with mid-lateral spiniform solenidion. Solenidiotaxy of tarsi varies with developmental stage.

Tibiae I and II of *T. leechi* with dorso-apical rhagidial setae and mid-dorsal spiniform solenidion. Genua I and II with mid-ventral spiniform solenidion. Tibia III with dorso-basal spiniform solenidion. Genu III with mid-lateral spiniform solenidion. Solenidiotaxy of tarsi also varies with age.

Larva

Hexapod, outer apical seta of hypostome absent. *tr* clubbed (Fig. 5*a*). Tarsus I with single rhagidial organ adjacent to stellate seta (Fig. 5*d*); tarsus II with single rhagidial organ with basal spine (Fig. 5*f*).

Anal region (Fig. 4*a*), *a4* absent, *a1* half length of *a3*. Genital field undefined.

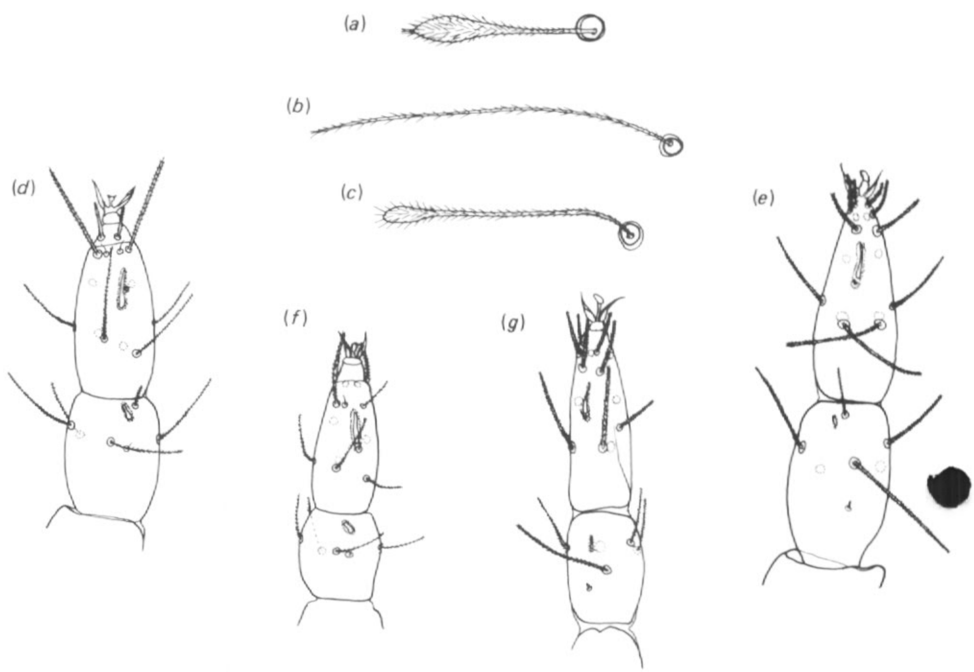

Fig. 5. Trichobothria (*tr*) of (*a*) *Rhagidia gerlachei* larva, (*b*) *R. gerlachei* protonymph and (*c*) *Tuberostoma leechi* protonymph. Tarsus I and tibia I of *R. gerlachei* (*d*) larva and (*e*) protonymph. Tarsus II and tibia II of *R. gerlachei* (*f*) larva and (*g*) protonymph.

Protonymph

Outer apical seta of hypostome present. *T. gerlachei* with *tr* long, finely barbed (Fig. 5*b*) (note that *tr* is now in the adult form, having changed from the juvenile form seen in the larva); *T. leechi* with *tr* slightly clubbed (Fig. 5*c*). Tarsus I of *R. gerlachei* with single rhagidial organ with stellate seta towards base (Fig. 5*e*); *T. leechi* with single rhagidial organ adjacent to stellate seta. Tarsus II single rhagidial organ with basal spine (Fig. 5*g*). Tibia I of *R. gerlachei* with 6 setae; *T. leechi* with 9 setae.

Anal region (Fig. 4*b*), *a3* longer than *es* (and about equal to *is*), *a1* and *a2* about equal, shorter than *a3*; *a4* internal to *a2*, small, inserted close to anal opening. Genital field: progenital lips with one pair of progenital setae, one pair of genital papillae.

Deutonymph

R. gerlachei with *tr* long, finely barbed; *T. leechi* with *tr* very slightly clubbed. Tarsus I with two rhagidial organs in separate fields with stellate seta beside basal rhagidial organ. Tarsus II of *R. gerlachei* with two rhagidial organs in confluent field with basal spine; *T. leechi* with two rhagidial organs in separate fields with basal spine in basal field.

Anal region (Fig. 4*c*), *a3* equal to *is*, *a2* slightly longer than *a1*, *a4* shorter than *a1*. Genital field: progenital lips with two pairs of progenital setae, two pairs of paragenital setae, and two pairs of genital papillae.

Tritonymph

Trichobothria, *tr*, slightly longer than *ev*, fine and tapering. Tarsus I with three rhagidial organs in separate fields, with stellate seta between basal and central rhagidial organs; tarsus II with three rhagidial organs in confluent field and with basal spine.

Anal region (Fig. 4*d*) *a3* almost equal to *is*, *a1* and *a4* subequal, shorter than *a2*. Genital field: four pairs of progenital setae, four pairs of paragenital setae, and two pairs of genital papillae.

Leg Chaetotaxy

The leg chaetotaxy of all life-stages is given in Table II. Setae which have a hollow core to their distal end, and are open proximally, are termed 'eupathidial' (see Booth and others (1985) for a full definition). Anabasis (André, 1981) is shown by some of the setae on tarsi I and II of both taxa. For example, on tarsus I two setae are reduced and flanked by large eupathidial setae (Fig. 5*d*), whereas on tarsus II only one of these setae is reduced and flanked by a eupathidial seta, the second seta of the pair being in its correct (final) location (Fig. 5*f*). Differences in the leg chaetotaxy can be used to separate the two taxa for all life-stages except the larvae. The protonymphs differ in the number of setae on tibia I, the deutonymphs in the number of setae on trochanter II and the tritonymphs by the number of setae on epimera III (as both the deutonymphs and adults of *T. leechi* have 4 setae on epimera III the tritonymph will also have 4 setae, while the tritonymph of *R. gerlachei* has 5 setae).

Comments

The tritonymph of *T. leechi* is probably very similar to that of *R. gerlachei*. The shape of the trichobothrium is likely to be the same as the adult, which is shorter, stouter and less tapering than that of *R. gerlachei*. One abberant deutonymph of *T. leechi*, with nine legs, was observed: the additional leg arose between legs III and IV, neither of which had the usual chaetotaxy.

Discussion

Multivariate statistical analyses have been used previously to elucidate taxonomic problems relating to species groups and complexes. Usher (1980) used a principal co-ordinate analysis to study hesperiid butterflies of the Afrotropical region, and Pitkin (1980) used a canonical analysis to investigate the *Onychiurus armatus* group of Collembola. Booth and others (1985) also used a principal co-ordinate analysis to investigate a genus of Antarctic mites, *Eupodes* and they demonstrated that what had previously been assumed to be a single taxon was in fact a collection of three species, one of which was divided into two subspecies. Discriminant function analysis has been used to study variation within and between species (Waloff, 1966), and it has also been used by Pitkin (1980) and Usher and Edwards (1986) to separate similar taxa of Collembola and Acari respectively.

Previous studies using a discriminant function approach have been based on adult material, although Usher and Edwards (1986) demonstrated that a discriminant function equation derived from data on adult individuals did discriminate the younger life-stages of *Apotriophtydeus*. The step-wise method used above to discriminate juvenile stages is shown to be reliable since deutonymphs, which can be separated by

Table II. Leg chaetotaxy of *Rhagidia gerlachei* (*R*) and *Tuberostoma leechi* (*T*) (rhagidial organs and solenidia excluded). The five figures (on femur, pairs of figures, representing telo- and basi-femur respectively) for each segment refer to the number of setae on that segment for the larva, protonymph, deutonymph, tritonymph and adult respectively.

Segment	*Species*	*Leg I*	*Leg II*	*Leg III*	*Leg IV*
Tarsus	*R*	14–16–19–20–20	12–14–16–16–16	10–10–13–14–14	*–7–13–14–14
	T	14–16–19–?–21	12–14–15–?–16	10–10–12–?–14	*–7–13–?–14
Tibia	*R*	5–6–9–11–11	4–5–6–8–8	4–5–5–7–7	*–1–6–6–6
	T	5–9–13–?–19	4–5–5–?–10	4–5–5–?–9	*–1–6–?–9
Genu	*R*	5–5–8–10–11	5–5–5–8–8	5–5–5–7–7	*–0–5–6–6
	T	5–5–10–?–19	5–5–6–?–12	5–5–5–?–9	*–0–5–?–10
Femur	*R*	5, 1–5, 1–5, 5–5, 5–5, 5	5, 2–5, 2–5, 6–5, 6–5, 6	4, 1–4, 1–4, 4–4, 4–4, 4	*–0–4, 1–4, 3–4, 3
	T	5, 1–5, 1–5, 5–? –9, 7	5, 2–5, 2–5, 6–? –7, 7	4, 1–4, 1–4, 4–?, –6, 4	*–0–4, 1– ?–6, 3
Trochanter	*R*	0–0–1–1–1	0–1–2–2–2	0–1–2–2–2	*–0–1–2–2
	T	0–0–1–1–1	0–1–1–1–1	0–1–2–2–2	*–0–1–2–2
Epimera	*R*	2–3–3–3–3	1–1–1–1–1	2–3–4–5–6	*–0–1–3–3
	T	2–3–3–3–3	1–1–1–1–1	2–3–4–4–4	*–0–1–3–3

* Leg IV absent in larva. ? Missing value for the unknown tritonymph of *T. leechi*.

differences in leg chaetotaxy, are correctly classified when the discriminant function based only on adult data is used, and protonymphs, which can be separated by the setae on tibia I, are also correctly classified by a discriminant function of the deutonymph data. The conclusion that can be drawn is that the larvae, which cannot be separated by conventional means, are correctly classified by the function based on protonymph data. Although the numerical methods used have a strong element of validation, based on the duality of the protonymph and deutonymph discrimination, it would be very desirable to complete the validation by breeding the two species in the laboratory. Unfortunately, techniques for laboratory culture of these species are not yet known.

Investigation of the two taxa shows that they are not, as suggested by Strandtmann (1970), 'sympatric over their entire range'. Fig. 1 shows that both taxa occur in the South Shetland Islands and in the region of the Antarctic Peninsula between Astrolabe Island (63° 17′ S, 58° 42′ W) and Charlotte Bay (64° 32′ S, 61° 37′ W). *T. leechi* does not appear to occur south of 65° S, though *R. gerlachei* continues at least as far south as the Refuge Islands (68° 21′ S, 67° 08′ W), the southernmost locality for which collections were available. The unexpected feature of the distribution is that neither taxon appears to extend along the Antarctic Peninsula north of Astrolabe Island, although extensive collections were made, both by hand and of vegetation, at the four northern Peninsula localities indicated on Fig. 1. Both species have, however, been reported further north on South Georgia. Unlike the species of *Eupodes* and Tydeidae (particularly *Pretriophtydeus* and *Apotriophtydeus*) present in the maritime Antarctic, there does not appear to be any evidence of habitat specialisation by either *R. gerlachei* or *T. leechi*.

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