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## Comments on the identity of *Neoseiulus californicus* sensu lato (Acari: Phytoseiidae) with a redescription of this species from southern China

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### Abstract

The identity of *Neoseiulus californicus* sensu lato is reviewed and its polymorphic nature in published descriptions is discussed. Some mistakes in previous redescrptions of this species are clarified by studying the voucher specimens. A new strain of this species was discovered from *Eriobotrya japonica* in Dinghushan National Nature Reserve, Zhaoqing, Guangdong Province, southern China, and both adult male and female of this population are redescrbed. Previous records of *N. californicus* and *N. fallacis* in China are reviewed. Preanal glands are described for the first time for a phytoseiid species. World distribution records for *N. californicus* sensu lato are reviewed, with extension of its range to southern China and Australia/Oceania.

**Key words:** Phytoseiidae, *Neoseiulus*, *Eriobotrya japonica*, Guangdong Province, China

### Introduction

The Phytoseiidae is the most important family of predatory mites, with over 2,300 known species placed in over 90 genera (Moraes *et al.* 2004, Chant & McMurtry 2007, Beaulieu *et al.* 2011). Many species of this family have been shown to be effective biocontrol agents of phytophagous mites and small insects on crops, and several commercially available species are widely used for the control of plant-feeding mites, thrips and whiteflies on greenhouse crops (McMurtry & Croft 1997, Gerson *et al.* 2003, Zhang 2003). In China, over 300 species of the Phytoseiidae have been described or recorded (Wu *et al.* 2009, 2010).

During a recent survey of phytoseiids for potential use in biocontrol, one species of the genus *Neoseiulus* closely related to *Neoseiulus californicus* (McGregor, 1954) sensu lato was discovered in Guangdong, southern China. In this article, we discuss the identity of *N. californicus* sensu lato, clarify some mistakes in previous descriptions of this species and provide a redescription based material from China in comparison with specimens from all over the world. The preanal glands are described for the first time for a phytoseiid species. We also briefly review the Chinese records of *N. californicus* and also closely related species *Neoseiulus fallacis*.

## Material and methods

Specimens were first rinsed with 100% alcohol to remove any associated dust and debris. Individual specimen was then mounted in Hoyer's medium on glass slides (Krantz & Walter 2009).

SEM images were taken using a NOVA NanoSEM 430; light microscopic images were taken using a Nikon i90 microscope with a Nikon SS-Fi1 camera.

Terms and notations for idiosomal chaetotaxy, adenotaxy and mating apparatus follow Ragusa (2000), Beard (2001) and Chant & McMurtry (2007). Specimens were measured in micrometers.

Abbreviations for collections: CDFA—California Department of Food and Agriculture, Sacramento, California, USA; ESALQ-USP (Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, São Paulo, Brazil; INRA—Institut National de la Recherche Agronomique, Montpellier, France; IPPCAAS—Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing, China; IZCAS—Institute of Zoology, Chinese Academy of Sciences, Beijing, China; KAREC—Kearney Agricultural Research & Extension Center, University of California, Parlier, California, USA; MHNG—Muséum d'histoire naturelle de la Ville de Genève, Geneva, Switzerland; LAEZIU—Laboratory of Applied Entomology & Zoology, Faculty of Agriculture, Ibaraki University, Ami, Ibaraki, Japan.

## Results

### Taxonomic position and identity of *Neoseiulus californicus* (McGregor, 1954)

Taxonomic position: *Cydnodromus* or *Neoseiulus*?

The genus *Neoseiulus* is one of the most species-rich genera of the Phytoseiidae in the world (Chant and McMurtry 2007). The taxonomic history of this genus is complicated (see Tsolakis *et al.* 2012). In the last comprehensive revision of Neoseiulini, Chant and McMurtry (2003) adopted a broad sense *Neoseiulus* and divided it into 10 species-groups, with the *cucumeris* species-group being the largest. *N. californicus* belongs to the *cucumeris* species-group, *cucumeris* subgroup, which is the largest subgroup with over 100 species (Chant and McMurtry 2003). Within that subgroup, *N. californicus* belongs to a small cohort corresponding to the species that Athias-Henriot (1977) had referred to as *Cydnodromus*. In her re-definition of *Cydnodromus*, she placed in it: *N. baticola* (Athias-Henriot, 1977), *N. byssus* (Denmark & Knisley, in Knisley & Denmark, 1978), *N. californicus* (McGregor, 1954) *sensu* Athias-Henriot, 1977, *N. fallacis* (Garman, 1948), *N. fallacoides* (Tuttle & Muma, 1973) and *N. lamticus* (Athias-Henriot, 1977). She considered *N. chilensis* (Dosse, 1958) a synonym of her *N. californicus*. Ragusa (2000) described a new species—*Cydnodromus picanus*—and also suggested that *N. wearnei* should be placed in *Cydnodromus sensu* Athias-Henriot (1977). However, *C. picanus* was recently shown to be a junior synonym of *N. idaeus* Denmark & Muma, 1973—based on morphological, molecular and biological data—by Tixier *et al.* (2011). Tixier *et al.* (2008) showed that *N. marinus* (Willman, 1952) and *N. ornatus* (Athias-Henriot, 1957)—two species previously suspected by some authors to be synonyms of *N. californicus* and *N. chilensis*, respectively—are valid species that can be reliably separated from *N. californicus sensu* Athias-Henriot, 1977.

*Cydnodromus* has been considered a synonym of *Neoseiulus* by most recent researchers (Beard 2001, Chant and McMurtry 2003, 2007, Moraes *et al.* 2004, Tixier *et al.* 2008, Wu *et al.* 2010, Denmark & Evans 2011), although it is still used as a valid genus in some publications (e.g. Ragusa 2000, Tsolakis *et al.* 2012). Here we follow the view of most phytoseiid specialists in accepting *Neoseiulus* in the broad sense according to Chant and McMurtry (2003, 2007).

#### The identity of *Neoseiulus californicus*

McGregor (1954) described *N. californicus* on the basis of a male collected from a lemon fruit in Whittier, California. In the same paper, he also described *N. mungeri* from two females collected from lemon in Whittier, California. McGregor (1954) showed that *N. californicus* females (Plate 22) have “an inconspicuous tooth” on the movable cheliceral digit, and three teeth (two subapical) on the fixed cheelical digit; the ventrianal shield is broadly convex laterally—not clearly wasited as in subsequent descriptions of this species (e.g. Schuster & Pritchard 1963; Athias-Henriot 1977; Tixer et al. 2008).

Chant (1959) examined the type specimens of both species and also that of *N. marinus* (Willmann, 1952); he synonymized *N. mungeri* with *N. californicus*, and also *N. californicus* with *N. marinus*.

Schuster & Pritchard (1963) disagreed with Chant (1959) regarding the synonymy of *N. californicus* and *N. marinus* and re-described his “*californicus*” based on male and female specimens that he had collected in Riverside and San Diego, California, having one tooth on the movable cheliceral digit and two subapical teeth on the fixed digit. They did not mention any study of the type specimens of McGregor (1954), nor made any attempts to compare his “*californicus*” with the original descriptions of *N. californicus*. In addition to difference in the shape of ventrianal shield in the female, Schuster & Pritchard (1963)’s description differs from that of McGregor (1954) in several other aspects: (1) setae Pa level with anterial margin of anus versus more posteriorly positioned Ps setae in the original description; (2) preanal pores more closer together than in the original description; (3) gd<sub>1</sub> posteromedial of, rather than posterolaterad of, the bases of setae j<sub>3</sub>.

Athias-Henriot (1977) described her “*N. californicus*” with 3 teeth on the movable digit and suggested the synonymy between *N. chilensis* (Dosse, 1958) and her “*N. californicus*”, without examination of the type specimens of either species. There were no attempts by Athias-Henriot (1977) to recognize the differences in tooth dentation, although this is an important character for species diagnosis fully recognized and used in separating other species in both papers (Schuster & Pritchard 1963; Athias-Henriot 1977). In addition to differences in the dentation of the chelicera, the “*N. californinus*” sensu Athias-Henriot (1977) differ in adenotaxy, relative lengths of dorsal setae and shape of ventrianal shield from that described by McGregor (1954).

McMurtry & Badii (1989) performed cross-breeding experiments between “*N. californicus*” sensu Athias-Henriot (1977) collected in California and *N. chilensis* collected from Peru and Chile, and showed that they can exchange genetic material and produce viable offspring. Voucher specimens (from Chile and Peru) of McMurtry & Badii (1989) were examined in this study (see below).

Ragusa and Varga (2002) followed the concept of *N. californicus* sensu Athias-Henriot (1977) but noted the differences among descriptions by McGregor (1954), Schuster & Pritchard (1963), and Athias-Henriot (1977).

Guanilo *et al.* (2008a) redescribed *N. californicus* from Peru. They stated that the “females collected in this study are similar to those described by El-Banhawy (1979) and Schuster & Pritchard (1963), but differ in that the movable cheliceral digit has “2 teeth instead of 1 tooth”. They also stated that the fixed cheliceral digit has “2 teeth” and the chaetotaxy for genu III is “1, 2/0-2/0, 1”. A study of a voucher specimen of Guanilo *et al.* (2008a) from Tacna revealed that (1) the movable cheliceral digit has 3 teeth, (2) fixed cheliceral digit has 5 teeth and (3) the chaetotaxy for genu III is 1-2/1, 2/0-1. These agree with *N. californicus* sensu Athias-Henriot (1977) as redescribed in this paper.

Guanilo *et al.* (2008b) redescribed *N. californicus* from Argentina. They stated the “movable cheliceral digit 25 long, with 1 tooth; fixed cheliceral digit 26 long, with 3 teeth”. A study of a voucher specimen of Guanilo *et al.* (2008b) from San Miguel de Tucumán revealed that the movable

cheliceral digit has 3 teeth and fixed cheliceral digit has 5 teeth, in agreement with those of *N. californicus* sensu Athias-Henriot (1977).

Tixier *et al.* (2008) followed the concept of *N. californicus* sensu Athias-Henriot (1977) and removed *N. marinus* from synonymy with “*N. californicus*” sensu Athias-Henriot (1977); they re-examined a paratype of *N. marinus* and confirmed the absence of teeth on the movable digit.

Our study of voucher specimens of *N. californicus* sensu Athias-Henriot (1977), including female specimens from Chile studied by Athias-Henriot (1977), and those from France and Spain studied by Tixier *et al.* (2008), showed that (1) setae  $J_5$  are basally serrate (Fig. 3) as redescribed here in this paper, (2) the atrium of spermathecal apparatus is conical as correctly described by Athias-Henriot (1977), but not oblong as described and illustrated by Tixier *et al.* (2008); (3) there are 16 pairs of lyrifissures, correctly illustrated by Athias-Henriot (1977) but incorrectly by Tixier *et al.* (2008: “six pairs of poroids visible”); and (4) the distribution of muscle marks on the dorsal shield was correctly illustrated by Athias-Henriot (1977) but incorrectly by Tixier *et al.* (2008). These results highlight the importance of accurate descriptions and voucher specimens.

Kade *et al.* (2011) redescribed *N. californicus* from Senegal, stating “fixed and movable cheliceral digits with 3 and 2 teeth, respectively”. The specimens are not available for this study.

We should add that Tixier *et al.* (2008) and previous authors (except Chant, 1959) were not able to find the type material of *N. californicus*. Ragusa and Varga (2002) noted that the type material of *N. californicus* were preserved in the Los Angeles County Museum of Natural History (based on personal communication with D.A. Chant in 2002). We also searched again for the type material of this species without success. In the absence of the type specimens of McGregor (1954), the identity of *N. californicus* can only be inferred from the original descriptions, but not those of Schuster & Pritchard (1963) nor Athias-Henriot (1977); but unfortunately, most researchers in the last three decades have ignored the original descriptions by McGregor (1954). The real identity of *N. californicus* can best be resolved by collecting new specimens from the type locality (Whittier, California). Tixier *et al.* (2008, 2013) mistakenly claimed Riverside as its type locality.

Our search for the type specimens of *N. chilensis* failed. Dosse (1958) deposited the type material in his Institut für Pflanzenschutz in Hohenheim. His successor, Dr Claus Zebitz, the current professor of Applied Entomology at the University of Hohenheim confirmed that Dosse's type specimens are no longer preserved there.

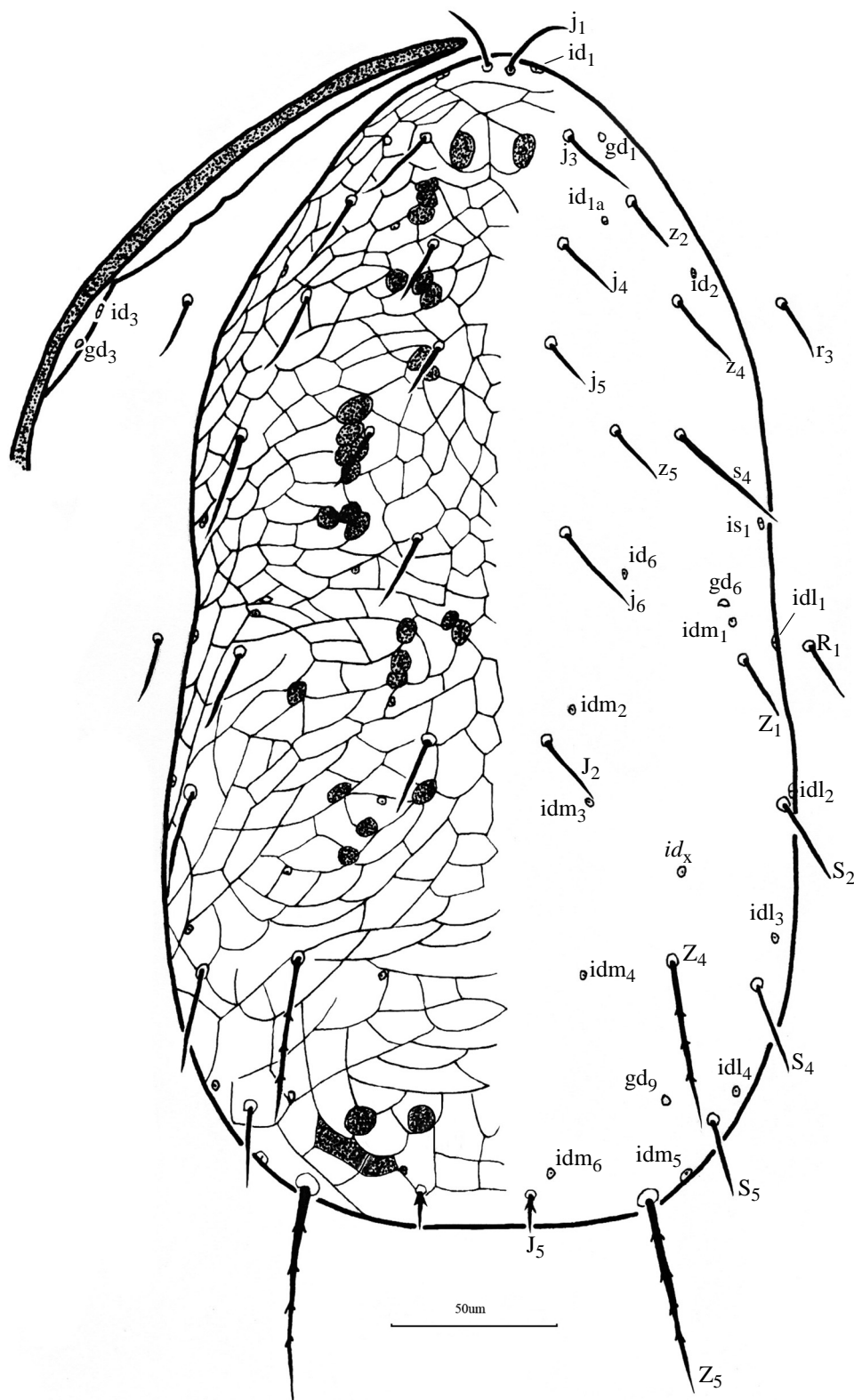
*Neoseiulus californicus* sensu lato as currently known is polymorphic. The following redescription agrees with the concept of Athias-Henriot (1977) as accepted by most authors.

### Redescription of *Neoseiulus californicus* (Figs 1–12)

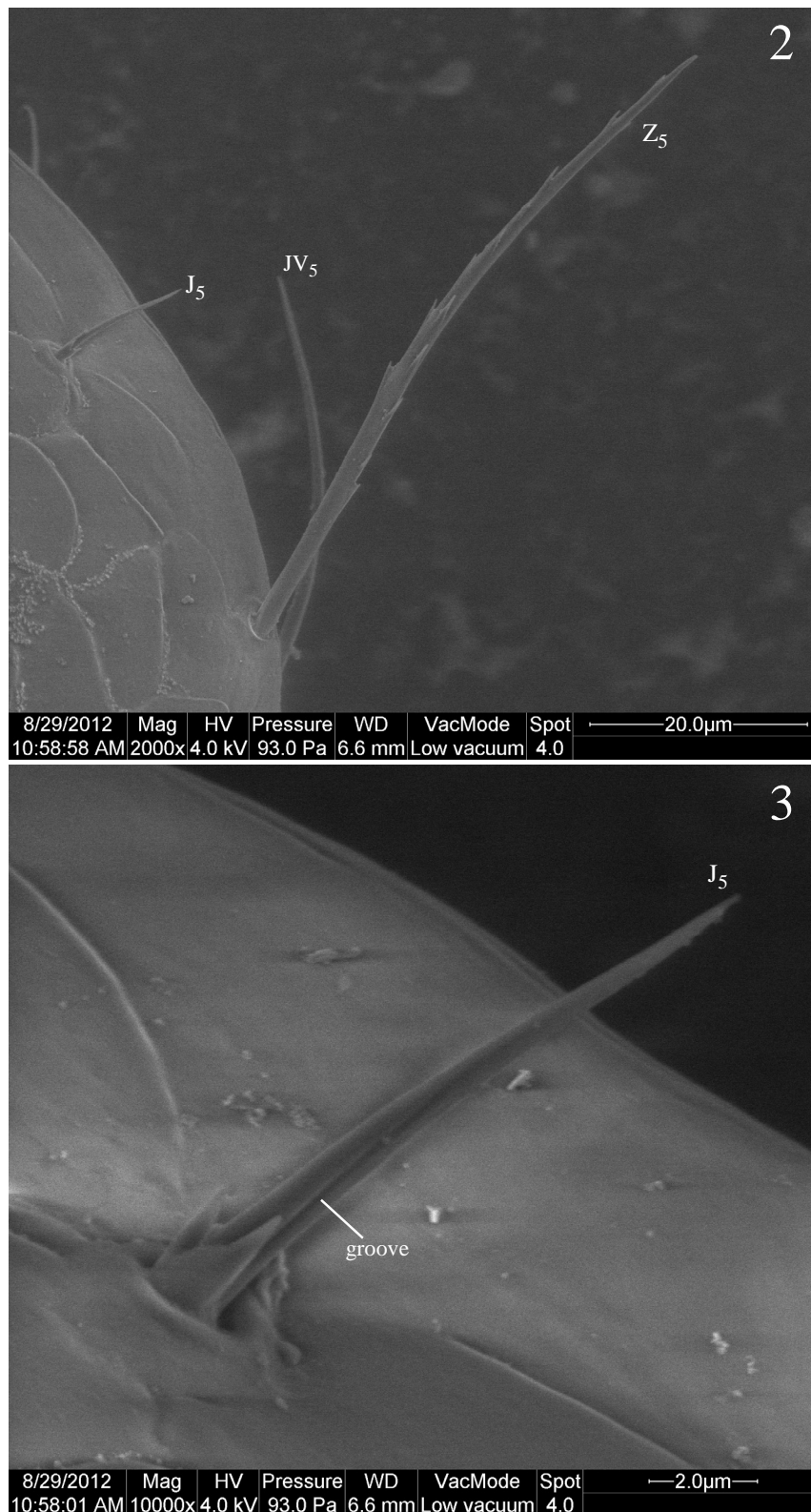
Adult female (Figs 1–7, n=30).

**Dorsum:** Dorsal shield peanut-shaped, with a slight waist at level immediately anterior to  $Z_1$ ; 376 (363–388) long and 156 (150–163) wide at level of  $s_4$ ; reticulate throughout, moderately sclerotized, with numerous muscle marks as shown in Fig. 1.

All dorsal setae smooth except serrated  $Z_4$ ,  $Z_5$  (Figs. 1, 2) and  $J_5$ , the latter which is strongly serrated only near the base and with a groove along 0.6x its length from the base (Fig. 3). Dorsal setae shorter than distance to respective following setae of each longitudinal series; measurements of dorsal setae:  $j_1$ : 23 (20–25),  $j_3$ : 31 (25–35),  $j_4$ : 23 (19–25),  $j_5$ : 22 (18–25),  $j_6$ : 27 (24–32),  $J_2$ : 33 (29–38),  $J_5$ : 12 (11–13),  $z_2$ : 28 (25–32),  $z_4$ : 29 (25–33),  $z_5$ : 22 (19–24),  $Z_1$ : 32 (29–35),  $Z_4$ : 52 (50–56),  $Z_5$ : 70 (63–78),  $s_4$ : 37 (33–43),  $S_2$ : 40 (35–45),  $S_4$ : 39 (35–43),  $S_5$ : 33 (30–38),  $r_3$ : 24 (22–27),  $R_1$ : 23 (20–25).



**FIGURE 1.** *Neoseiulus californicus*. Dorsal idiosoma showing the plate and peritreme.



**FIGURES 2–3.** *Neoseiulus californicus* (female). 2, seta Z<sub>5</sub> with JV<sub>5</sub> and J<sub>5</sub>; 3, seta J<sub>5</sub> enlarged, showing strong serration near the base and also a groove from the base (SEMs).

Dorsal shield bearing 19 pairs of pore-like structures, including three pairs of gland openings ( $gd_1$ ,  $gd_6$  and  $gd_9$ ) and 16 pairs of lyrifissures (Fig. 1):  $gd_1$  closer to  $j_3$  than to  $z_2$ , anterolaterad of a line connecting bases of  $j_3$  and  $z_2$ ; most lyrifissures eye-shaped or spindle-shaped, but  $id_6$ ,  $idm_1$ ,  $idm_2$ ,  $idm_3$ ,  $idm_4$ , and  $idm_6$  more rounded.

Peritremes extending to level of seta  $j_1$ , with  $id_3$  and  $gd_3$  lateral to seta  $r_3$  (Fig. 1).

**Venter:** Sternal shield subequal in length and width, reticulated, posterior margin distinct, straight to slightly curved, bearing three pairs of simple setae [ $St_{1-3}$  subequal in length: 29 (26–32)] and two pairs of lyrifissures (Fig. 4).  $St_4$  (29 (28–30) long) and a lyrifissure on each meta-sternal shield. Genital shield (123 long, 72 wide) relatively narrow, posteriorly truncate, bearing one pair of simple setae [ $st_5$  27 (25–30) long], which are short and not reaching posterior margin of genital shield (Fig. 4). A linear sigillum present immediately posterior to genital shield, about as long as posterior width of genital shield; a pair of small sigilla located postero-lateral to genital sigillum (Fig. 4). Ventrianal shield pentagonal, 122 (110–131) long, 105 (97–113) wide at level of setae  $ZV_2$ , well reticulated, with 3 pairs of preanal setae; a pair of crescent-shaped preanal pores ( $gv_3$ ), 24 apart; primary metapodal shield 30 (27–32), secondary metapodal shield 12 (10–15). Five pairs of lyrifissures in surrounding soft cuticle.  $JV_5$  [52 (48–55) long] about three times as long as  $ZV_1$ ,  $ZV_2$  and  $JV_4$ .

**Spermathecal apparatus:** Calyx relatively thin-walled, cup-shaped to bell-shaped, arms diverging slightly distally (Fig. 5). Atrium small, partly incorporated into base of calyx, maximum diameter about as thick as arms of calyx, tapering towards connection with major duct which is narrow, parallel-sided, and about as long as calyx.

**Gnathosoma:** Movable cheliceral digit tridentate, all denticles recurved; fixed digit pentadentate, 3 anterior to pilus dentilis and 2 basal to it, with the basal-most one being much smaller than others (Fig. 7).

**Legs:** No macrosetae on legs I, II and III; basitarsus IV with one macroseta 51 (48–55) long, with blunt tip (Fig. 6). Chaetotaxy of genu II 2-2/0, 2/0-1; genu III 1-2/1, 2/0-1.

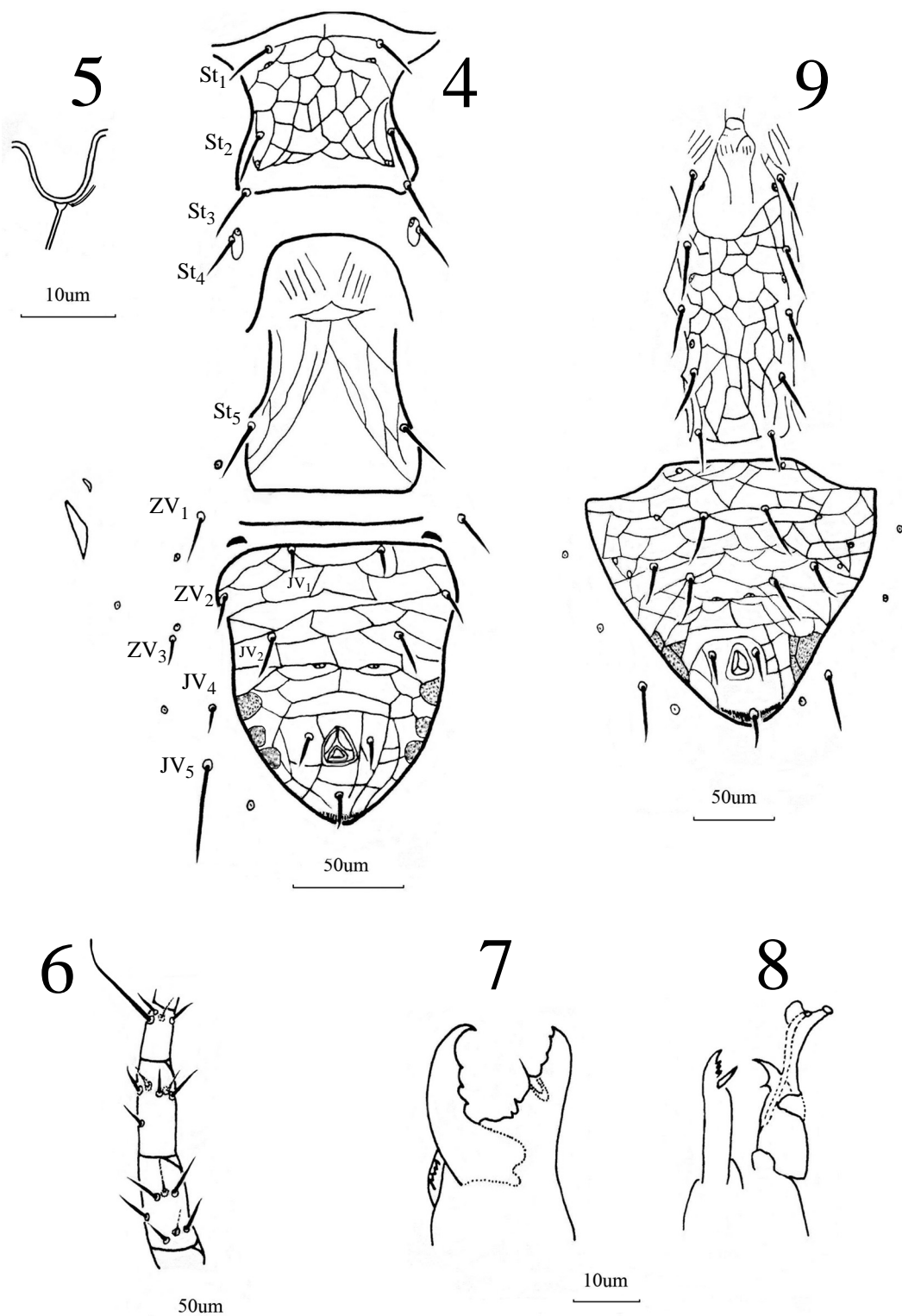
Adult male (Figs 8–9,  $n=20$ )

**Dorsum:** Dorsal shield 281 (275–290) long and 154 (148–162) wide at the level of  $r_3$ , similar to the female in chaetotaxy, adenotaxy, solenotaxy, and ornamentation, except the presence of  $gd_4$ , which is crescent-shaped and postero-lateral to  $s_4$ . Podonotal and opisthonotal shield with reticulation. All setae simple and relatively short except serrated  $Z_4$  and  $Z_5$ ; measurements of setae:  $j_1$ : 18 (17–20),  $j_3$ : 24 (23–28),  $j_4$ : 17 (16–20),  $j_5$ : 17 (16–19),  $j_6$ : 22 (18–25),  $J_2$ : 25 (23–28),  $J_5$ : 10 (8–10),  $z_2$ : 21 (20–25),  $z_4$ : 22 (20–25),  $z_5$ : 18 (17–20),  $Z_1$ : 25 (22.5–28),  $Z_4$ : 46 (43–50),  $Z_5$ : 52 (48–55),  $s_4$ : 28 (25–33),  $S_2$ : 32 (29–35),  $S_4$ : 32 (28–38),  $S_5$ : 27 (23–32),  $r_3$ : 21 (19–23),  $R_1$ : 19 (16–20).

**Venter:** Sternigenital shield reticulated, bearing five pairs of setae.  $St_1$ : 22 (20–24),  $St_2$ : 21 (19–23);  $St_3$ : 20 (19–23);  $St_4$ : 20 (19–21);  $St_5$ : 19 (18–22); three pairs of lyrifissures also present. Ventrianal shield reticulated, subtriangular in shape (Fig. 9), 110 (103–120) long and 160 (145–174) at the widest level, with three pairs of preanal setae and four pairs of lyrifissures; a pair of preanal pores crescent-shaped; anterior margin a little protruding; posterolateral patch of muscle marks level with anal opening. Three pairs of lyrifissures in surrounding soft cuticle.

**Gnathosoma:** Movable chelicerae digit unidentate, fixed digit tridentate (Fig. 8). Spermatodactyl relatively short, shaft more or less linear, foot at about right angle to shaft with rounded toe and slightly tapered heel (Fig. 8).





**FIGURES 4–9.** *Neoseiulus californicus*. 4, ventral view in part (female); 5, Spermathecal apparatus (female); 6, Leg IV (basitarsus-genu, female); 7, chelicera (female); 8, chelicera (male); 9 ventral view in part (male).

#### Material examined

55 females and 35 males, Dinghushan, Zhaoqing City, Guangdong Province, China. Nov. 15, 2010, *Eriobotrya japonica*. Most specimens are deposited in IPPCAAS; ten voucher specimens are deposited in IZCAS.

#### Comparative non-Chinese specimens of *Neoseiulus californicus* examined in this study

**CIHLE:** Curicó, Teno, 5 females (slide R-83-8-3 in CDFA), III-9-83, ex Apple URC Insectary VI-8-83 (voucher sp. IX-14-83 from Jack & Hall); Olme, Valparasio, 1 female (slide coll. Athias E868 in MHNG), 13.IV.1961, grape, on *Brevipalpus*, N. Hitchens collector.

**PERU:** Urubamba, 4 females (slide R83-7-1 in CDFA), II-22-83, Ex: Avocado, URC Insectary VI-8-83 (Voucher sp m, IX-14-83 from Jack & Hall); 1 female, Tacna: Tacna—Pocollay (17°59'27"S, 70°13'06"W), 12-VII-2006, on *Datura stramonium*, collector A. Guanilo.

**ARGENTINA:** 1 female, San Miguel de Tucumán—Vipos (26°28'34.2"S, 65°18'42.3"W), 15-V-2007, on *Solanummelongena*.

**USA:** California, Napa, Carneros, 1 female (slide in KAREC), 5-3-07, ex Grape, L. Varela; collector California, Kern, 1 female (slide in KAREC), 7-10-07, ex soy bean in greenhouse, Y. Ouyang collector).

**SPAIN:** Valencia, 1 female (slide in INRA), ex *Fragaria vesca*, 2003.

**FRANCE:** Mauguio, South of France, near Montpellier, 2 females (2 slides in INRA), ex *Solanum melongena*, 2003.

**THE NETHERLANDS:** exotic material reared in Fuzhou, China, collected 29 Oct 2012, Yanxuan Zhang (introduced in 2009 from The Netherlands).

**JAPAN:** Chiba, Ichihara, 10 females (slide in LAEZIU), 17-VIII-1995, T. Gotoh.

#### Distribution

Moraes *et al.* (2004)'s world catalogue listed *N. californicus* from AFRICA (Algeria), the AMERICAS (Argentina, Brazil, Chile, Colombia, Cuba, Guatemala, Mexico, Peru, Uruguay, USA, Venezuela), EUROPE (France, Italy, Spain) and ASIA (Japan and Taiwan).

Recent new country records for AFRICA: Senegal (Zannou *et al.* 2006, Kade *et al.* 2011); Tunisia (Kreiter *et al.* 2010; Okassa *et al.* 2011); South Africa (Okassa *et al.* 2011).

Recent new country records for the AMERICAS: Guadeloupe (Kreiter *et al.* 2006); Canada and Mexico (Denmark & Evans 2011).

Recent additional country records for the EUROPE: Cyprus (Vassiliou *et al.* 2012); Greece: (Papadoulis *et al.* 2009); Portugal (Ferreira & Carmona 1994); Serbia (Stojnić *et al.* 2002); Turkey (Çakmak & Çobanoğlu 2006).

Recent new country records for the ASIA: South Korea (El Taj & Jung 2011; Okassa *et al.* 2011); China (Sichuan Province, Qin *et al.* 2013; Guangdong Province, this paper).

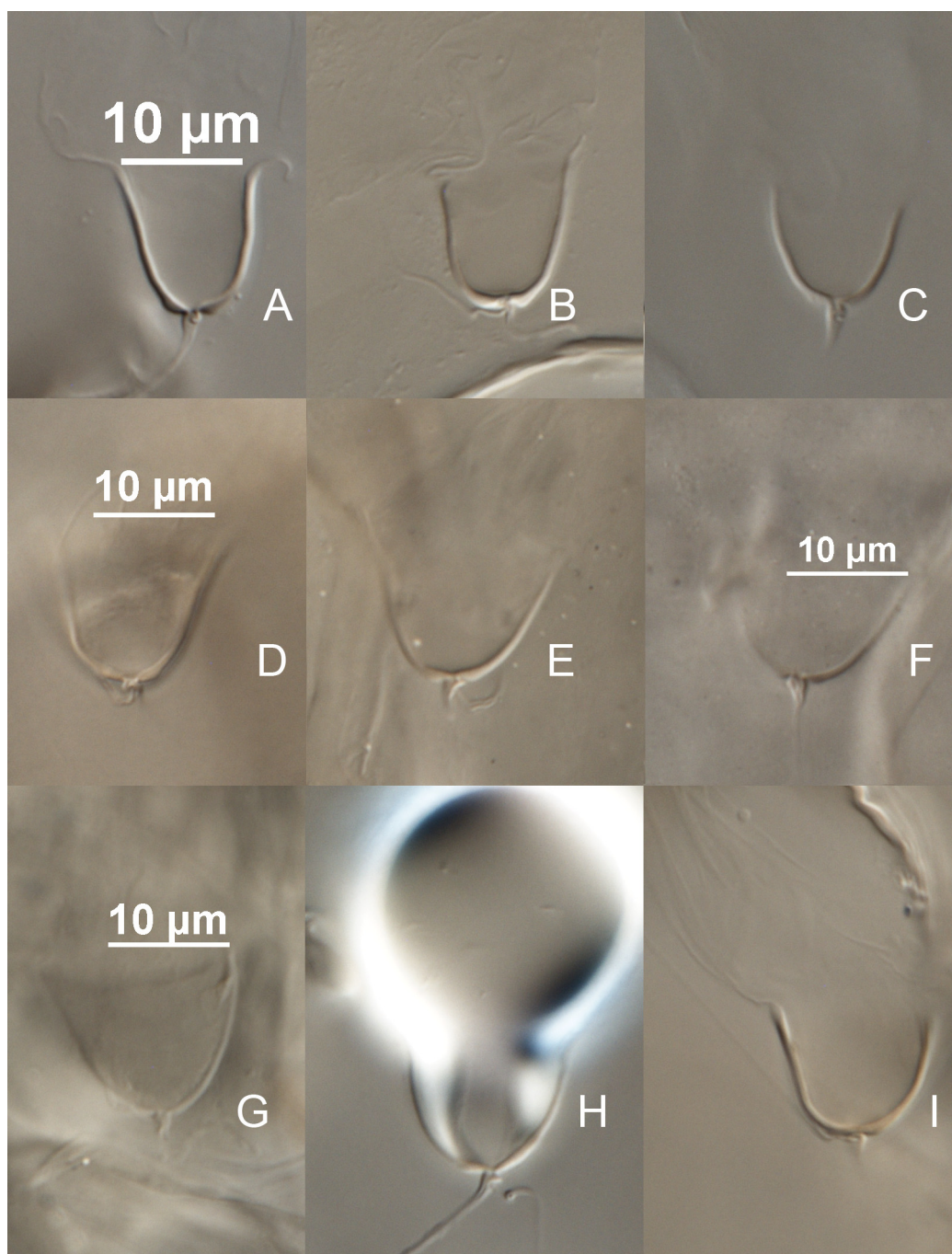
Recent new country records for the AUSTRALIA/OCEANIA: Australia (Steiner & Goodwin 2013; Tixier *et al.* 2013); Guam (Reddya & Bautista 2012, introduced from USA but established).

#### Discussions

##### Remarks on some morphological features in Chinese specimens

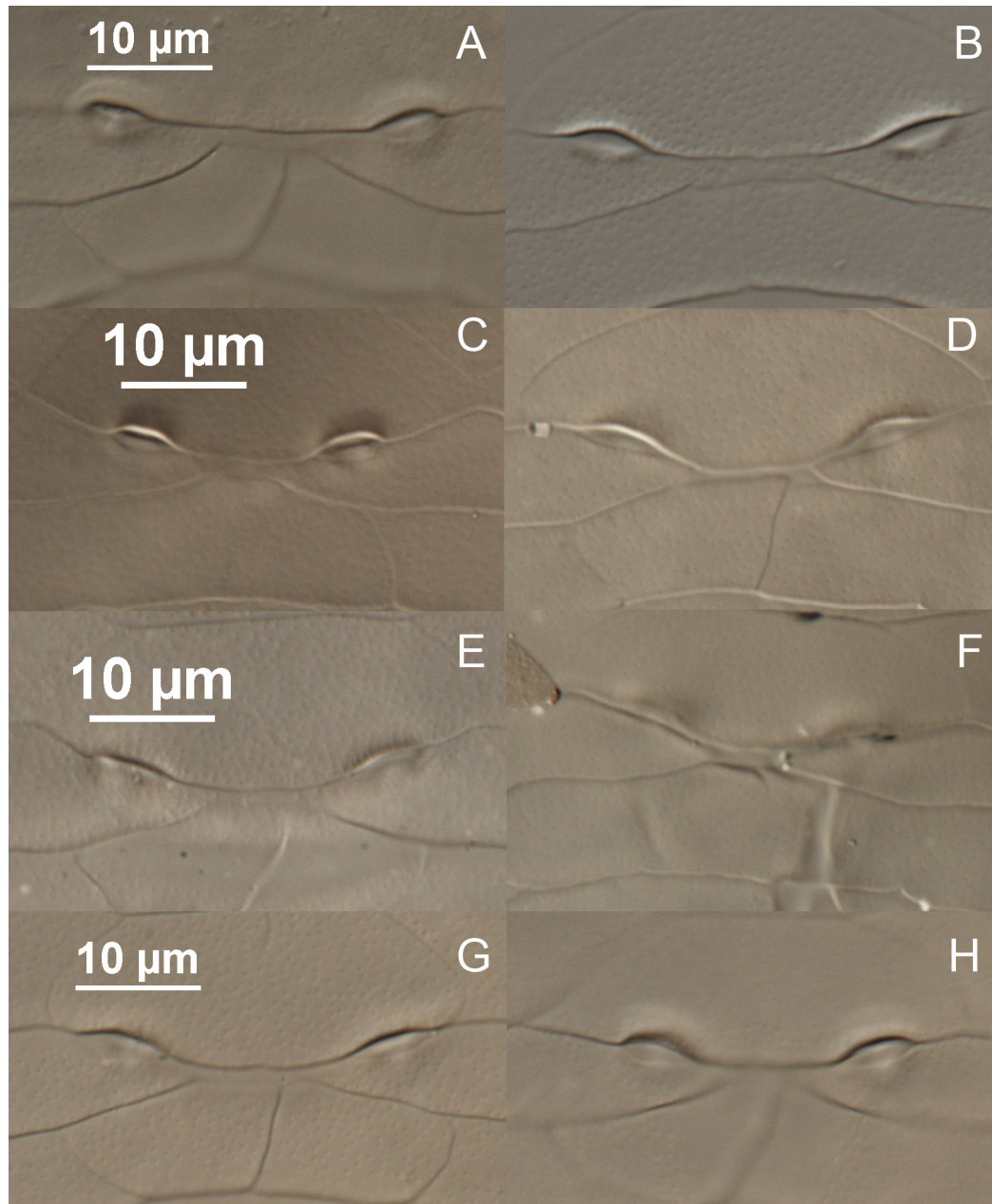
The Chinese population from Guangdong has extremely high reproductive rates (unpublished data). It has also some morphological differences from specimens collected from elsewhere:

(1) The calyx of spermathecal apparatus is obviously longer than wide in Chinese specimens (Fig. 10A–B), but it is mostly wider than long or as long as wide in overseas specimens (Fig. 10C–I).



**FIGURE 10.** *Neoseiulus californicus*. Spermathecal apparatus (female). **A–B**, China (Guangdong); **C**, Japan (Chiba); **D**, USA (Napa, California); **E**, France (Mauguio); **F**, Spain (Valencia); **G**, Chile (Valparasio); **H**, Chile (Curicó, voucher specimen from insectary culture at University of California at Riverside in 1983); **I**, Peru (Urubamba, voucher specimen from insectary culture at University of California at Riverside in 1983). All images under old immersion and of the same scale.

(2) The gland openings  $gv_3$  are closer to each other in overseas material (distance between mesad edges of  $gv_3$  opening about twice the width of  $gv_3$  opening, Fig 11B–H), whereas in Chinese specimens gland openings  $gv_3$  are further apart (the distance between mesad edges of  $gv_3$  opening about three times the width of  $gv_3$  opening—Fig. 11A).



**FIGURE 11.** *Neoseiulus californicus*. Ventrianal shield, part showing  $gv_3$  (female). **A**, China; **B**, Japan (Chiba); **C**, USA (Napa, California); **D**, France (Mauguio); **E**, Spain (Valencia); **F**, Chile (Valparasio); **G**, Chile (Curicó, voucher specimen from insectary culture at University of California at Riverside in 1983); **H**, Peru (Urubamba, voucher specimen from insectary culture at University of California at Riverside in 1983). All images under old immersion and of the same scale.

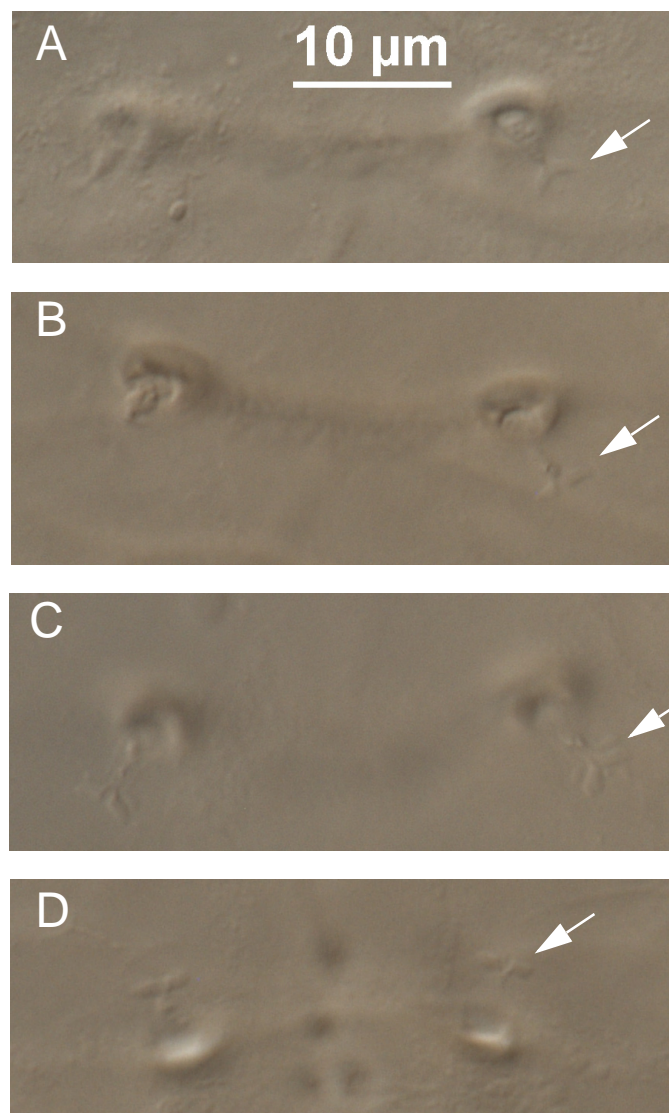


(3) Only basal 1/4 to 1/3 of setae  $Z_4$  is smooth in Chinese specimens, but basal half of  $Z_4$  is smooth in overseas material.

These differences are obvious in most specimens but sometimes there are exceptions, and here considered intraspecific variation.

#### Observation on $gv_3$ gland

We observed the internal structures under the preanal pores. There is a tube connecting  $gv_3$  gland and its opening. This tube is sometimes well developed and they form a broadly connected Y-shape with the two lobes of the gland in Chinese specimens (Fig. 12A), whereas the tube connecting  $gv_3$  gland and opening are relatively poorly developed and they form a narrowly connected T-shape with the lobes of the gland in overseas material—see Fig. 12B & D. In one specimen (Fig. 12C), we observed an additional pair of lobes distal to the normal pair.



**FIGURE 12.** *Neoseiulus californicus*. Ventrianal shield, part showing  $gv_3$  glands (female). **A**, China; **B–C**, commercial strain from Koppert (originated from California, USA); **D**, greenhouse-collected, ex soy bean, Kern, USA.

Athias-Henriot (1977) studied the preanal pores and pointed out the importance of its relative position and its shape. As far as we are aware, our discovery of the preanal glands is the first for a phytoseiid species. The preanal pores are connected to internal paired  $gv_3$  glands by a tube which is often not very well-sclerotized and difficult to see in old specimens. When the tube is vertical to the plane of the ventrianal shield in mounted slides, the tube and the glands are obscured. Further comparative studies of  $gv_3$  glands in different species and genera of the Phytoseiidae and other Mesostigmata will be very interesting and fruitful.

#### Records of related species in China

*Neoseiulus fallacis* was introduced from USA to China in 1983 and later released in 1987 for the control of *Panonychus ulmi* on apple in Qingdao, Shandong Province in northeast China (Wang *et al.* 1990). The released population overwintered successfully in the orchards and provided successful control of *P. ulmi* in 1988. During 1987–1988, *N. fallacis* was also released for the control of *P. ulmi* in Tianshui, Gansu in northwest China, providing “good control of the overwintering eggs of the spider mite” (Wu *et al.* 1991). However, it is not known whether the released mites became established, as there have been no further studies to assess its establishment in Gansu. A pesticide-resistant strain of *N. fallacis* was introduced to China in 1990 and tested in the laboratory against 23 commonly pesticides in China (Wu *et al.* 1994), but there have been no further reports on its release in China.

A mite identified by Weinan Wu as *N. fallacis* was reported from Guiyang, Guizhou in southwest China (Chen *et al.* 2009). Song *et al.* (2013) reported *N. fallacis* from papaya leaves in Guangzhou, Guangdong Province, China. Wu *et al.* (2009, pp. 72 to 74) described “*N. fallacis*” from China, but unfortunately they did not indicate the origin of the specimens or the distribution of the species in China. Based on the description given in Wu *et al.* (2009), his specimens are more similar to *N. californicus* sensu Athias-Henriot (1977) than *N. fallacis* sensu Athias-Henriot (1977), Schicha & Elshafie (1980), Schicha (1987) or Beard (2001). Beard (2001) reviewed variation in descriptions of *N. fallacis* from different publications and included her own observations. *N. fallacis* as currently known may be a complex of species.

*Neoseiulus californicus* was introduced from The Netherlands in 2009 into Fujian Province, China for possible control of spider mites in vegetable crops; thus far, only laboratory studies on its life history have been conducted (Zhang *et al.* 2012). We examined the voucher specimens from Zhang *et al.* (2012) and as expected these are *N. californicus* sensu Athias-Henriot (1977). The introduced population was kept in laboratory only and has not been released for biocontrol of mites in the field. Qin *et al.* (2013) reported a local population of *N. californicus* from Chengdu, Sichuan Province, southwest China.

#### Suggestions for future research

(1) Finding out the true identity of *Neoseiulus californicus*. *N. californicus* as currently described by various authors is obviously polymorphic as reviewed above (see also Ragusa & Varga 2002). Athias-Henriot (1959) first reported females of *N. californicus* (as *mungeri*) from Algeria and two years later she reidentified these females as *N. barkeri* (Athias-Henriot 1961: 400–401). Obviously, *N. californicus* sensu McGregor (1954) looks more like *N. barkeri* than *N. californicus* sensu Athias-Henriot (1977). Since McGregor’s type specimens cannot be found, the real identity of *N. californicus* can best be resolved by collecting new specimens from lemon at the type locality—Whittier, California.

(2) Cross-mating studies. The Chinese population of *N. californicus* sensu Athias-Henriot (1977) has some unique biological features and its morphology is also somewhat different from those from outside China. Experiments on cross-mating between the Dinghushan population with those

from the commercial strain (originated from California) will be interesting. If some genetic changes have evolved, then there may be reduction in at least the reproductive rates between inter-population crosses (compared with control within the same population).

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