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Descriptions of three new species of *Timema* (Phasmatoptera: Timematodea: Timematidae) and notes on three other species

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Abstract

During early 1999 the second author made an extensive search for specimens of *Timema* in southern and central California. Two undescribed species were found, *T. petita* and *T. landelsensis*. New collections provided additional data on *T. monikensis* Vickery & Sandoval, *T. boharti* Tinkham, and *T. knulli* Strohecker. The latter is reinstated as a valid species. A third new species, *T. morongensis*, received from a another researcher, also is described.

Key words

Phasmatoptera, *Timema*, new species.

Introduction

The order Phasmatoptera contains two very different sub-orders, the Timematodea and the Phasmatodea. A recent molecular phylogeny suggests that the Timematodea is an older group that separated from the other Phasmatoptera approximately 20-30 million years ago (Sandoval *et al.* 1998). Unlike the Phasmatodea, the Timematodea are very small, have short legs, and a number of other morphological traits that differ from Phasmatodea (Tilgner 1997; Tilgner *et al*. 1999). All species are apterous but many species of Phasmatodea are winged. Additionally, while Timematodea are restricted to the semi-arid western USA and Baja California, Mexico, Phasmatodea are mostly tropical and subtropical throughout the world.

As a result of the many morphological differences between Phasmatodea and Timematodea, the description of *Timema* (the only Timematodea genus) is based on different characters than those commonly used for the Phasmatodea. In outward appearance, species of *Timema* resemble each other rather closely, so much so that preparation of a key to species in the usual couplet form is very difficult and unsatisfactory. The only available key to species has been the pictorial key of Vickery (1993). This portrays the terminal structures of males and females of the known species at that time. The main characters that distinguish species are the male terminal structures. The terminal structures of females also are useful but to a lesser extent. A new pictorial key of all described species is shown in Fig. 29. Ecology, biogeography, color patterns and host plants are characters that alone may not be sufficient for species identification but combinations of these are useful, especially for parthenogenetic species. In most species of *Timema* the male terminalia are quite consistent within populations but may vary slightly among allopatric populations (*e.g.* in *T. californicum* Scudder and *T. podura* Strohecker). These geographically variable taxa are either populations in the process of divergence or may already be good species. Only laboratory breeding tests will be able to determine their specific status. In the meantime, it is useful to keep different names for taxa showing significant ecological, morphological and geographical identity.

In this study three new species are described, *T. petita*, *T. landelsensis* and *T. morongensis*: we provide new information for *T. knulli* Strohecker, *T. monikensis* Vickery & Sandoval and *T. boharti* Tinkham, and present a new pictorial key (Fig. 29) including all described species of *Timema*. The new descriptions elevate the total number of described *Timema* species to 21.

Method

During early 1999 an extensive search was made by Sandoval and Jennifer Law in southern and central California for specimens of *Timema*. Collection was by shaking branches of potential host plants inside a sweep net. For all localities, GPS coordinates, reference points, host plants, and color morphs were recorded. A third new species, collected in 1968, described here, was sent preserved in ethanol to Vickery for identification. All measurements are in millimetres (with range in parenthesis). All primary types are deposited in the California Academy of Sciences, San Francisco, CA, USA (CAS).

Timema petita Vickery & Sandoval sp. nov.

Holotype.— **Male**: California, Monterey County, HWY 1, 20 mi. [32 km] S Landels-Hill Big Creek Reserve (35° 43' 72.4" N; 121° 18' 96.3" W), on *Ceanothus thyrsiflorus*, 24-III-1999, C.P. Sandoval.

Diagnosis.— Small species, especially males, 13-19 mm; size comparable to *T. nakipa* Vickery but widely separated geo-

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graphically from that species; terminalia of male with dextral process narrower than that of *T. californicum* Scudder, another small species; subgenital plate of female apically acute, not broadly rounded as in the above-mentioned species. Blackish markings dorsally on head, pronotum and laterally on abdomen that occur on only one other species of comparable size, *T. poppensis* Sandoval & Vickery; but the dextral process of the male terminalia of this species is much broader. *T. petita* has a single color morph, dark green above and pale beneath. (in ethanol, the color fades to pale brown).

Description.— **Male:** head broader than long, eyes black, protruding, antennae with 21 segments; faint black oblique line behind each eye; pronotum with lateral dark markings, broader posteriorly, anterior corners acute, postero-lateral corners broadly rounded, posterior margin slightly concave (Fig. 1); meso- and metanota broader than pronotum, strongly convex laterally, each with three lateral elongate black spots; all femora with medium to very dark elongate paired dorso-lateral marks; abdomen of nearly uniform width to terminal tergum that is broadly expanded posteriorly; terminalia as in Fig. 4; both cerci with shallow, rounded apical invagination; intra-dextral process with noticeable teeth; subgenital plate small and broadly rounded (Fig. 12); body color dark green, with darker green marks dorsolaterally, uniformly pale beneath.

Measurements: body length 13.2; head width 1.9; pronotal length 1.6, width 2.2; fore femur 1.7; hind tibia 3.4. Ratios: pronotal width/length 1.35; hind tibia/fore femur 1.7.

The male terminalia resemble those of *T. knulli* but are much smaller. A paratype showing extreme condition is in Fig. 5 (variation to this extent is unusual in most species of *Timema*). However, *T. petita* lacks longitudinal white stripes as are found in *T. knulli,* and these species use different host plants: *T. petita* on *Ceanothus thyrsiflorus* and *T. knulli* on Redwood, *Sequoia sempervirens*.

Femoral striping and pronotal marks also are found on *T. knulli* and *T. morongensis*. *T. poppensis* Vickery & Sandoval (1999), a smaller species, also has this type of thoracic marking. (See Figs 1, 2, 3).

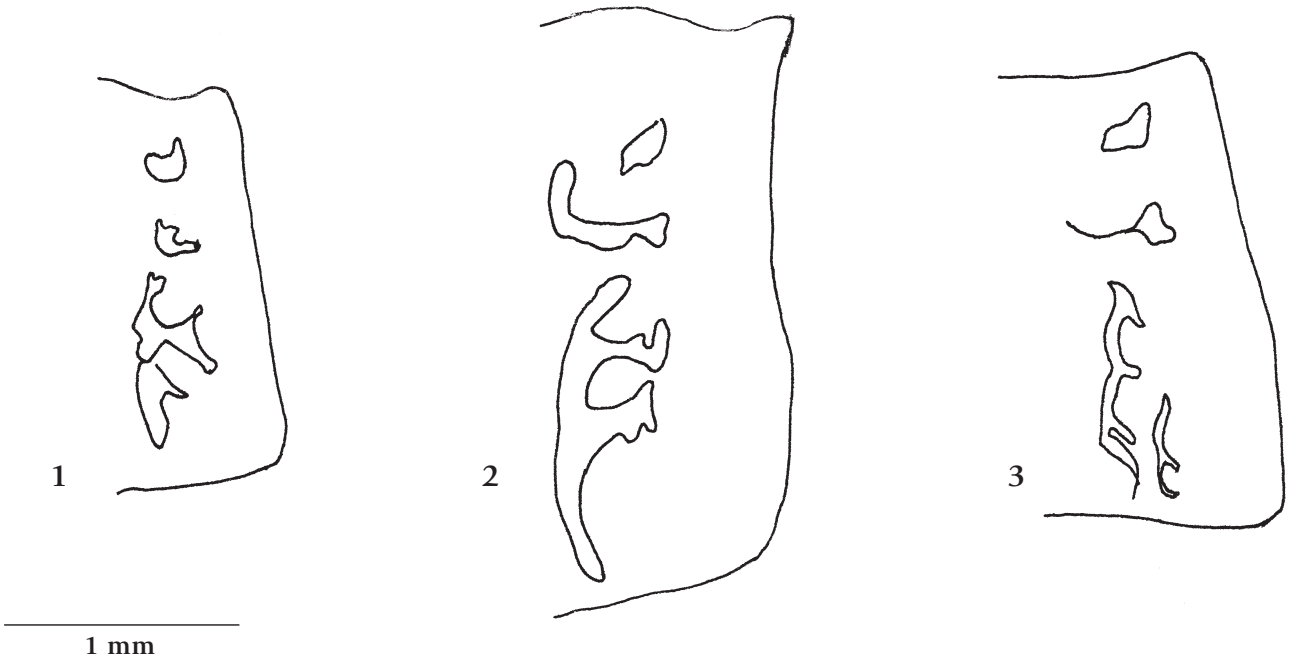
Female: Allotype, same data as holotype. Head much narrower than pronotum, otherwise similar to male; eyes protruding, oblique narrow dark line behind each eye; pronotum broad, broadest posteriorly with broadly rounded posterolateral corners, pronotal marks much less distinct than in male; meso- and metanota unmarked, broadly convex laterally; abdomen tapering from metanotum to terminal tergum (Fig. 17), not broader then preceding tergum, tapered on posterior two-thirds to bilobed apex; cerci with prominent coarse teeth in dorsal view but not in lateral view (Fig. 21); subgenital plate narrowed on apical two-thirds to acute apex (Fig. 25); dorsum of body with conspicuous small white spots; legs, underside and terminalia not spotted.

Measurements: body length 20.5; head width 2.3; pronotal length 2.0, width 3.1; fore femur 1.8; hind tibia 3.5.

Paratypes.— 14 ♂♂, 7♀♀ ; same data as holotype.

The terminalia of a few males differ slightly from the holotype. One male specimen has unusual terminalia: the dextral cercus and intradextral process appear to be normal but the sinistral cercus is replaced by a near mirror image copy of the dextral structure (Fig. 6).

Measurements, males (n = 14): body length 13.8 (12.4-19.3); head width 1.9 (1.8-2.3); pronotal length 1.5 (1.4-1.7), width 2.2 (2.1-2.3); fore femur 1.8 (1.6-2.0); hind



Figs 1-3. (*Timema* spp., all to same scale) Pronotal marks, males: **1**. *T. petita;* **2**. *T. morongensis*; **3**. *T. knulli.*

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tibia 3.0 (2.8-3.2). Ratio pronotal length to width 1.46; hind tibia to fore femur 1.66.

Measurements, females (n = 7): body length 21.6 (20.0-23.0); head width 2.3 (2.2-2.3); pronotal length 2.2 (2.1-2.3), width 3.2 (2.8-3.3); fore femur 2.0 (1.8-2.1); hind tibia 3,7 (3.4-3.9). Ratios: pronotal width to length 1.45; hind tibia to fore femur 1.85.

Paratypes are deposited in CAS and also in Lyman Entomological Museum, Ste-Anne-de-Bellevue, QC (LEM) and in University of California, Santa Barbara, CA (UCSB).

Timema landelsensis Vickery & Sandoval sp. nov.

Holotype.— **Male**: California, Monterey County. Landels-Hill Big Creek Reserve, Highland Camp (36° 11'36.5" N; 121° 33'10.0"W), on Manzanita (*Arctostaphylos hooveri*), 24-iii-1999, C.P. Sandoval.)

Diagnosis.— Sexual species; female subgenital plate of *T. landelsensis* is unique, narrowing from base then narrowing abruptly at 2/3, to acute apex (Fig. 26); superficially resembles *T. californicum*, but male genitalic processes longer, broader and distinctly cleft apically (see Figs 7 and 29); resembles parthenogenetic *T. shepardi* Sandoval & Vickery (a single male is known of this species), but are isolated geographically, and lack dark dorsal markings as on *T. shepardi*.

Description.—**Male**: head slightly broader than long, antennae with 22 segments, 2 and 4 very short, middle segments longest, pale; eyes pale, slightly protruding; pronotum little broader posteriorly, postero-lateral corners rounded into concave posterior margin; pronotum with three small dark marks on each side on apical third; meso- and metanota distinctly convex laterally, each with small elongate lateral black marks; legs unspecialized, tarsal arolia large; abdomen tapering posteriorly to expanded terminal segment; terminalia as in Fig. 7, sinistral cercus cleft apically, dextral cercus broadly expanded with broad incurved apex; intradextral process broad, nearly truncate apically, strongly toothed on dextral margin; subgenital plate broadly rounded apically (Fig. 13).

The terminalia resemble somewhat those of the single known male of the parthenogenetic species *T. shepardi* Vickery & Sandoval (1999), a species that also feeds upon Manzanita. *T. landelsensis* lacks the dark markings of *T. shepardi* and the conspicuous pale spots on the head and thorax of that species. These species are isolated on different mountain ranges 150 miles apart. It interesting to note that the species of *Archytostaphylos* utilized by *T. landelsensis* is endemic to the Santa Lucia Range where *T. landelsensis* occurs.

Color: green with lateral pale spots on abdominal terga; other parts of the body, including the legs, are not spotted.

Measurements: body length 18.8; head width 2.2; pronotal length 1.8, width 2.4; fore femur 2.1; hind tibia 3.5. Ratios: pronotal width to length 1.33; hind tibia to fore femur 1.66.

Allotype.— **Female**: Same data as holotype.

Similar to the male but larger; eyes pale, not prominent; palps pale; pronotum broader than head, expanded posteriorly with broadly rounded postero-lateral corners, lacking dark marks; meso- and metanota strongly convex laterally; legs unspecialized, unmarked, femur sulcate beneath; abdomen gradually tapered, terminal tergum not broader than preceding segment, tapered from anterior fourth to strongly bilobed apex; lobes distinct, area between them shallowly rounded (Fig. 18); supra-anal plate broad and short; cerci elongate with fine pubescence, distinctly oblique, longer dorsally in lateral aspect (Fig. 22), teeth of cerci not visible; subgenital plate triangular on apical third (Fig. 26), not on apical two-thirds as in *Timema shepardi*.

Color: pale green, fading to yellowish-green in ethanol. Head and thorax with pale whitish spots, these fewer on abdominal terga, legs and underside not spotted; meso- and metanota with oblique depressed lateral lines.

Measurements: body length 21.1; pronotal length 2.4, width 3.1; fore femur 1.6; hind tibia 3.6; cercus 1.9. Ratios: pronotal width to length 1.24; hind tibia to fore femur 2.25.

Paratypes.— Same data as holotype, 2 ♂♂, 1 juvenile ♂, 4 ♀♀, 8 juvenile ♀♀ . Deposited in CAS, LEM and UCSB.

Males are very similar to male holotype but 3.3 mm shorter. One female is marked as is the allotype with whitish spots, even on terminal segment; other specimens lack the spots.

Measurements: females (n = 4): body length 21.5; head width 2.3; pronotal length 2.3, width 3.0; fore femur 1.6; hind tibia 3,3; cerci 1.8.

Timema morongensis Vickery sp. nov.

Holotype.— **Male**: California, Riverside County, 3 mi [4.8 km] S Morongo valley, 2000 ft, 24-iii-1968, TJ Zavortink, *Erigonum* no. 6803241p.

Specimens of *T. morongensis*, collected in Riverside County by T.J. Zavortink, were sent to Vickery for identification. This species is described here. No other species of *Timema* is known to feed on *Eriogonum*. Further ecological observations need to be conducted to determine if *Eriogonum* is in fact the host for this species.

Diagnosis.— Large, male 19.5, female 29.6; head of male broader than pronotum, of female same breadth as pronotum; dorsal marks laterally on pronotum (Fig. 2); male terminal processes broad, not cleft, intradextral process with strong teeth (Fig. 8); female subgenital plate elongated to rounded apex (Fig. 27); host plant probably *Eriogonum*.

Description.— **Male**: large for genus; head broader than pronotum, eyes black, not protruding, antennae broken, 8 segments left on one, 5 on the other; medium to dark brown, darker than pronotum; anterior corners of pronotum acute, pronotum expanded very little posteriorly, postero-lateral corners rounded, posterior margin linear; pronotum with series of marks laterally (Fig. 2), these reversed on opposite side; meso- and metanota convex laterally, legs unspecialized, unmarked, femora sulcate beneath; abdominal terga un-

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marked, tapered to posterior apex; terminalia as in Fig. 8; both cerci broad apically, not cleft, dextral cercus concave apically, sinistral cercus with upper lobe convex; intra-dextral process with strong teeth; subgenital plate small, rounded apically (Fig. 14).

Color: brownish, possibly green when alive.

Measurements: body length 19.5; head width 2.6; pronotal length 1.9, width 2.3; fore femur 2.7; hind tibia 3.6. Ratios: pronotal width to length 1.21; hind tibia to fore femur 1.33.

Allotype.— **Female**: same data as holotype. Large, as large as *Timema knulli* Strohecker (until now considered as the largest females of *Timema*) or larger; similar to male but head not broader than pronotum, vertex mesally acute, laterally obtuse, eyes black, antennae with 22 or 23 segments; dark oblique streak behind each eye; pronotum with marks as on the male but these much less well defined; terminal tergum broad, tapered to bilobed apex; cerci long, teeth visible only in dorsal view (Fig. 19), laterally as in Fig. 23; subgenital plate long, tapered in apical three/fourths to narrowly rounded apex (Fig. 27).

Measurements: body length 29.6; head width 3.1; pronotal length 2.7, width 3.3; fore femur 2.8; hind tibia 4.7; cerci 2.7. Ratios: pronotal width to length 1.14; hind tibia to fore femur 1.67.

Only the primary types are known.

The pronotal markings are similar to those of *T. knulli*, another large species and also of *T. petita*, which is much smaller than the other two. In other characteristics these species are distinctly different but the similarity of the pronotal marks indicates ancestral relationship.

Other specimens collected in 1999 provide additional information on some other species of *Timema*. These are *T. monikensis*, *T. boharti* and *T. knulli*.

Timema monikensis Vickery & Sandoval (1998)

This species was collected in the Santa Monica Mountains of southern California, 34° 07' 17. 2" N; 118° 50' 44.1" W, in 1998. It was considered to be parthenogenetic as after careful searching only females were found. (Mate guarding is a common behavioral characteristic in species of *Timema* and females customarily have males riding on their backs whether mating or not.). Collections made by Sandoval in 1999 at the type locality produced four males together with 16 females. As males were scarce, we still believe the main method of reproduction of the species is by parthenogenesis. We do not know if the males were fertile or infertile.

T. monikensis appears to have some characteristics of two other species, *T. chumash* and *T. cristinae*, which occur on neighboring mountain ranges. Color is the same as *T. cristinae*; body shape is in between *T. cristinae* and *T. chumash*, and male terminalia are somewhat similar to *T. chumash*. *T. monikensis* feeds on hosts of both species. Ongoing allozyme studies are attempting to determine if *T. monikensis* is a species resulting from hybridization between *T. chumash* and *T. cristinae*. This does not represent a variant population at the extreme of its range, such as may occur in some species of the Suborder Phasmatodea, as the entire range of this species is very restricted. The terminalia are quite unlike those of most other species but bear resemblance to the genitalia of *T. chumash*.

Description.— **Male**: body medium large, green with numerous white dots on the body, but not on the legs, terminalia or underside, body darker at apical end of abdomen; terminalia bulky (Fig. 8), sinistral cercus broad, deeply invaginated on inner side, tapering to acute apex; dextral cercus also broad, bilobed apically; intra-dextral process long, narrow, hooked apically, with strong teeth on dextral side; subgenital plate rounded apically.

Timema boharti Tinkam (1942)

Another species collected by Sandoval in 1999 is *Timema boharti* Tinkham, a species that has been considered to be rare and uncommon. On Laguna Montain it was found only at the top of the mountain, near the Observatory, on March 30. The male terminalia are illustrated here, as those by Vickery (1993, p. 686, Figs 13 and 23) are not typical of the species. Only a few dried specimens had then been available for study. Figs 10 and 15, drawn from specimens preserved in liquid, are more useful in determining the species.

Timema knulli Strohecker (1951)

Timema knulli was known only by the pinned type series for many years. It is the second largest species of the genus. A collection of *T. californicum* Scudder (1895) from Mount Hamilton that ranged from typical of that species to an approximation of the structure, but not of the size of *T. knulli*, led Vickery in Sandoval & Vickery (1996) to place *T. knulli* as synonymous with *T. californicum*. Strohecker (1951) surmised that *T. knulli* might represent an unusual aberration of *T. californicum*.

Specimens collected in 1999 at Landels-Hill Big Creek Reserve, Monterey County (36° 04' 30.6" N; 121° 36' 01.9" W), however, are undoubtedly *T. knulli* so this taxon is here removed from synonymy. The collection comprised 14 ♂♂ and a juvenile ♂, and 11 ♀♀ plus 3 juvenile ♀♀. They were taken from Redwood (*Sequoia sempervirens)*. The different host plant further supports the placement of *T. knulli* and *T. californicum* as different species. *T. knulli* is similar in color to the sexual *T. poppensis* and its asexual relative *T. douglasi*. However, they differ in host plants, size, and shape of the male terminalia (Figs 11, 29). Additionally, *T. knulli* and these other two species do not overlap in geographical distribution. While *T. knulli* occurs only in the Santa Lucia range, in Monterey County, *T. poppensis* and *T. douglasi* have more northern distribution with the southernmost limit at Santa Cruz Mountain.

Redescription of ***Timema knulli***.— **Males**: large for the genus, body mainly green with 2 dorsal dark green stripes; body color of both males and females similar to *T. poppensis* Vickery & Sandoval and *T. douglasi* Sandoval & Vickery; antennae with 18 segments, dark reddish brown; pronotum with lateral impressions (Fig. 3), these darkened to some

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extent on most specimens; legs reddish-brown with paired darker streaks dorsally on femora; male terminalia (Fig. 11) reddish in most specimens, some pale green; subgenital plate (Fig. 16) green.

Measurements: body length 20 (15.2-25.5); head width 2.6 (1.9-2.8); pronotal length 2.3 (1.9-2.7), width 2.7 (2.4-3.2); fore femur 2.7 (2.5-2.9); hind tibia 4.6 (4.3-4.9).

Female color is similar to that of males, some have pronota marked as in males; head with dark lateral stripes behind eyes, body with lateral white stripes, at least on thoracic segments. Terminalia as in Figs 20, 24 and 28. These figures are more representative of the species than those in Vickery (1993, pp. 688, 689 and 690, Figs 29, 39 and 49) which were drawn from pinned specimens that were shriveled and distorted.

Measurements: body length 27 (22.1-29.3); head width 3.1 (2.6-3.4); pronotal length 2.6 (2.3-3.1), width 3.6 (2.9-4.2); fore femur 2.8 (2.7-3.2); hind tibia 5.2 (3.7-5.9).

Another population of *T. knulli* was sampled the same day by Sandoval in Big Creek Reserve on *C. thyrsiflorus*. These specimens averaged very slightly smaller and pronotal marks were less apparent than those of the previous population: 2 ♂♂, 1 juvenile ♂, 5 ♀♀ and one juvenile ♀.

Discussion

Timema walking-sticks comprise a fascinating group of insects which are uniform in general appearance and yet speciose and diverse in ecological adaptation. Perhaps some of the reasons for their success in conquering the mountains is related to their ability to utilize new host plants as they dispersed and to adapt ecologically to these hosts, particularly by evolving new cryptic color patterns (Crespi & Sandoval 2000). Possibly populations became separated by crustal upheavals. Ecological and molecular studies have produced a trend of splitting and describing new species as new information helps the recognition of new taxa. When a new molecular phylogeny including the new species is available, a revision of the genus will be useful, many species having been described since the last revision (Vickery 1993).

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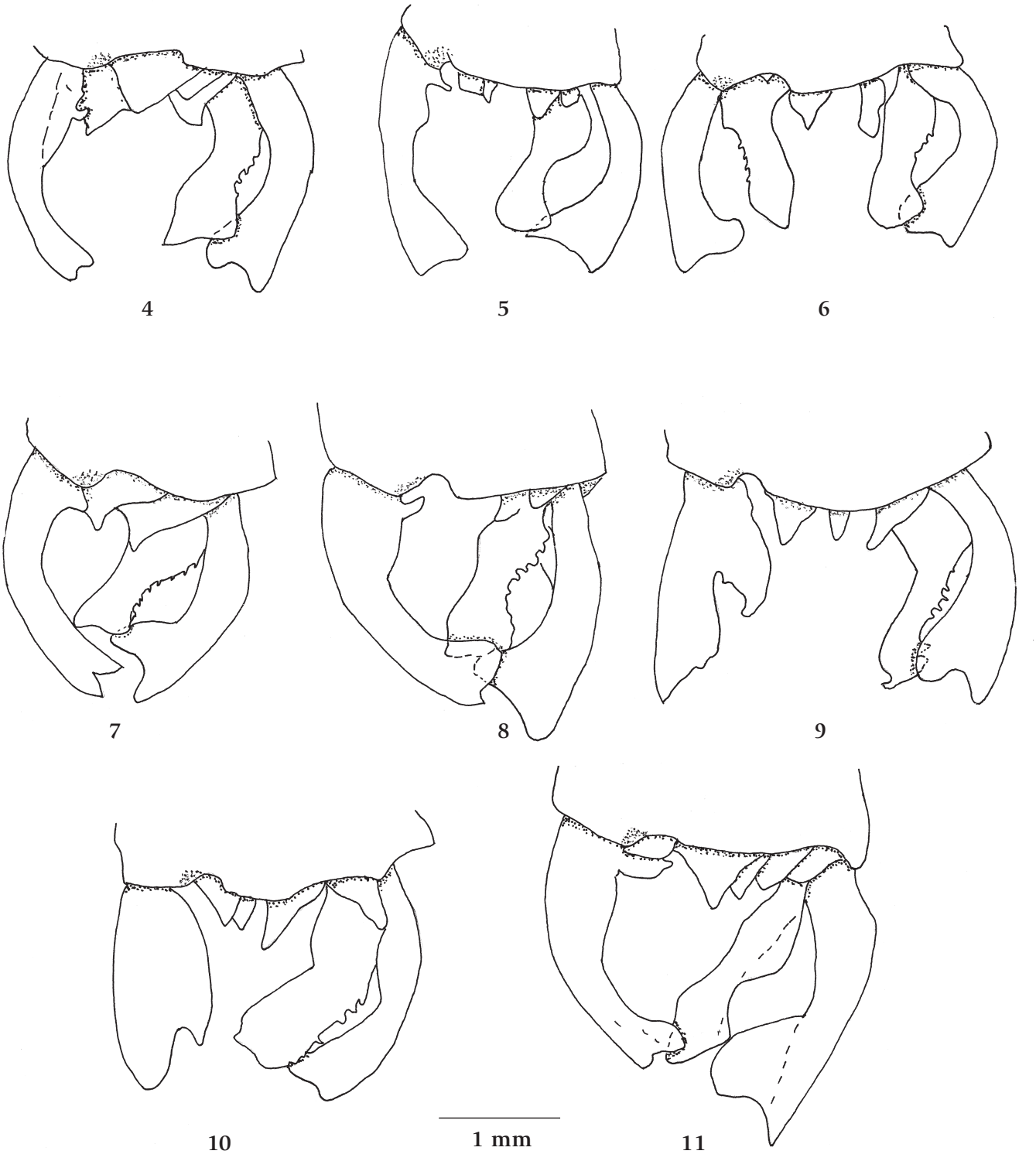
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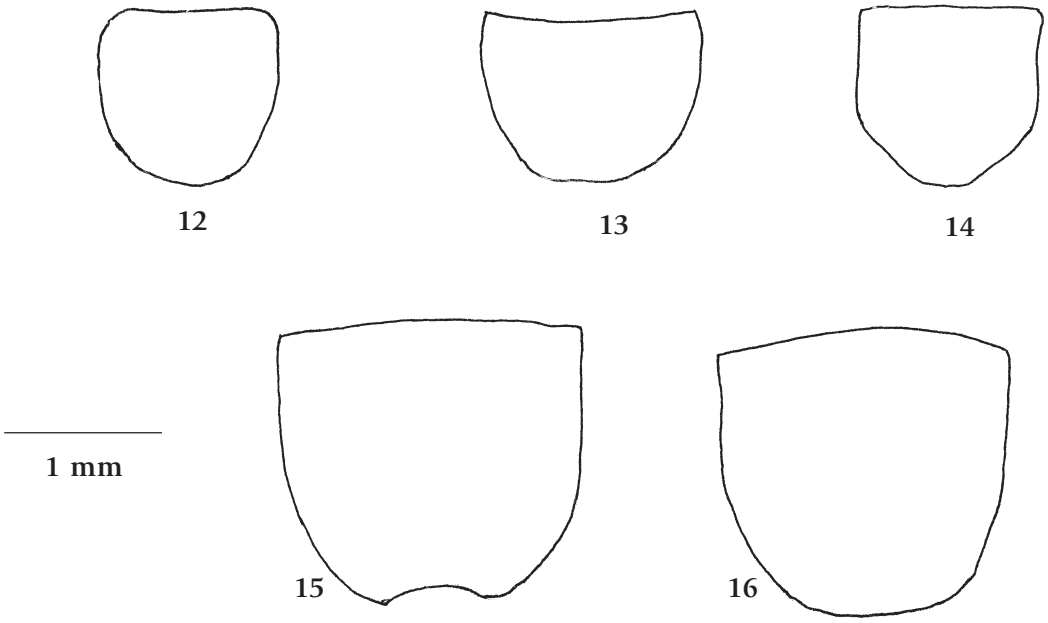
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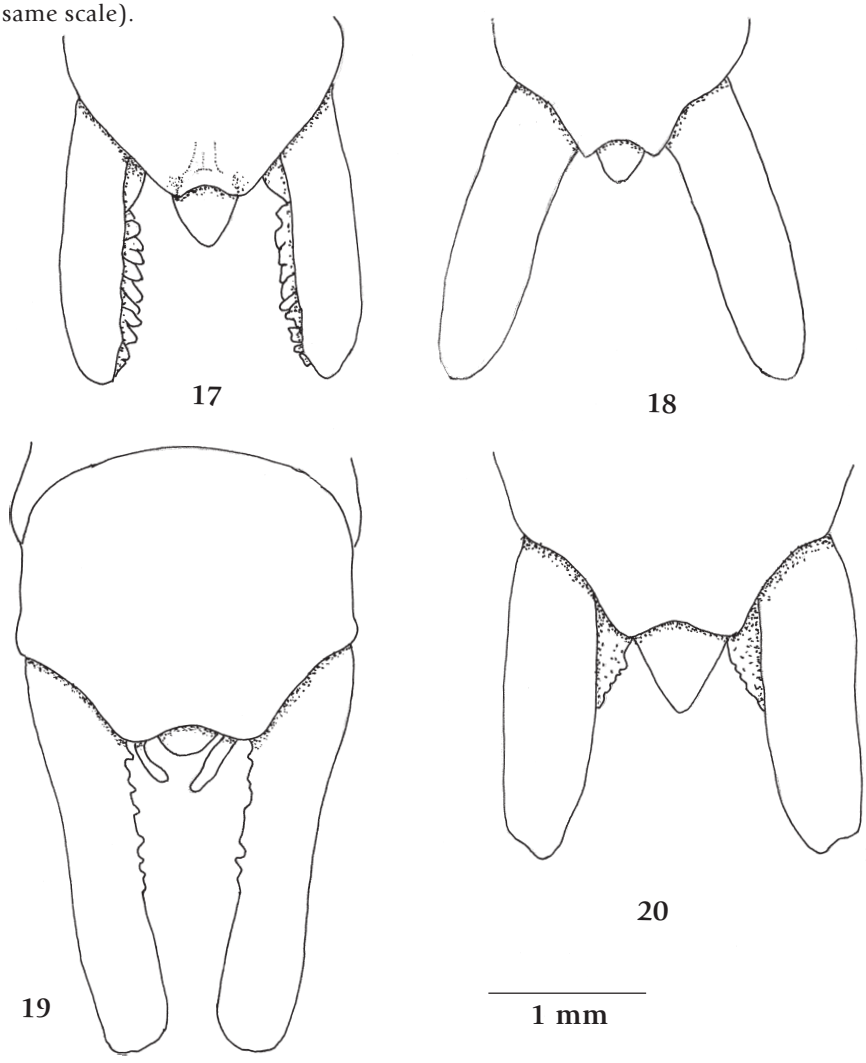


Figs 4-11. Male terminalia, dorsal : **4**. *T. petita*; **5.** *T. petita*, variant; **6**. *T. petita*, aberration; **7**. *T. landelsensis*; **8**. *T. morongensis*; **9**. *T.monikensis*; **10**. *T. boharti*; **11**. *T. knulli*. (*Timema* spp., all to same scale).

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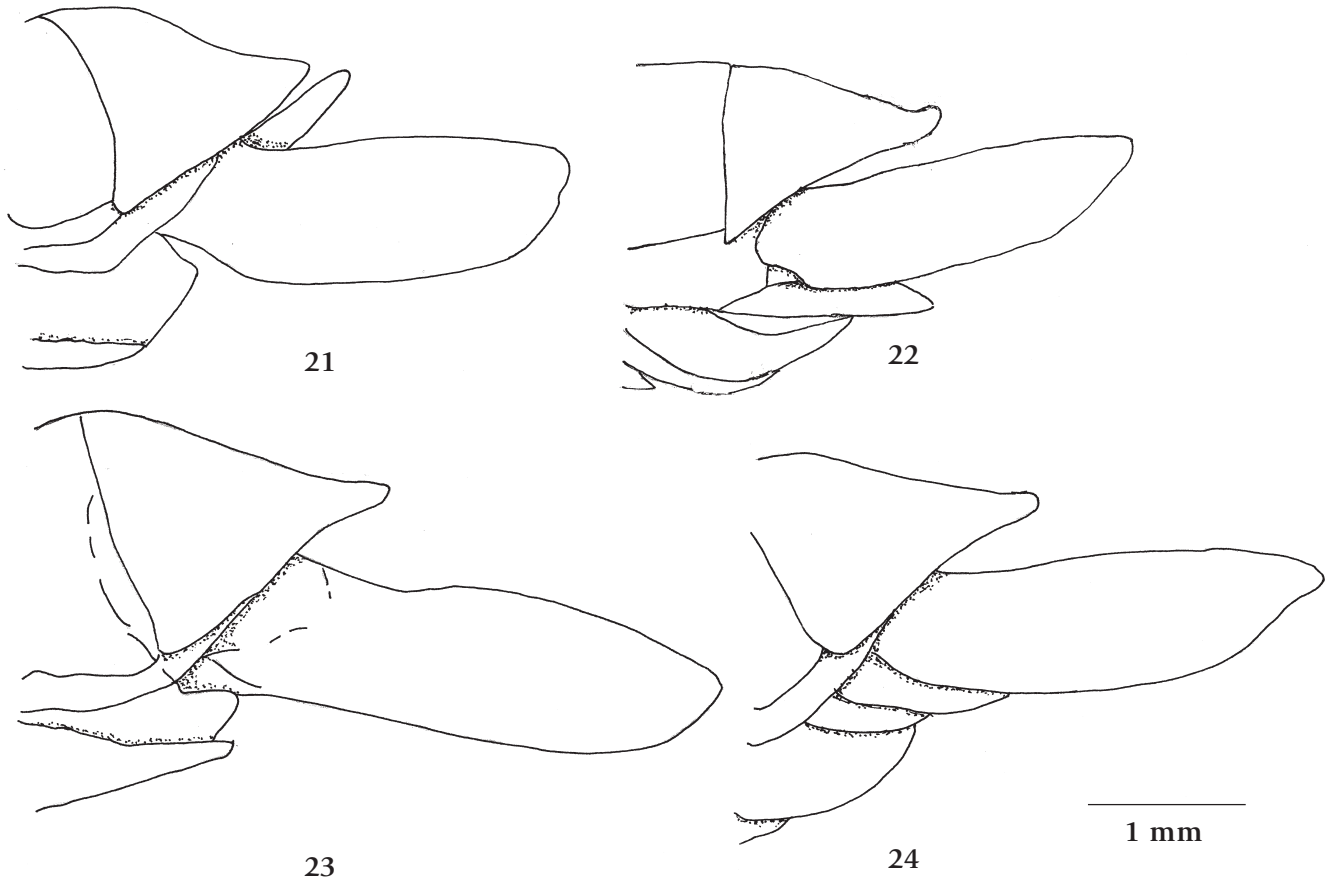


Figs 12-16. Male subgenital plate, ventral: **12**. *T. petita*; **13**. *T. landelsensis*; **14**. *T. morongensis*; **15**. *T. boharti*; **16**. *T.knulli*. (*Timema* spp., all to same scale).

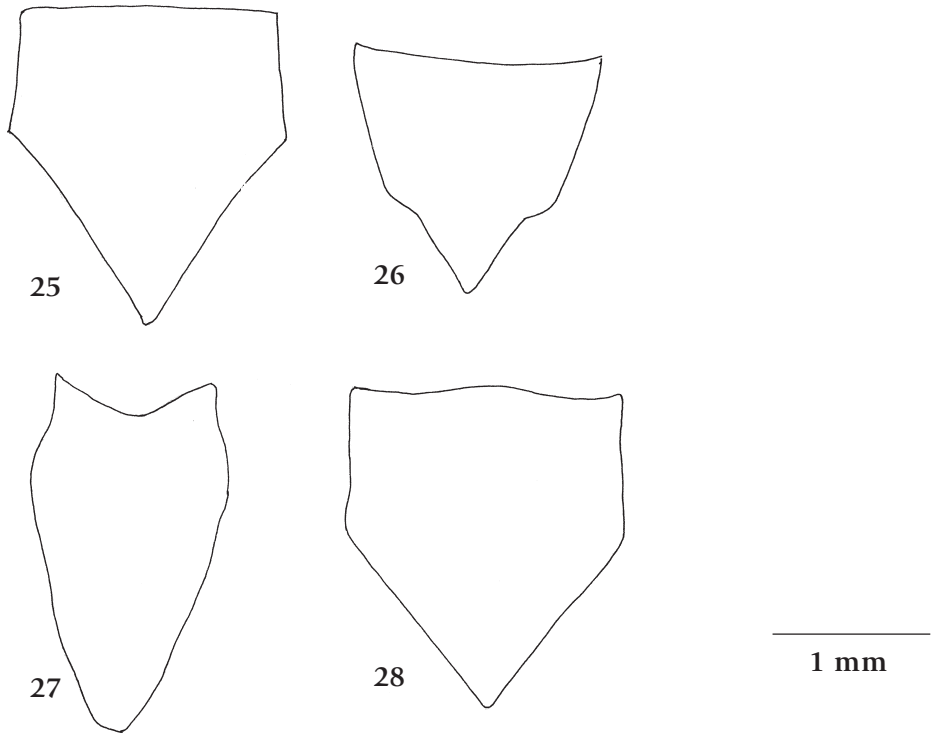


Figs 17-20. Female terminalia, dorsal: **17**. *T. petita*; **18**. *T. landelsensis*; **19**. *T. morongensis*; **20**. *T. knulli*. (*Timema* spp., all to same scale).

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Figs 21-24. Female terminalia, lateral: **21**. *T. petita*; **22**. *T. landelsensis*; **23**. *T. morongensis*; **24**. *T. knulli*. (*Timema* spp., all to same scale).



Figs 25-28. Female subgenital plate, ventral: **25**. *T. petita*; **26**. *T. landelsensis*; **27**. *T. morongensis*; **28**. *T. knulli*. (*Timema* spp., all to same scale).

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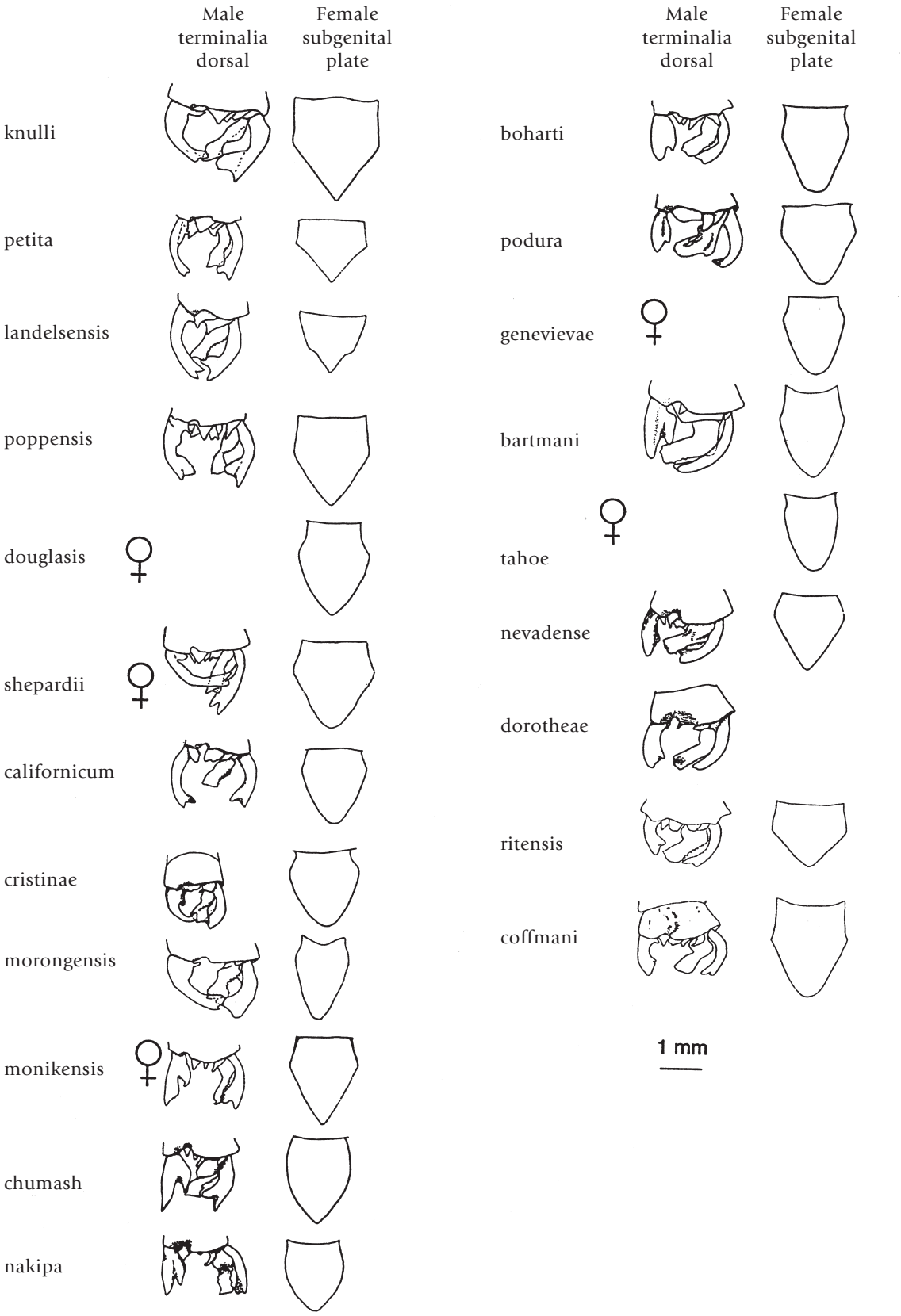


Fig. 29. Male terminalia, (dorsal) and female subgenital plate, (ventral), of all described species of *Timema*.

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