

THE CHIRONOMIDAE LARVAE ASSOCIATED WITH THE TSUNAMI-IMPACTED WATERBODIES OF THE COASTAL PLAIN OF SOUTHWESTERN THAILAND

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ABSTRACT. – One environmental consequence of the December 2004 Indian Ocean tsunami was the inundation with seawater of many water bodies along the affected coastal plain. A repeated series of benthic surveys across the impacted range in southern Thailand from Ranong to Krabi, including unimpacted control sites, has enabled identification of the associated insects, allowing detection of biotic responses. Larval Chironomidae (Diptera) were diverse, with 29 species identified, belonging to 15 genera in three subfamilies. The genus *Conochironomus* Freeman is reported formally for the first time from the region. The larval differentiation of the dominant genus, *Kiefferulus* Goetghebuer (comprising three species), is established here for the first time. *Kiefferulus longilobus* (Kieffer) is restricted to the most saline impacted sites where it is the only chironomid present; congeners *K. calligaster* Kieffer and *K. barbatitarsis* Kieffer are associated with ‘recovery’ sites of high but reducing conductivities. The multispecies genera *Dicrotendipes* Kieffer, *Polypedilum* Kieffer and *Tanytarsus* v. d. Wulp show varying patterns of association with impact and recovery. Ranges of conductivity and dissolved solids are provided for all species of Chironomidae. Illustrated keys are provided to allow identification of all species recovered.

KEYWORDS. – Chironomidae, salinity, post-tsunami, *Kiefferulus*, *Conochironomus*.

INTRODUCTION

In recent faunal surveys of the aquatic insects of Thailand, many aquatic habitats have been sampled: ranging from high elevation waterfalls and rivers and streams of the Chiang Mai/Doi Inthanon area to rice fields and low-lying water bodies in the southern provinces of the country (e.g. Vitheepradit et al., 2003; Vitheepradit & Sites, 2007). Thus, when the tsunami of 26 December 2004 struck, some biotic samples already existed from pools and ponds prior to the impact. National Science Foundation funding to Sites (NSF, DEB-0531513) has allowed survey of numerous impacted and proximate unimpacted habitats on four occasions between May and June 2005, and June 2006. Pending detailed analysis of the responses of the total biota, the identity, distribution and responses to saline inundation and subsequent recovery of the Chironomidae (Diptera) are presented.

Chironomidae are almost ubiquitous in all kinds of water bodies (Cranston, 1994) in which certain larvae can function as detritivores, algal feeders or predators. Existing identification keys allow generic identification for larvae from the Holarctic region (e.g. Wiederholm 1983) and from Malaysia (Cranston, 2004). The latter includes taxa found by the author in earlier Thai surveys, but several more genera and one subfamily added subsequently will be incorporated into a specific guide to immature Chironomidae of Thailand.

Identification of chironomid larvae to species-level presents more difficulties than do the often diagnostic pupal exuviae or particularly the adult males which usually have species-specific genitalia. Although identification via provision of taxonomic names usually requires rearing to the traditionally-described adult male stage, suites of larval characters can be found and used in species discrimination. Ideally, all species and specimens should be reared, but in intensive and extensive surveys this is impractical, and rearing success rates for tropical species tend to be low. Fortunately, several important species have been reared, either from these particular ‘post-tsunami’ sites or from elsewhere in Thailand or in the wider Indo-Australian region.

In total across all impacted and unimpacted sites, 29 species-level taxa of Chironomidae were found. All were readily identifiable to genus and agree well with current taxonomic concepts. Given the difficulty in assigning all larvae to named species in the absence of rearings, and the increasing evidence for the existence of cryptic species, these units here are termed morphospecies. Some could be identified reliably to named species (for example, in the genera *Dicrotendipes* and *Kiefferulus*), whereas others could be discriminated reliably and repeatedly, although their actual identity remains uncertain. These latter morphospecies are referred to by code/voucher names, some of which are those

used for Australian taxa in Cranston (2000). Such coding implies apparent larval identity but this cannot be verified because of the lack of association with adult males and also mostly by lack of potentially diagnostic pupal association.

MATERIALS AND METHODS

Standing bodies of water were selected (by R. W. Sites and A. Vithepradit) to include those impacted by the tsunami, and others that could be treated as unimpacted 'controls', being more inland and at slightly higher elevations, including those with peaty waters. Thus, 28 sites were sampled in May–June and September 2005 and January and June 2006. The northernmost site was in Leam Son National Park (9°36'N) in Ranong Province, the southernmost at Hard Jow Mai, 7°27'S) in Krabi; several sites in Phuket were included. Elevations ranged from 2 to 40 m a.s.l. Temperatures, conductivities and levels of dissolved solids were recorded for each site on every visit using standard field equipment. All aquatic insects were collected with stout-framed pond nets of mesh size ca. 140 µm with which aquatic macrophytes were swept and beaten, and the benthos stirred by the collectors (Sites and Vithepradit) from within the water body. All organisms were removed from the net, with 'stop-rules' based on no further collection of a morphospecies being collected in two successive samples by each of two collectors. Such a 'stop-rule' is more difficult to apply for larval Chironomidae for which identity is essentially unknown until microscope slide preparation. Thus species densities/abundances cannot be construed from the data; however, absence of any chironomid taxon from any site appears to be genuine.

Chironomid larvae were preserved in 100% ethanol, with some in isopropanol for potential molecular study. Living duplicates (as assessed by eye) were separated individually into cotton-stoppered vials and held in a cooled ice chest to avoid potentially lethal air temperatures of > 35°C. Associated stages were preserved together within the rearing vial. All larvae were dissected (head amputated) and mounted on a microscope slide; numbers of individuals were so high that an economical method of processing had to be developed. Thus multiple larvae from a single site were mounted per slide, each under an individual 10 mm diameter cover slip, mounted directly from the preservation medium into Hoyers mountant. Particularly interesting taxa and those that were partially or fully reared were mounted using the standard technique: clearing in KOH, followed by neutralisation in glacial acetic acid and mounting from isopropanol-1-ol into Euparal. Hoyer's mountant can cause crystallization problems, perhaps attributable to poor quality components (Bruce Halliday, CSIRO Entomology, Canberra, pers. comm.). The mountant's advantages, when many specimens must be handled economically, are that no prior clearing is required, the mountant's water solubility facilitates remounting and the optical benefits of the medium are excellent compared to Euparal and especially Canada balsam, allowing high quality

photographic images. Specimens, including vouchers for all taxa are held in the Enns Entomological Museum University of Missouri-Columbia, the Bohart Museum, University of California, Davis and the Zoological Reference Collections of the Raffles Museum of Biodiversity Research, National University of Singapore.

Optimal photographic results were obtained using a Leica® DMRX compound microscope with Nomarski® interference optics. Photographs were taken with an Automontage™ system, allowing automated retention of focused parts of a sequence of exposures at different focal depths. All subsequent manipulations were made in Adobe® Photoshop™. Photographs provide many benefits compared to line drawings, especially for novices; however, for those that require line drawings the illustrations and keys provided by Cranston (2004) for the Malaysian fauna can be consulted.

Abbreviations used in Figures: ant, antenna; dmt, dorsomentum teeth; fen, fenestra (pit); fr, setal fringe; lig, ligula; ll, labral lamellae; m, mentum; md, mandible; mp, maxillary palp; ph, pecten hypopharyngis; pmd, premandible; SI, SII, labral setae I, II; S₉, S₁₀, ventral cephalic setae 9, 10; sc, sclerite; sm, submentum; S_{sm}, seta submenti; vmp, ventromental plate; VP, ventral pit.

RESULTS

From the 28 sampled sites, chironomids belonging to three subfamilies were recovered, representing the Tanypodinae with eight morphospecies in seven genera, the subfamily Orthoclaadiinae with a single representative, and the Chironominae with 20 morphospecies in eight genera. Keys to these taxa are provided below.

Rearing success was limited, with more associations discovered serendipitously from pharate adults within pupal skins encountered while sampling. Nonetheless, a site-by-date-by-taxon matrix could be compiled, allowing interpretation of species responses.

Key to subfamilies of larval Chironomidae found

1. Antenna retractile into head (Fig. 3, ant). Hypopharynx with distinctive toothed ligula (Figs. 4, 5, lig). Mentum, the medioventral plate, usually weakly sclerotised (Fig. 15, arrow, m) Tanypodinae
 - Antenna non-retractile (Figs. 22, 38). Mentum, the most prominent mouthpart forms a strongly sclerotised plate (Figs. 20, 21, m). Hypopharynx without ligula 2
2. Mentum associated with variably developed, but always broad and usually striated ventromental plates (Figs. 20, 21, vmp) Chironominae
 - Mentum with small, non-striate ventromental plates (Fig. 17, vmp) Orthoclaadiinae

Key to genera of larval Tanypodinae found

1. Body segments bearing lateral longitudinal dense setal fringe (Fig. 1, fr). Mentum (technically dorsomentum) distinct, toothed (Fig. 7, m) 2
 - Body segments lacking setal fringe. Mentum or dorsomentum indistinct, not toothed (Fig. 15, m) 4 (tribe Pentaneurini)
2. Dorsomentary teeth weak, not aligned on plate (Fig. 2, dmt). Mandible strongly hooked (Fig. 3, md) *Clinotanypus*
 - Dorsomentary teeth strong at margin of plate (Fig. 7). Mandible straight to curved, never hooked (Fig. 6) 3
3. Ligula with median tooth largest, all teeth directed anteriorly (Fig. 4); pecten hypopharyngis absent. Mandible squat, with expanded base and short apical tooth *Tanypus*
 - Ligula with median tooth smaller than medially-curved sublateral teeth (Fig. 5); pecten hypopharyngis present (Fig. 5 ph). Mandible with many spine-like teeth (arrowed) on mesal surface (Fig. 6), without distinct basal tooth *Fittkauimyia*
4. Basal segment of maxillary palp divided into 2 or more sections (Fig. 8, mp) 5
 - Basal segment of maxillary palp simple, undivided (Fig. 9) 6
5. Submentum with seta S_{10} linearly aligned with S_{sm} and S_9 setae, with VP lying posterolateral to that alignment (Fig. 10). Division of maxillary palp into 2 sections at about 1/3 from segment base *Paramerina*
 - Submentum with S_{sm} nearly aligned with VP and S_{10} seta, with S_9 anteromedial to that alignment (Fig. 11). Basal palp segment divided into 2–5 sections (Fig. 8); if only 2 sections, then division is anterior to basal 1/3 *Ablabesmyia*
6. One claw of posterior parapod dark, with inner teeth (Fig. 12). VP more posterior than any ventral cephalic seta (Fig. 13) *Monopelopia*
 - All claws of posterior parapod pale, simple. S_{sm} far posterior to VP (Fig. 14) *Larsia*

SUBFAMILY ORTHOCLADIINAE

The only genus of Orthoclaadiinae found, *Parakiefferiella* Kieffer, is distinguished here by the presence of a modestly developed unstriated ventromental plate (Fig 17, vmp), antenna with short 3rd segment (Fig. 18) and rather extended apical mandibular tooth (Fig. 19).

SUBFAMILY CHIRONOMINAE

Key to genera of larval Chironominae found

1. Ventromental plates wide and short, meeting at midline (Fig. 20, vmp). Antenna arising from pedestal (Fig. 22). Lauterborn organs distinct, on elongate stems (Figs. 22–24, LO) *Tanytarsus*
 - Ventromental plates fan-shaped to semilunar, often well separated medially (e.g. Fig. 27). Antenna not on pedestal; Lauterborn organs variable, not on stems (Fig. 25) 2 (tribe Chironomini)

2. Posterior body with trailing ventrolateral appendages arising from abdominal segment 8; segment 9 dorsally with a rounded protruding ‘hump’ (Fig. 26, arrow). Ventromental plates subtriangular, almost in contact medially (Fig. 21, vmp). Antenna (Fig. 25) as long as head *Zavreliella*
 - Ventromental plates more semilunar, more widely separated medially (Figs. 27, 30, 33, 40–42, 46–47, vmp). Antenna shorter than head 3
3. Antenna with 6 segments, Lauterborn organs on apices of 2nd and 3rd segments (Fig. 28, LO) *Conochironomus*
 - Antenna 5-segmented, Lauterborn organs opposite on apex of 2nd segment (Fig. 31) 4
4. Labral setae SI and SII setae simple, blade-like (Fig. 29, SI, SII); labral lamella absent (Fig. 29) *Parachironomus*
 - Setae SI seta plumose (Fig. 34, SI), SII not blade-like; labral lamellae present (Fig. 34, II) 5
5. Outer face of mandible with basal striations (Fig. 32, arrow) *Chironomus*
 - Mandible lacking basal striations 6
6. Ventromental plates narrow, only ca. twice as wide as long (Figs. 40–42, vmp) *Dicrotendipes*
 - Ventromental plates broader, at least 2.5 times as wide as long (Figs. 46–47, vmp) 7
7. Dorsocentral elongate sclerite on head (e.g. Fig 44, frons) with antero-medial ‘fenestra’ (Figs 43–45, fen, arrows). Premandible with 5–6 teeth (as in Fig. 35, pmd) *Kiefferulus*
 - Dorsocentral head sclerite without ‘fenestra’ (e.g. frontoclypeus, Fig. 57). Premandible with 2–3 teeth (as in Fig. 36) *Polypedilum*

SUBFAMILY TANYPODINAE

***Clinotanypus* Kieffer**
(Figs. 1–3)

Three species of *Clinotanypus* have been described from the region: *C. crux* (Wiedemann) and *C. obscuripes* (de Meijere) from Indonesia as adults by Johannsen (1931), and in their immature stages by Zavřel (1933). Kieffer (1924) described *C. pictidorsum* from Java.

Larval *Clinotanypus* cannot be differentiated yet and the only regional rearings known are pharate pupae. The known biologies within this essentially tropical genus suggest that the larvae are predatory, eurythermic and tolerant of organic pollution. The two larval records in this study come from dilute ponds with low conductivities (103, 194 $\mu\text{S}\cdot\text{cm}^{-1}$) and low dissolved solids (65, 97 ppm).

***Tanypus* Meigen**
(Fig. 4)

Tanypus has been reported from the region previously only as *T. punctipennis* Meigen by Johannsen (1931) from Sumatra, with the larva and pupa described briefly by Zavřel (1933).

Known biologies within this worldwide genus suggest that the larvae are predatory in warm shallow pools, especially those with high nutrient loadings. The four larval records in this study come from ponds with conductivities ranging from dilute (49 and 103 to more saline 727 and 4,440 $\mu\text{S}\cdot\text{cm}^{-1}$) and with a similar wide range in dissolved solid concentrations (24, 51 364, 2,230 ppm).

***Fittkauimyia* Karunakaran**

(Figs. 5–7)

Fittkauimyia appears to be represented by a single Indo-Oriental species *F. disparipes* Karunakaran. Although described from Singapore, the taxon was known earlier from a larva reported by Zavřel (1933) from Indonesia as *Tanytus* sp. *Fittkauimyia disparipes* appears to be very tolerant of organic pollution and is clearly an acidophilic species in Singapore and in Northern Territory of Australia. Ashe (1990) records the genus from Sulawesi. The predatory larvae were found in three dilute ponds in this study, with conductivities ranging from 29–49 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 14–25 ppm. Acidity was not measured.

***Ablabesmyia* Johannsen**

(Figs. 8, 11)

Ablabesmyia is a widely distributed genus, readily recognised in the larval stage by the two or three dark, simple claws amongst the dominant yellow ones on the posterior parapod. Two distinct larval types are recognised from the division of the basal segment of the maxillary palp: with two sections in the *A. notabilis* group, and with four or five parts in the *A. hilli* group (Fig. 8). The number of regional species belonging in each grouping is quite uncertain and an extensive rearing programme would be required since adult males are needed for species delimitation.

The first published regional record of the genus concerns *A. moniliformis* Fittkau (1962), recorded from Sumatra as *Pentaneura monilis* Linnaeus, sensu Johannsen (1931) with immature stages recorded by Zavřel (1933). Ashe (1990) recorded the genus from Sulawesi.

Larvae belonging to the *A. notabilis* group were found in three tsunami-impacted sites, with conductivities of 168, 669 and 3,940 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 84, 336 and 2,000 ppm, respectively. One larva belonging to the *A. hilli* group was found in a single disturbed peaty site with conductivity of 255 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 128 ppm.

Late instar larval *Ablabesmyia* have gut contents often comprising smaller chironomids, especially of *Tanytarsus* species.

***Larsia* Fittkau**

(Figs. 14–16)

Larsia is a frequently-occurring genus especially in warm streams and rivers, but is encountered less often in tropical standing waters. Pupal evidence suggests that diversity is higher than the sole published regional record of *L. albiceps* (Johannsen, 1931) whose immature stages were described by Zavřel (1933) from Sumatra. Regionally, larvae were found only in dilute, unimpacted sites ranging in conductivity from 50–1570 $\mu\text{S}\cdot\text{cm}^{-1}$ and in dissolved solids from 23–1,570 ppm. A single pupa, from the most dilute site, has a thoracic horn (Fig. 16) unlike any other found in the genus in Asia or Australia: no association with larvae from any other site can be made with any certainty. However, the larvae from this survey are not the same as those identified tentatively as *L. albiceps* from Australia (Cranston, 2000) judging from slight differences in the arrangement of the cephalic setae and especially the strength of the transverse ‘creases’ of the mentum (gula and submentum) in the Thai specimens (Fig. 15, m, sm) compared to Australian specimens.

***Monopelopia* Fittkau**

(Figs. 9, 12, 13)

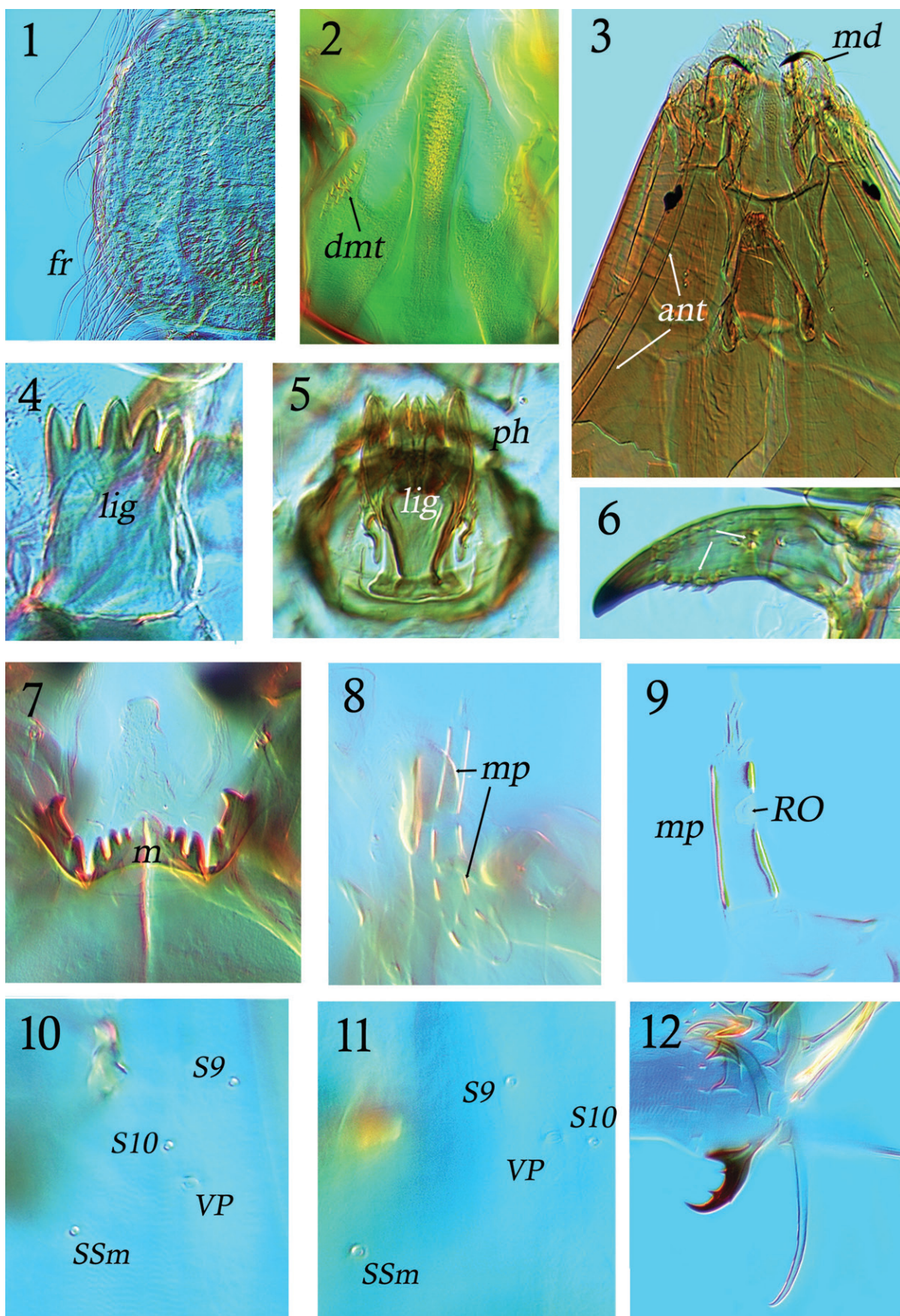
The only previously published record of this genus from Southeast Asia is of *Pentaneura divergens* Johannsen, assigned to *Monopelopia* by Fittkau (1962) based on the immature stages (Zavřel, 1933). In this survey the larvae, which are quite characteristic (for Pentaneurini) were found in several pools of varying conductivities from 27–3,240 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 14–1,630 ppm.

***Paramerina* Fittkau**

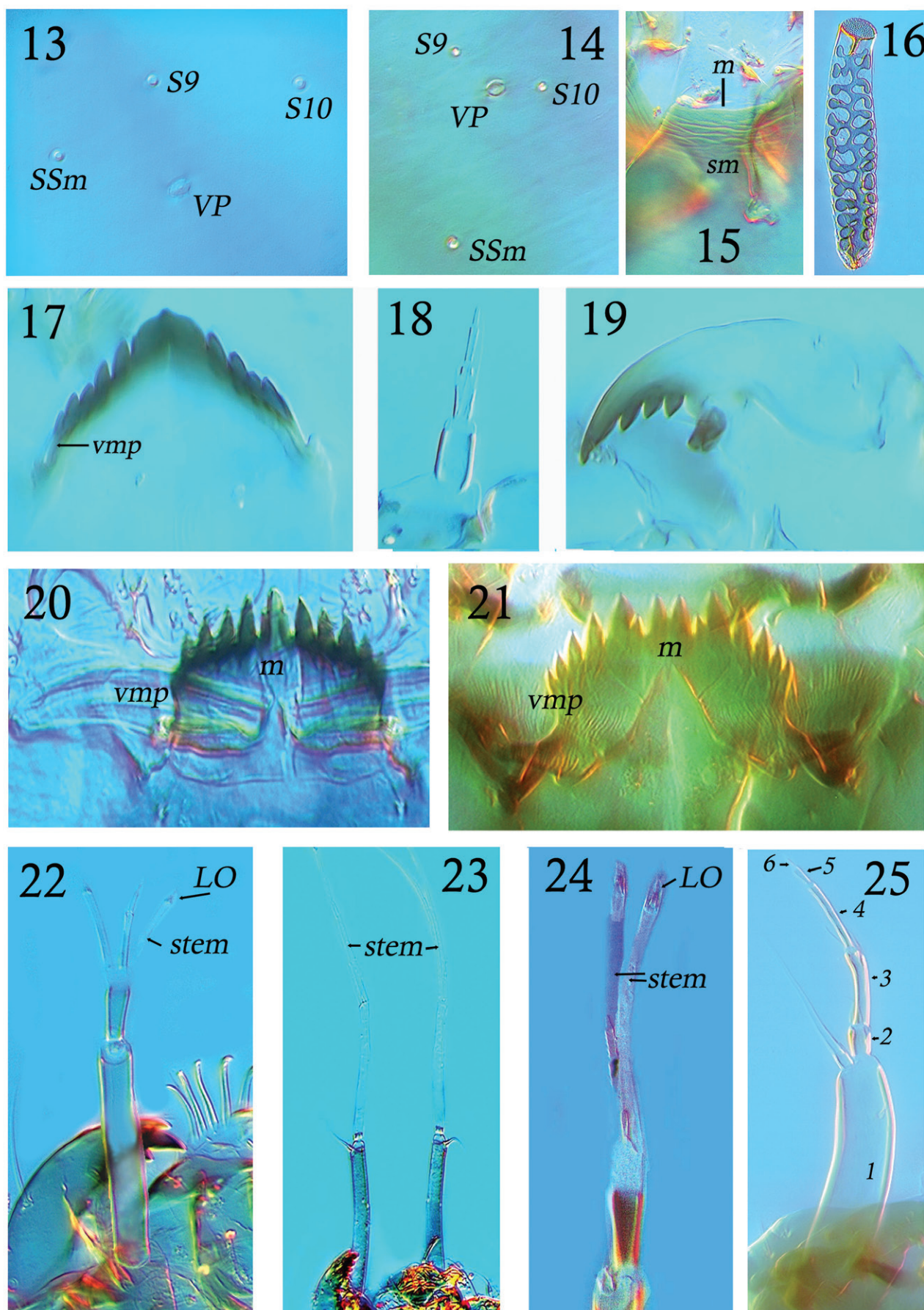
(Fig. 10)

Paramerina is a worldwide genus, quite speciose, and with larvae tolerant of a wide range of environmentally deleterious conditions. *Paramerina aucta* (Johannsen) and *P. dolosa* (Johannsen) from Indonesia, assigned to the genus by Fittkau (1962) are described in their immature stages by Zavřel (1933). *Paramerina ignobilis* (Johannsen) from Sumatra is undescribed in immature stages but appears to be restricted to tree holes from Indonesia to northern Australia. Species discrimination in *Paramerina* is based largely on subtle differences in the pupa with little or no ability to confirm or support larval features.

Thai specimens here allocated to *Paramerina* pose some problems: although usually the genus is recognisable by the palp divided into two parts, with a large ring organ lying between the two parts, this feature may be indistinct or not present. Without this it, larval separation from *Zavreliomyia*



Figs. 1–12. Thai post-tsunami Chironomidae. *Clinotanypus* sp.: 1, lateral body setal fringe; 2, dorsosentum; 3, ventral head (anterior). *Tanypus* sp.: 4, ligula. *Fittkauimyia* sp.: 5, ligula, pecten hypopharyngis; 6, mandible; 7, mentum. *Ablabesmyia* sp.: 8, maxillary palp. *Monopelopia* sp.: 9, maxillary palp. Ventral head setae and pit of: 10, *Paramerina* sp., 11, *Ablabesmyia* sp. *Monopelopia* sp.: 12, posterior parapod claw. Abbreviations: ant, antenna; dmt, dorsosentum teeth; fr, fringe; lig, ligula; m, mentum; md, mandible; mp, maxillary palp; ph, pecten hypopharyngis; RO, ring organ of maxilla; SSm, seta submentata; S9, S10, cephalic setae 9, 10; VP, ventral pit.



Figs. 13–25. Thai post-tsunami Chironomidae. Ventral head setae and pit: 13, *Monopelopia* sp., 14, *Larsia* sp. *Larsia* sp.: 15, mentum; 16, pupal thoracic horn. *Parakiefferiella* sp.: 17, mentum; 18, antenna; 19, mandible. Menta: 20, *Tanytarsus formosanus*; 21, *Zavreliella* sp. Antennae: 22, *Tanytarsus formosanus*; 23, *Tanytarsus* ‘Thai 1’; 24, *Tanytarsus* ‘Thai 2’; 25, *Zavreliella* sp. Abbreviations: LO, Lauterborn organ; m, mentum; sm, submentum; SSm, seta submenta; S9, S10, cephalic setae 9, 10; vmp, ventromental plate; VP, ventral pit.

may not be possible: both have similar mouthparts (ligula and mandible), similar cephalic setal patterns and a darkened posterior to the procercus. An often-cited difference is the posterior parapod claws all being pale in *Zavreliomyia* and including one small clearly bifid claw. Ambiguously placed specimens from Thailand have a contrastingly dark posterior parapod claw among simple claws, but an apparently undivided palp.

Few larvae have been found only in unimpacted dilute sites, with conductivities of 35–168 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 17–84 ppm.

SUBFAMILY ORTHOCLADINAE

The subfamily Orthoclaadiinae is very poorly represented in samples from low-lying, warm, ponds and pools in southwestern Thailand. Remarkably, no algal-feeding species of the eurythermic genus *Cricotopus* were found, although this ubiquitous genus is present in flowing waters throughout the country.

Parakiefferiella Thienemann

(Figs. 17–19)

Parakiefferiella is a widespread genus, first reported from the region from pupal exuviae from Sulawesi (Ashe, 1990). One larva clearly belonging to this genus, but probably in 3rd (penultimate) instar, came from an unimpacted site, amongst the most dilute at 28 $\mu\text{S}\cdot\text{cm}^{-1}$ conductivity and 14 ppm dissolved solids.

SUBFAMILY CHIRONOMINAE TRIBE TANYTARSINI

Tanytarsus v.d. Wulp

(Figs. 20, 22–24)

Tanytarsus is a worldwide genus with many species, with taxonomy based especially on the complex male genitalia, on diagnostic pupal exuvial spine and spinule patterns. Larvae are much more difficult to distinguish, and in every region studied, there is a mismatch between the number of larval types recognised and the substantially greater total number of species present.

One readily-recognisable species, *T. formosanus* Kieffer, occurs throughout regional standing waters. The species identity is confirmed by pharate pupae (that is, with characteristic pupal abdominal patterning visible within the late 4th instar larva) and some pharate adults, with male genitalia visible within pupae. The larva conforms to that described by Ekrem (2001), who resolved the convoluted taxonomy and nomenclature of this widespread Old World species. As elsewhere, the larvae of *T. formosanus* in Thailand exhibit wide environmental tolerance, occurring in tsunami-impacted and unimpacted ponds, including disturbed and

undisturbed peat swamps. Maximum conductivities tolerated were as high as 7,800 $\mu\text{S}\cdot\text{cm}^{-1}$ with dissolved solids of 3,900 ppm, in impacted sites in which the species can be common and persistent across the survey period. Unassociated larvae likely to be conspecific based on basic morphology are also present in dilute water.

Two further types of larval *Tanytarsus* can be distinguished by the relative lengths and pigmentation pattern of the antennal segments and by differences in the relative and absolute length of the Lauterborn organs stems. A species with very long stems to the Lauterborn organs (Fig. 23), here termed ‘Thai sp. 1’ occurs sporadically in dilute water bodies with conductivity of 43–260 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 22–120 ppm. A third larval morphotype ‘Thai sp. 2’ with intermediate lengthened stems to the Lauterborn organs (Fig. 24) occurs in both unimpacted dilute (44–100 $\mu\text{S}\cdot\text{cm}^{-1}$, 22–52 ppm) ponds and in one impacted site of 1,650 $\mu\text{S}\cdot\text{cm}^{-1}$ and 820 ppm dissolved solids. All larval *Tanytarsus* larvae are considered to be collector-gatherers (detritivores).

SUBFAMILY CHIRONOMINAE TRIBE CHIRONOMINI

Chironomus Meigen

(Figs. 32, 34–36)

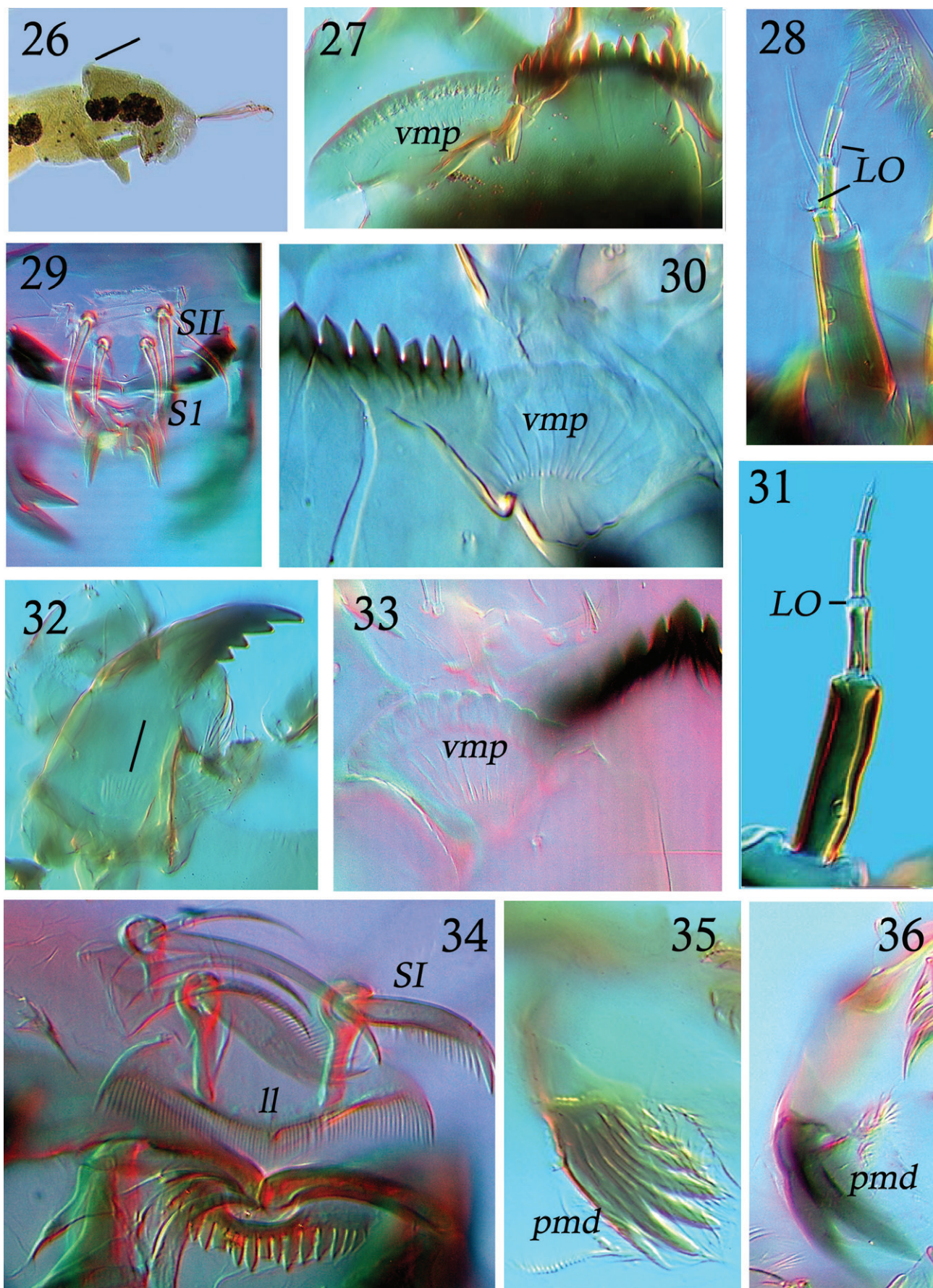
Chironomus is one of the largest, and most difficult genera of chironomids. Adult morphology is rather homogeneous, and progress in separation of larvae is modest. Larvae are collector-gatherers, often found in organically enriched aquatic environments, both lotic and lentic. Two larval types are distinguished:

Chironomus javanus (Kieffer) is somewhat atypical in resembling that of *Kiefferulus* in having numerous premandibular teeth, specifically 6–7 teeth (Fig. 35, pmd). However, this larva displays the characteristic striations at the base of the mandible (Fig. 32, arrow) possessed by virtually all species of *Chironomus* and molecular data show it is a *Chironomus* (Martin et al., 2007). The remaining larvae belonging to *Chironomus*, all with a two-toothed premandible (Fig. 36, pmd), belong to what is undoubtedly a heterogeneous assemblage of species which, lacking rearings to adult males, cannot be discriminated or named with certainty. Amongst them undoubtedly is *C. kiiensis* Tokunaga, identified as such from a pharate male although without being able to confirm the distinctive wing pattern in the teneral pharate wing.

Conochironomus Freeman

(Figs. 27–28)

When Cranston & Hare (1995) revised the genus *Conochironomus*, species were known only from Australia and Africa. Since then, the distinctive larvae and pupae have been found in Thailand (P.S. Cranston, F. Reiss, unpublished data). Furthermore, a new genus and species named and



Figs. 26–36. Thai post-tsunami Chironomidae. *Zavreliella* sp.: 26, posterior body. *Conochironomus* sp.: 27, mentum; 28, antenna. *Parachironomus* 'K3': 29, labrum; 30, mentum. *Kiefferulus* sp.: 31, antenna. *Chironomus* sp.: 32, mandible. *Parachironomus* sp.: 33, ventromental plate. *Chironomus javanus*: 34, epipharynx; 35, premandible. *Chironomus* sp.: 36, premandible. Abbreviations: II, labral lamella; LO, Lauterborn organ; pmd, premandible; SI, SII, labral setae I, II; vmp, ventromental plate.

described from Sumatra by Kikuchi & Sasa (1990) must be allocated to *Conochironomus*.

In the post-tsunami survey, two larvae were found, one in a recovering tsunami-impacted site (505 $\mu\text{S}\cdot\text{cm}^{-1}$, 259 ppm), the other in a more dilute unimpacted, non-peaty pool of conductivity 205 $\mu\text{S}\cdot\text{cm}^{-1}$ and with 102 ppm dissolved solids. *Conochironomus* larvae are collector-gatherers.

Dicotendipes Kieffer

(Figs. 37–42)

Dicotendipes is one of the few genera to have been studied adequately in the region, thanks to the work of Epler (1988). Three widely-distributed species are recognised that can be distinguished using the keys of Epler (1988) and Cranston (2000). *Dicotendipes pelochloris* (Kieffer), whose immature stages were described as *Cladotendipes inferior* (Johannsen) by Lenz (1937), occurs in several post-tsunami impacted ponds. All larval occurrences were in recovering or minimally-impacted ponds, of conductivity 169–897 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 84–449 ppm.

The immature stages of *D. septemmaculatus* (Becker) have been described by Epler (1988) and Cranston (2000). The species has been reported regionally from Lake Toba, Sumatra (Kikuchi & Sasa 1990). Larvae of *D. septemmaculatus* were found in three dilute pools (104–192 $\mu\text{S}\cdot\text{cm}^{-1}$ conductivity, dissolved solids 92–96 ppm).

One larva apparently conspecific with those identified as *D. 'sarinae/K4'* from northern Australia (Cranston, 2000) was found in a moderately impacted pool recovering 18 months post-tsunami (440 $\mu\text{S}\cdot\text{cm}^{-1}$ conductivity, dissolved solids 222 ppm).

These three species can be distinguished as larvae as follows:

1. Frontal apotome of dorsal head with ovoid fenestra (Fig. 37). Outermost mental teeth composite and fused (Fig. 40) *D. pelochloris*
- Frontal apotome of dorsal head without such ovoid fenestra (Figs. 38, 39). Outermost mental teeth separate apically (Figs. 41, 42) 2
2. Frontal apotome with narrow, elongate process (Fig. 38) *D. septemmaculatus*
- Frontal apotome without indication of fenestra or process (Fig. 39) *D. 'K4'*

Dicotendipes larvae are collector-gatherers: larvae of some species will tolerate quite high nutrient and salinity levels.

Kiefferulus Goetghebuer

(Figs. 31, 43–47)

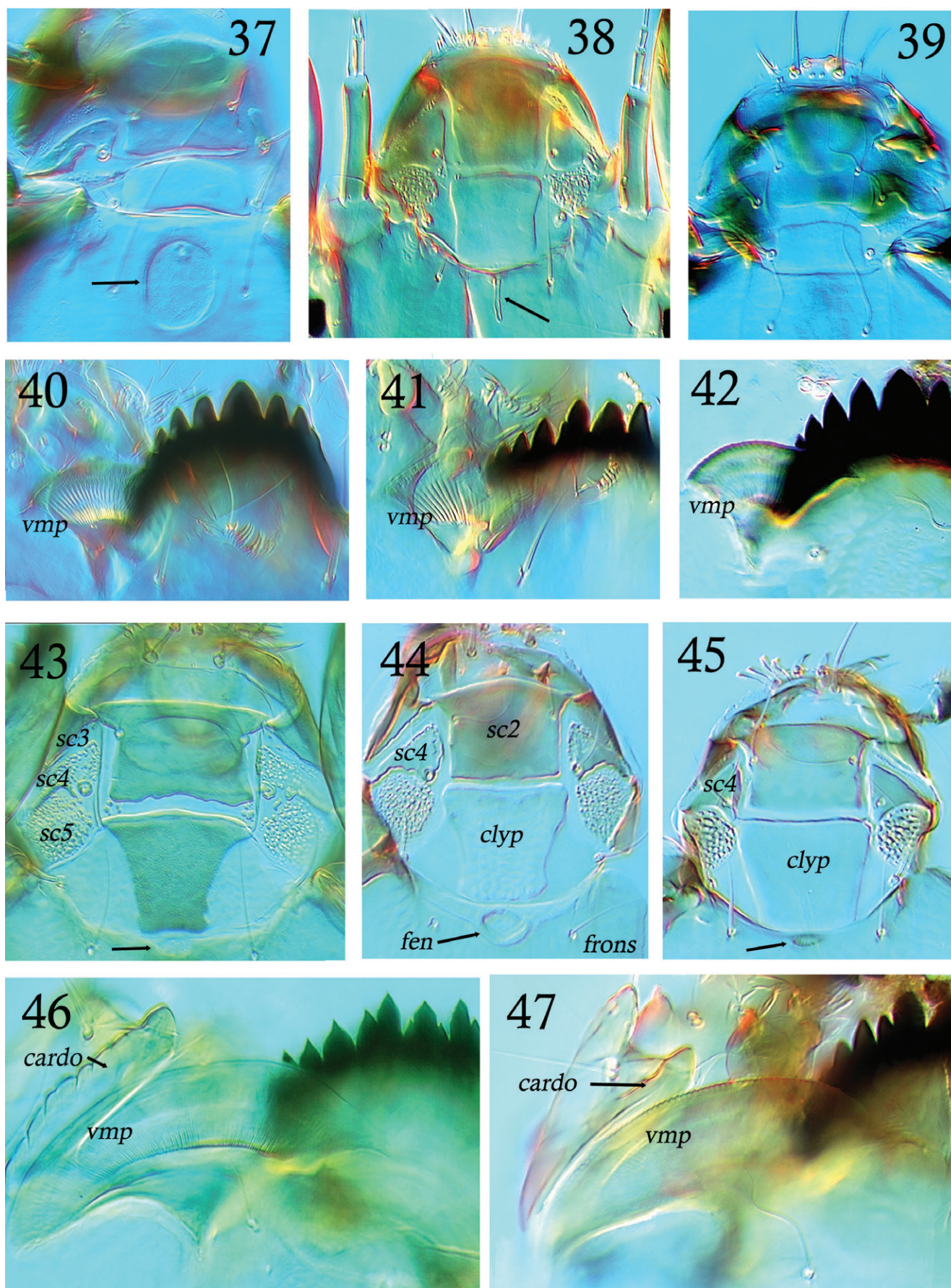
Of all the taxa found in this study, *Kiefferulus* proved most problematic. One species whose nomenclature and identity

has proved rather straightforward is *Kiefferulus longilobus* (Kieffer) recognised by Cranston et al. (1990) as restricted to saline coastal-subcoastal habitats in the Indian and Pacific Oceans. In our post-tsunami survey *K. longilobus* dominated in the highest salinities (reaching 3,900 $\mu\text{S}\cdot\text{cm}^{-1}$, i.e. seawater equivalent), usually involving the most recent and long-lasting tsunami-impacted sites. One coastal pool in which *K. longilobus* was abundant was later discovered to be subject to continuing periodic marine tidal inundation. The lowest conductivity in which the species occurred, 4,400 $\mu\text{S}\cdot\text{cm}^{-1}$, was at a site in which it co-occurred with the other two regional *Kiefferulus* species.

The taxonomy and nomenclature of other local *Kiefferulus* species proved problematic, with too many historic names for what evidently are few taxa. Species are separable as larvae, very easily distinguished as pupae and have distinctive male genitalia. The problem has been that species were frequently re-described under different names, their respective types were not examined and early descriptions often are inadequate for subsequent recognition. These difficulties were exacerbated by the nomenclature (including at generic level) proposed by Johannsen and Lenz in their studies of the German Sunda Expedition material (Johannsen, 1932; Lenz, 1937). Not surprisingly, Hashimoto et al. (1981), in their study of the Chironomini from Thai rice fields, placed these and variably related species into a 'catch-all' genus: *Chironomus*. Hashimoto et al.'s rice field study was based entirely on swept, predominantly male, adult midges, neglecting the often more diagnostic immature stages.

Today, many rearings connecting larvae to pupae or pharate adults provide associated material for many species. Diagnostic features from larval, pupal and adult male genital features respectively can be reconciled. For the present study, types (of adult males) have been examined where available, and the oldest names for the three local species determined. *Chironomus calligaster* and *Chironomus barbatitarsis* described from Indian and Burmese specimens located in the Indian Museum collections by Kieffer (1911) appear to be the earliest names for the two *Kiefferulus* species. Unfortunately, junior synonyms for both names, also from Kieffer, attained usage even though Chaudhuri & Ghosh (1986), who recognised both names by studying type material in the National Zoological Collection of the Zoological Survey of India, described their immature stages and allocated both species correctly to *Kiefferulus*.

Some previous studies have placed the three local species of *Kiefferulus* in different genera: *longilobus* in '*Carteronica*', *barbatitarsis* or its synonyms in *Nilodorum* and *Stictotendipes* and *calligaster* and its synonyms in *Kiefferulus*. In the regional catalogue (Sublette & Sublette, 1973) the many names are scattered throughout four genera, and the two valid names were treated as unplaced. The conclusion that these three taxa (*longilobus*, *barbatitarsis* and *calligaster*) are congeneric was proposed by Cranston et al. (1990) based on comparative morphology and phylogenetic analysis, and has been confirmed by a molecular study (Martin et al., 2007).



Figs. 37–47. Thai post-tsunami Chironomidae. *Dicotendipes* spp.: dorsal heads: 37, *D. pelechloris*; 38, *D. septemmaculatus*; 39, *D. sarinae*. Mentum and ventromental plate: 40, *D. pelechloris*; 41, *D. septemmaculatus*; 42, *D. sarinae*. *Kiefferulus* spp., dorsal head sclerites: 43, *K. longilobus*; 44, *K. calligaster*; 45, *K. barbatitarsis*. Mentum, ventromental plate, anterior cardo: 46, *K. calligaster*, 47, *K. barbatitarsis*. Abbreviations: cly, clypeus; fen, fenestra; sc1–4, labral sclerites 1–4; vmp, ventromental plate.

Kiefferulus calligaster occurs in all types of ponds surveyed in this study, ranging from highly saline to the most dilute, including peaty and non-peaty, disturbed and unimpacted. Its upper tolerance limit appears to be 12.4 mS.cm^{-1} for conductivity, and 2,700 ppm for dissolved solid concentration, but all records are below the maximum conductivities encountered.

Kiefferulus barbatitarsis occurs also in all types of ponds, often co-occurring with *K. calligaster*. At an upper tolerated salinity limit with conductivity of $18,700 \mu\text{S.cm}^{-1}$, it can co-occur with *K. longilobus*.

The regional species of *Kiefferulus* can be distinguished in the larval stage by the following key:

1. Posterior body without ventral tubules. Labral sclerites 3, 4 and 5 dissociated, all granular and indistinctly separated (Fig. 43, sc3–5) *K. longilobus*
 - Posterior body with paired ventral tubules, from short to at least as long as width of segment bearing them. Labral sclerites 3, 4 and 5 recognisably distinct, 4th sclerite complete (Figs. 44, 45, sc3) 2
2. Cardo anteriorly formed as crenulate ridge; anterior margin of ventromental plate smooth (Fig. 46). Clypeus more narrowed posteriorly and dilated anteriorly; fenestra rounded (Fig. 44, fen) *K. calligaster*
 - Cardo anteriorly formed as weak, non-crenulate ridge; anterior margin of ventromental plate crenulate (Fig. 47). Clypeus subrectangular; fenestra narrow, elongate (Fig. 45, arrow)
..... *K. barbatitarsis*

The larvae of *Kiefferulus* are collector-gatherers found in fine sediments, especially in ponds, pools (including those in drying rivers) and in rice paddies. *Kiefferulus longilobus* has been reported as a nuisance (as swarming adults) around marine incursion inland waters (Cranston et al., 1990).

***Parachironomus* Lenz**

(Figs. 29, 30, 33)

The genus *Parachironomus* is widespread, but it is never abundant in the region: no species was found in Sulawesi by Ashe (1990). *Parachironomus tobaquartus* Kikuchi & Sasa (1990) was described in the adult stage from Lake Toba, Sumatra.

Two species occurred as larvae in post-tsunami pools and both belong to the *arcuatus* group (Pinder & Reiss, 1983) having simple SI setae and a convex mentum with dark teeth. One is identical to *P. 'K1'* (Cranston, 2000) reported from northern Australia, having numerous small teeth laterad to a typical mentum (Fig. 30). This larval type was found only on three consecutive sampling occasions at one site (Hard Kloung Luang) in Krabi. The other, a single individual from a dilute and unimpacted pool, differs in having a typical mentum for *Parachironomus* but with very narrow ventromental plates and a strongly scalloped anterior margin (Fig. 33).

***Polypedilum* Kieffer**

(Figs. 48–59)

This most species-rich genus of Chironominae is very common in tropical waters, including those of Thailand. The larvae of the genus require taxonomic study: there are many names, many species and different names have been used for the same organisms in different parts of the range. The current subgeneric system does not work for all larvae.

Features that can assist in discriminating between larvae:

Mentum (Figs. 48, 51–53): relative heights of teeth and evenness of size of increasingly lateral teeth; ventromental plates: relative dimensions, inner contour, medial separation and number of striae;

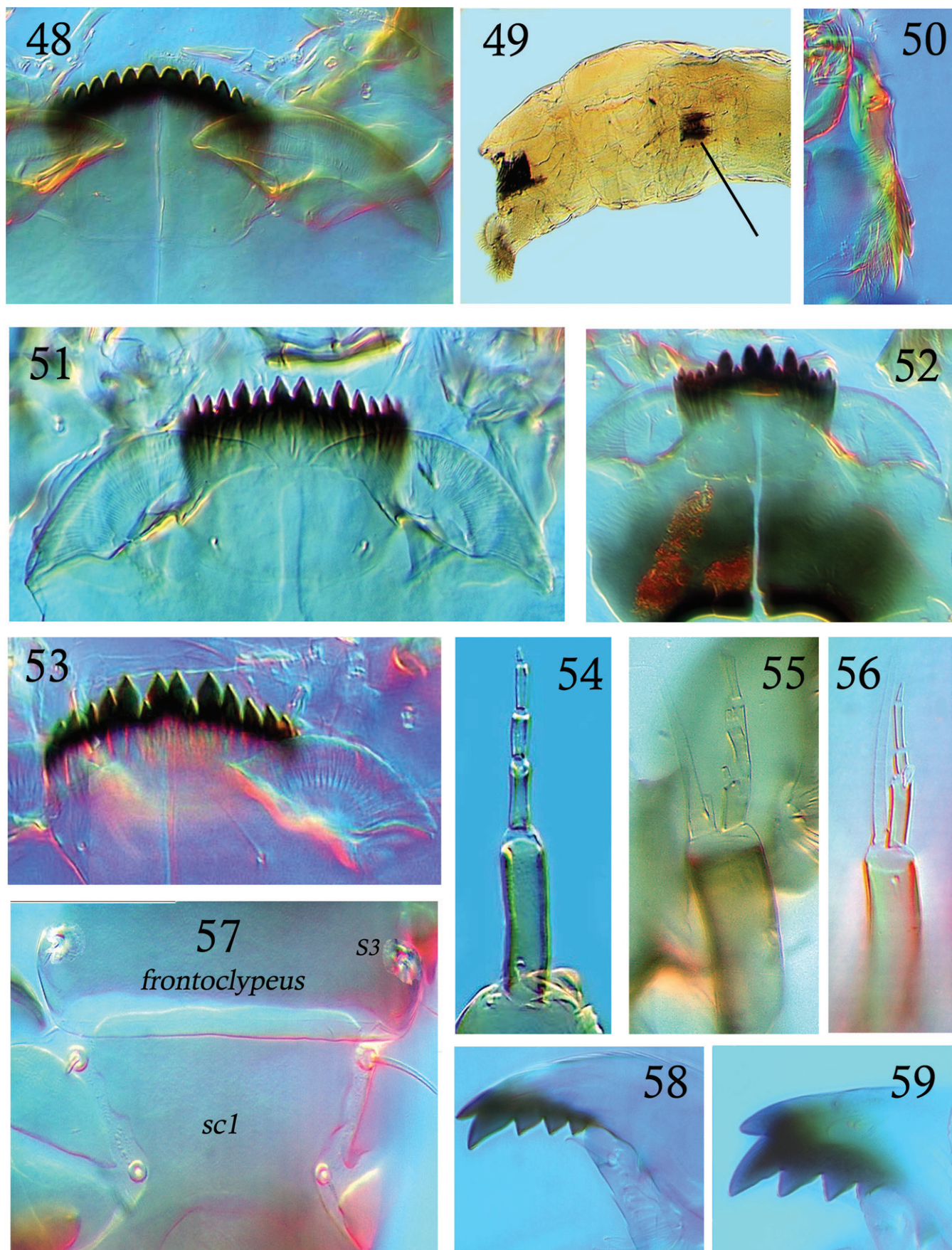
Mandible (Figs. 58–59): number of inner teeth, extent of pigment and size of outer tooth;

Dorsal surface of head (Fig. 57): shape of anterior margin of frontoclypeal apotome, depth of any hyaline anterior submargin thereof, position of cephalic seta S3 relative to anterior and lateral margins;

Antenna (Figs. 54–56): relative and absolute lengths of segments and blade.

Polypedilum leei Freeman is easily-recognisable amongst the regional species by the mentum (Fig. 48) with all teeth more or less equal in size combined with a five-toothed premandible. The presence in the anterior abdomen of a sclerotised 'crop' (Fig. 49, arrow) is highly characteristic, perhaps even unique. Larvae of *P. leei* occurred in several sites recovering from tsunami impact ($314\text{--}1,847 \mu\text{S.cm}^{-1}$ conductivity, 157–927 ppm), including three sequential samples from one site and also in the dilute, unimpacted pond ($25\text{--}42 \mu\text{S.cm}^{-1}$ conductivity, dissolved solids 13–21 ppm) in which *P. nubifer* (see below) occurred. A pharate larva and a pharate female pupa confirms the identity and association.

Polypedilum 'Thai sp. 1' has a mentum with relatively even tooth height, although the first laterals are lower than the medians and 2nd laterals, but not excessively so (Fig. 51). The premandible has the typical two apical teeth of most congeners, but unlike *P. leei*. The larva resembles *Polypedilum* 'B1' figured in an Australian guide (Cranston, 2000), with a ratio of the ventromental plate width to height near to three ($108 \times 38 \mu\text{m}$) and with a distinctive rather elevated cluster of outer (5th–7th) mental teeth. However, the curvature of the ventromental plate of *P. 'B1'* is not evident in the Thai specimen, and conspecificity is unlikely. The single larva of this type occurred in an unusual pond which had water chemistry of $1,571 \mu\text{S.cm}^{-1}$ and dissolved solids 786 ppm on the one occasion in which the larva was found, but although unimpacted, showed increasing conductivity with the passage of time.



Figs. 48–59. Thai post-tsunami Chironomidae. *Polypedilum leei*: 48, mentum, ventromental plate; 49, anterior thorax; 50, premandible. Mentum, ventromental plate: 51, *Polypedilum* ‘Thai sp 1’; 52, *Polypedilum. nubifer*; 53, *Polypedilum (Pentapedilum)* ‘K1’. Antenna: 54, *Polypedilum* ‘Thai 2’; 55, *P. nubifer*; 56, *P. ‘K1’*. 57, Dorsal head sclerites, *P. ‘Thai 2’*. Mandible; 58, *P. ‘K1’*, 59, *P. ‘Thai 2’*. Abbreviations: S3, cephalic seta 3; sc1, labral sclerite 1; vmp, ventromental plate.

Polypedilum nubifer Skuse, the type species of *Polypedilum*, has a typical mentum (Fig. 52) but is atypical for the genus in having the Lauterborn organs alternate on an antenna apparently composed of four segments (Fig. 55). Although larvae of *P. nubifer* are common in eutrophic and disturbed habitats almost globally, in post-tsunami surveys the species was found only in two consecutive samples from one pond of conductivity 25–42 $\mu\text{S}\cdot\text{cm}^{-1}$, dissolved solids 13–21 ppm.

Polypedilum (Pentapedilum) 'K1'. This larva is unusual amongst surveyed *Polypedilum* in that the first lateral mental teeth are very small, each almost adpressed to a median tooth (Fig. 53), the ventromental plate width-height ratio is ca. 2.0, the antennal 3rd segment is half the length of the 4th (Fig. 56) and the mandible has three distinct inner teeth (Fig. 58). In all these features the larva is identical to *Polypedilum (Pentapedilum) 'K1'* from northern Australia, which may belong to *P. nodosum* (Johannsen) described from Indonesia. A larva of this type occurred on consecutive sampling dates in a pond recovering from impact (to conductivity of 515, then 314 $\mu\text{S}\cdot\text{cm}^{-1}$, and to dissolved solids of 259 and 157 ppm respectively).

The most common, widespread and salinity-tolerant species of *Polypedilum* is one that falls within a complex of species scarcely distinguishable in the larval stage. This complex includes the widespread *P. convexum* (Johannsen), the recently-described *P. australotropicus* Cranston, and several Australian taxa distinguishable only with difficulty in the larval stage. The occipital margin is pale, the frontoclypeus shows only a modest pale area anteriorly (Fig. 57) and the antenna has segments 3 and 4 more or less similar in length (Fig. 54). The mandible has two free inner teeth (Fig. 59) (note that the innermost 'tooth' is not free-standing as seen in Fig. 58 but is fused into the mola). Given the apparent lack of conspecificity with previously recognised species, the species here is termed *Polypedilum 'Thai 2'*.

Zavreliella Kieffer
(Figs. 21, 25, 26)

Two larvae belonging to *Zavreliella* were found in dilute unimpacted, non-peaty pools of conductivity 77 and 180 $\mu\text{S}\cdot\text{cm}^{-1}$ and dissolved solids of 38 and 90 ppm, respectively. *Zavreliella marmorata* (v.d.Wulp) has been reported from Indonesia (Reiss, 1990) and pupal exuviae of the genus have been reported from Sulawesi (Ashe, 1990).

DISCUSSION

As is well understood, species of Chironomidae vary significantly in the responses of different species to environmental factors, providing support for a role in biological monitoring of water quality (e.g. Rosenberg, 1993; Johnson, 1995). Thus it is no surprise that the Chironomidae of the coastal ponds of southwestern Thailand affected by the tsunami of December 2004 show variation according to past and prevailing environmental conditions, notably

the elevated and subsequently declining conductivity due to salinity. Whether larval Chironomidae are the optimal organisms for studying responses to environmental change remains open to debate. Although larvae can be identified to genera using, for example, Cranston's (2004) regional key to genera, as shown here it is species responses that are distinctive. Species-level identification of larval Chironomidae is difficult, requiring microscope slide preparation and high power optics for separation of congeners, e.g. in *Kiefferulus*, *Tanytarsus* and *Polypedilum*. Furthermore, in the potentially speciose and likely indicative genus *Chironomus*, larval morphology alone is unlikely to distinguish cryptic species. An alternative approach, using the cast pupal skins of emerged adults (the exuvial technique, e.g. Hardwick et al., 1995) can ease handling and allow identification more readily to morphospecies. However, collection of floating exuviae is poorly compatible with standardized benthic sampling, requiring extra effort, equipment and time. Furthermore, exuviae in tropical standing waters seem to be much less persistent than in running and cooler standing waters, due to degradation by microorganisms. Adult sampling is compromised similarly by additional effort and equipment, and in this case by inability to assert that captured species emanated from the water body under study. Further, all techniques suffer from inability to enforce any 'stop rule' when sampling for maximum diversity—even by those with expertise in the field, live chironomids, but especially larvae, cannot be field-identified (or even the number of morphospecies assessed) with confidence. Nevertheless, in keeping with Campbell & Parnong's (2001) plea, here I provide the means to gain ecological insights using chironomid larvae to identify and interpret biotic changes with salinity, which may be valuable in interpreting impacts associated with continuing introduction of seawater prawn farms.

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