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Taxonomy and ecology of *Phreatoicus typicus* Chilton, 1883 (Crustacea, Isopoda, Phreatoicidae)

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Phreatoicus typicus Chilton, 1883 was the first described species of the isopod family Phreatoicidae. The species is here redescribed using three female specimens from the syntype series, of which one is designated as lectotype. Until this paper, males of this species had not been described and the biology of the species was poorly understood. New specimens of both sexes from Canterbury Plains (South Island, New Zealand), collected as a part of a year-long environmental survey of groundwater wells near sewage oxidation ponds, are used to supplement the species redescription. The survey also collected data on the biology of phreatoicids and environmental correlates to their presence. Males of *P. typicus* showed only limited sexual dimorphism, and were similar to those of a related species, *P. orarii* Nicholls, 1944. *Phreatoicus typicus* is easily separated from *P. orarii* and *Neophreatoicus assimilis* (Chilton, 1894) using characters apparent in the mandible, maxillula and pleotelson tip. Among four wells that were subjected to detailed biological and physicochemical analyses, *P. typicus* was found at only two sites. These two wells shared substantially higher concentrations of coliform bacteria and lower fine sediment loads than the wells that lacked *P. typicus*. Thus, unsedimented but polluted groundwaters may be providing a suitable habitat for these isopods. Although our size frequency data for *P. typicus* were biased toward larger sizes, sufficient numbers of adults were taken to make some general observations on life history. Well-defined cohorts changed in size during the sampling period. Males and females achieved approximately the same maximum length (near 20 mm) and were mature above lengths of 11.5 mm. The iteroparous life cycle may span more than one year, and synchronous reproduction was signaled by a large recruitment to the adult sizes during the winter months.

Keywords Crustacea, Isopoda, Phreatoicidea, 'well shrimp', ground water, pollution, life cycle, bacteria

INTRODUCTION

Phreatoicus typicus Chilton, 1883 was an exciting find for zoologists of late last century. This species was the first described member of a "primitive" isopod group found only in the Southern Hemisphere (Nicholls 1943, Banarescu 1990). The initial discussions of this species were undecided about its status as an isopod (cf. Thomson & Chilton 1886 – an amphipod or Stebbing 1888 – a tanaid), although later workers (e.g., Sheppard 1927) had no such problems. This species is also significant as the type member of the New Zealand phreatoicideans, which are phylogenetically distinct from the better known Australian fauna (Wilson & Keable in press, Wilson & Johnson in press). Even though *P. typicus* is common in groundwater localities of the Canterbury Plain of the South Island New Zealand, it remains

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poorly known. In particular, the males have never been described, and the ecology and population biology has not been previously studied. This paper addresses these areas, providing a new insight into the habitat preferences of these interesting and phylogenetically important crustaceans.

MATERIALS AND METHODS

Site Habitats. Collections were made from wells at Templeton on the central Canterbury Plains. The following description of the wells and site is based on Martin & Noonan (1977), Close (1984) and Sinton (1984). The wells surround a small sewage treatment and disposal plant discharging approximately 900 $m^3.day^{-1}$ of effluent from three oxidation ponds onto a border-dyked disposal area. Strips within this 25 ha disposal area are irrigated in rotation and the covering rye grass/clover pasture is grazed periodically by sheep. Soils, comprising Templeton silt and sandy loam (0.25–2.0 m depth), overlie coarse to very coarse silty gravel interspersed with layers of sand and clay to an undetermined depth (>24 m). Groundwater lies at a depth of approximately 12 m and has horizontal flow velocities of 111–196 $m.day^{-1}$ in a northwest to southeast direction, and downward velocities in the wells ranging between 0.2 and 1.9 $m.min^{-1}$ (Sinton & Close 1983).

Animals, including phreatoicidean specimens, were collected from eight wells over December 1985–September 1986 during a larger investigation of organic carbon flows in the Canterbury groundwater ecosystem (Fenwick in prep). Most phreatoicideans came from three wells (wells 2, 4 and 8), which are immediately downstream of the disposal area. Well 1 was located 500 m upstream of the disposal area, and Wells 10 and 11 are situated approximately 170 and 300 m downstream of the oxidation pond disposal area. These wells were of two types. Wells 1–4 were 75 mm diameter bores sunk to 18 m depth, with the lower 6 m screened (with holes of about 1.5–2 × 60 mm) to about 1 percent of the total bore surface. Well 11 was 100 mm in diameter, reaching 24 m depth and screened to about 20 percent over the lower 12 m.

Sampling and Environmental Measurements. Phreatoicidean specimens were collected from wells using a weighted, stainless steel bailer open at one end and a folding net (0.25 mm mesh) with a flexible, sprung rim that exactly fitted the internal diameter of the well casings when expanded. The bailer containing the folded net was lowered to the bottom of a well, briskly raised and lowered 4–5 times to flush any animals on the bottom into the water column, then lowered to the bottom again. The net was then gently pulled out of the bailer and up to the surface on its separate nylon line. In this way, the entire water column was filtered and any animals clinging to the well walls were also collected. At other times, animals found clinging to lines and equipment suspended in wells were also collected. These collections were made coincidental to other research, so *P. typicus* was not collected on a systematic basis. Consequently, relative abundance of *P. typicus* in the different wells may not be representative of the actual population abundance. Specimens were preserved in 5 % formalin, usually within 30 minutes of collection and transferred to 70 % ethanol after 1–5 days.

Water temperatures were measured using a spirit thermometer as soon as the bailer samples were retrieved from wells. Measurements of pH were made on fresh samples in the field using a Gallenkamp pH stick. Suspended load for each well was calculated from increases in dry weight of five dried, pre-weighed GF-C filter discs after 100 ml subsamples (undisturbed for 20–30 min.) were drawn through them under light vacuum. Dissolved oxygen determinations were made using the modified Winkler method (Golterman 1970) from two, 250–300 ml replicate samples. These samples were collected by gently lowering the bailer to just below the well water level, and then siphoning the water obtained into oxygen bottles, which were stoppered. The samples were stored in an insulated box, and then processed to a relatively stable $Mn(OH)_2$ floc stage within two hours of collection.

The dichromate wet oxidation method (Maciolek 1962) was used for quantitative organic carbon determinations. Five 100 ml aliquots of a separate water sample were evaporated to dryness at a temperature of 60°C for total organic carbon determinations. Another five subsamples were filtered (0.45 μm membrane filters) under light vacuum, evaporated and analysed for dissolved organic carbon content. Two additional 100 ml samples from each well (one filtered through a 0.45 μm membrane filter) were stored in plastic bottles at -20°C for subsequent quantitative analyses for ammonia nitrogen, total Kjeldahl nitrogen, nitrate nitrogen, total phosphorus, dissolved reactive phosphorus and chloride, by the Water Quality Section, Christchurch Hydrology Centre, Ministry of Works and Development. See Close (1984) for a description of methods.

Samples for biochemical oxidation demand (BOD_5) were taken along with samples for physico-chemical determinations. One glass-stoppered bottle of water (250–300 ml) from each well and one containing distilled water were inverted, placed in a container of water and incubated in darkness at 18–20°C for five days. The dissolved oxygen concentrations in these bottles (modified Winker method, paired subsamples for each bottle) were compared with those in a second set prepared at the same time but which were analysed immediately following collection. Thus, biochemical oxidation demand determinations incorporated a correction for any changes in dissolved oxygen concentration in the distilled water controls.

During May-June 1986, bacterial population densities in water from wells 1, 2, 4 and 11 were determined. Samples collected in a stainless steel jerk sampler (sterilized by two rinses with absolute ethanol, followed by two rinses with sterile water) were stored in sterile 250 ml glass bottles in crushed ice and processed within four hours. The Water Quality Section of Christchurch Hydrology Centre, Ministry of Works and Development, determined coliform bacteria densities using membrane filtration.

Taxonomic and life history methods. All localities are from South Island, New Zealand, unless otherwise stated. A DELTA database (Dallwitz 1980; Dallwitz et al. 1993; Wilson & Keable in press) was used to generate the species description. The DELTA program INTKEY was employed to evaluate diagnostic characters for *Phreatoicus typicus* relative to other phreatoicidean taxa. Specimens of the other species in *Phreatoicus*, *P. orarii* Nicholls, 1944 were not available for comparison. The features of this species were determined from the original description and illustrations, and compared to those of *P. typicus*. The female reproductive status (Table 2, Figure 12) was determined by oostegite development. Preparatory 1 females had oostegite buds reaching as far as the ventral midline. Preparatory 2 females had oostegite buds exceeding the ventral midline, but not greater than the sternite width. The brooding condition was characterised by oostegites greatly overlapping and wider and longer than sternites (see also Wilson & Ho 1996).

TAXONOMY

Phreatoicus typicus Chilton, 1883

(Figures 1–10)

Phreatoicus typicus Chilton, 1883: 89, pl. 4.— Chilton 1894: 196, pl. 18.-Thomson & Chilton 1886: 151 (part). Stebbing 1888: 543, 687. Stebbing 1893: 388–391. Sheppard 1927: 109. Nicholls 1944: 5–8.

Material examined.

Lectotype female (Fig. 1, Canterbury Museum catalogue number IZ 3550), axial body length approximately 18.5 mm, one of three syntype females examined for this description. Chilton

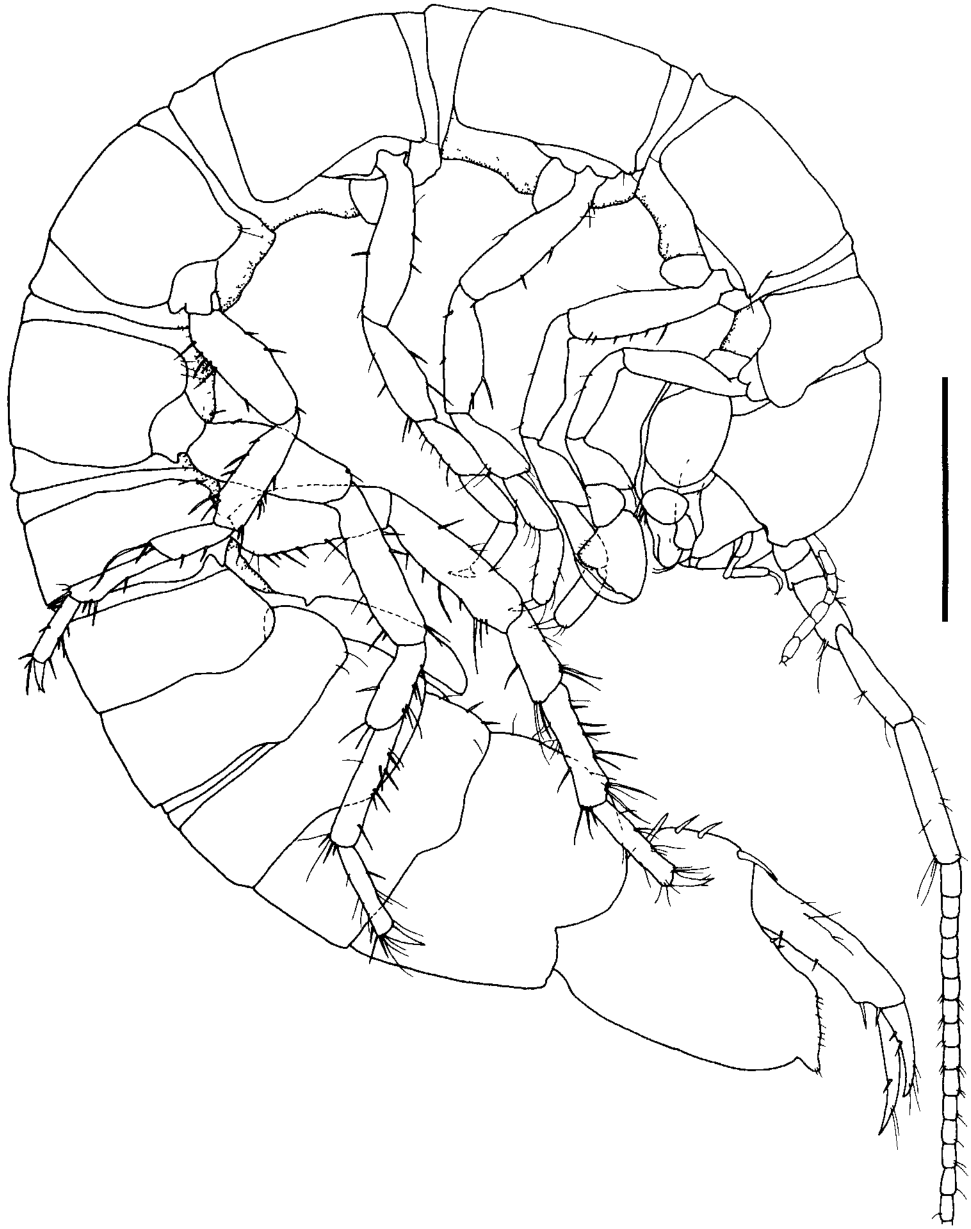

Fig. 1 Lectotype preparatory female, Canterbury Museum cat. no. IZ 3550. Scale bar = 2 mm

(1894) indicates that only 7 syntype females were present in the original collection of this species and that no males were described, later confirmed by Nicholls (1944:8). The lectotype has internal tissues that appear brown, shrunken, and that were possibly once dried. Its somites have expanded articular membranes, so that its measured length is probably greater than in undamaged specimens of same size. Two remaining syntypes (paralectotypes), Canterbury Museum catalogue number IZ 3549. *Type locality*: Eyreton, Canterbury Plains, in freshwater well.

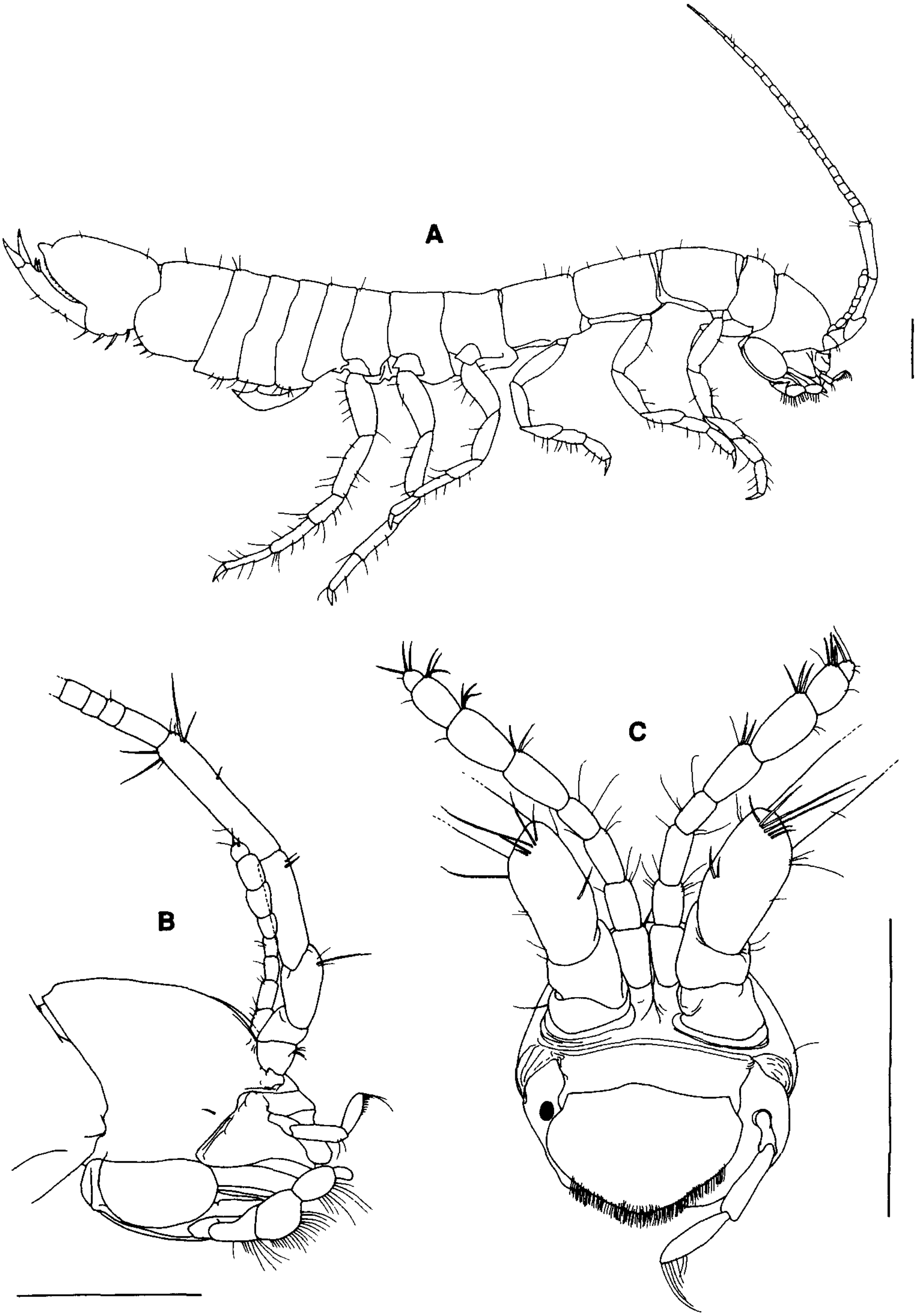

Fig. 2 Copulatory male, AM P52733. A, habitus, lateral view. B-C, head, lateral and anterior views. Scale bar = 1 mm

Other material. Male (dissected for this description) 12.8 mm, preparatory female 13.8 mm, male 11.5 mm, male 12.8 mm, Australian Museum registration numbers (AM) P52733 (dissected male, figured) and P52734 (2 males, 1 female); 13 specimens (2 males, 11 females) AM P52747; 39 specimens, Canterbury Museum (Christchurch) registration number IZ 3548; 229 specimens held by by G. D. Fenwick. Locality: Well 2, Templeton, Canterbury Plains, 43°33.11′S, 172°26.38′E (latitude and longitude determined from map), collected 11 June 1986 by G. D. Fenwick, from sediments at bottom of well, depth approximately 30 m.

Diagnosis. *Head* length greater than width in dorsal view, width subequal to pereonite 1 width; lateral profile of dorsal surface flattened curve, cuticle granular; cervical groove extending just above anterolateral margin of pereonite 1; clypeal notch absent; mouthfield angling anteriorly, mandibular insertion axis in lateral view strongly tilted, with line projected anteriorly along mandibular insertion intersecting base of antenna. *Pereonite 1* length 0.67 width in male. *Pereonites 2–4* coxal articulation fused. *Pleonites 1–4* relative lengths unequal, pleonite 4 length greater than pleonites 1–3. *Pleotelson* telsonic region or tailpiece distinct, reflexed dorsally, not trilobed, forming medial lobe only. *Antennula* with 7–8 articles; penultimate article broad and flattened. *Antenna* article 6 length shorter than articles 4 and 5 combined. *Mandibular palp* article 3 with 10–11 setae; incisor processes thin and spine-like; left incisor process with 2 cusps, with dentate ridge near level of lacinia; right incisor process with 1 cusp; spine rows with distal part on projection raised above proximal part; molar process wider than long. *Maxillula* medial lobe width greater than lateral lobe width; medial lobe with 10 pappose setae. *Maxilla* inner lateral lobe with 15 long, bidenticulate setae; medial lobe proximal and distal setal rows separated by gap, proximal portion smoothly continuous with distal portion. *Maxilliped* epipod distal tip truncate, ventral surface setae absent. *Pereopod I* propodal palm in male convex to straight, lacking spine-like projections; with stout denticulate setae and stout robust simple setae; with low conical setae on ridge, 6 altogether. *Pereopods II-IV* carpus lacking broad based setae. *Pereopod IV* not sexually dimorphic; dactylus subequal to propodal palm, with distal accessory claws or spines in both sexes; propodus lacking broad based setae on ventral margin in female. *Penes* straight and short extending past posterior midline and on to pleonite 1. *Male pleopod I* exopod broadest proximally; endopod appendix masculina distal tip extending near to distal margin of endopod; endopod proximal article distal tip rounded. *Pleopodal II-V* protopods with small medial projections. *Uropodal* protopod longer than endopod, dorsomedial margin with robust and simple setae and with rounded projection having robust setae.

Colouration. Cuticle of body without pigment or substantial calcification, specimens appearing translucent white in ethanol, with internal organs visible.

Description. *Head* length greater than width in dorsal view; width 1 pereonite 1 width; lateral profile of dorsal surface flattened curve; cuticle granular; tubercles absent. Eyes absent. Cervical groove straight, extending just above the anterolateral margin of pereonite 1. Mandibular groove absent. Mandibular notch absent. Clypeal notch absent. Antennal notch present. Frontal process above antennula absent. Mouth field adjacent to the posterior margin of head, maxillipeds inserting 0.01 head length from posterior margin of head.

Pereon narrow, width subequal to head width; dorsal surface smooth; setae on dorsal surface scattered, length of setae 0.1 body depth. Pereonite 1 in dorsal view wider than medial length, length 0.67 width in male, length 0.71 width in female. Pereonites 2–7 in dorsal view anteriorly longer than wide, decreasing posteriorly to wider than long; respective length-width ratios in male – 1.21, 1.24, 1.29, 1.04, 0.89, 0.52; respective length-width ratios in female – 1.42, 1.64, 1.29, 1, 0.84, 0.57. Coxal articulation of pereonites 2–4 fused, 5–7 free.

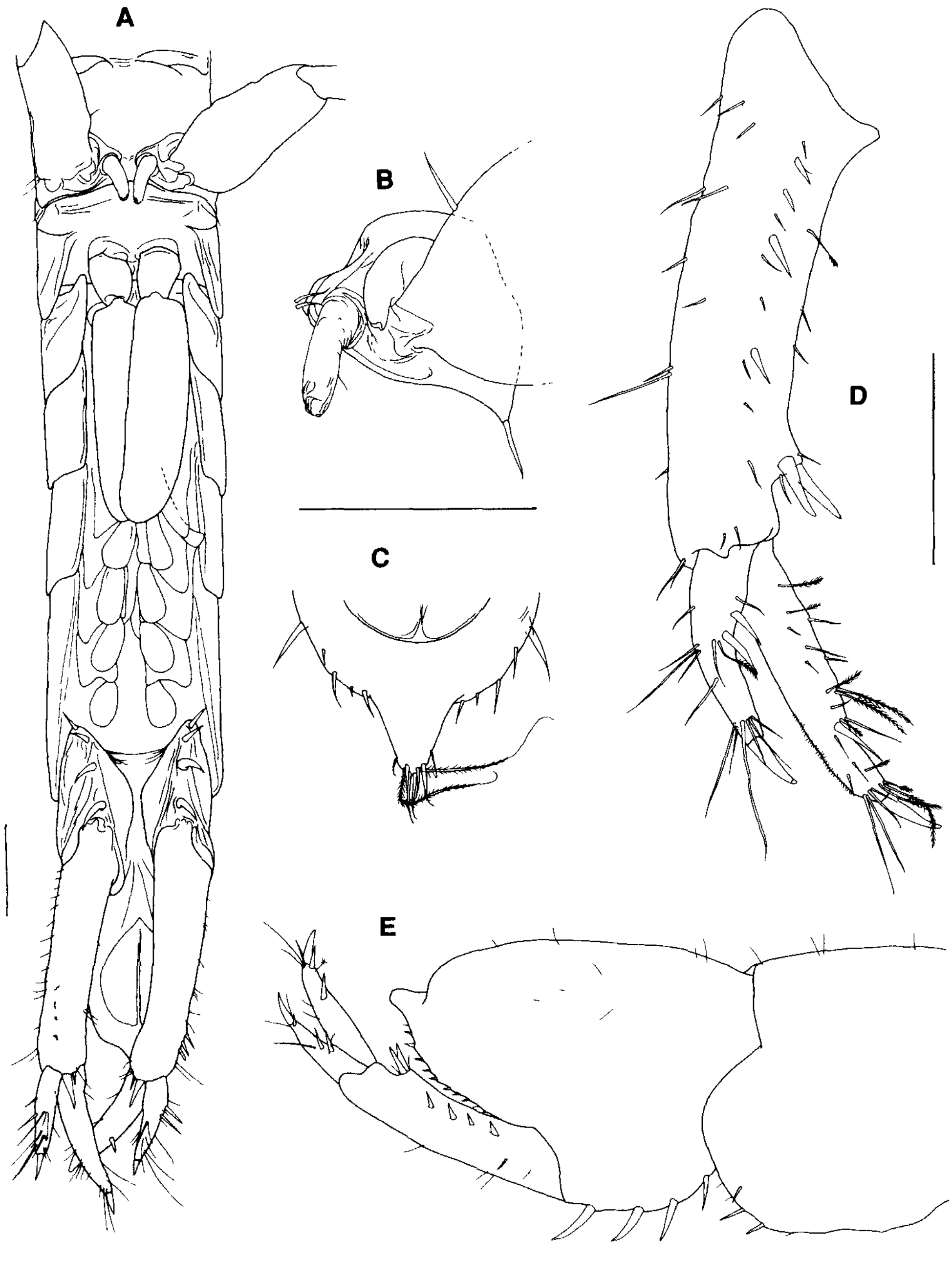

Fig. 3 Copulatory male, AM P52733. A, pleon and pereonite 7, ventral view. B. pereopod VII coxa and penes. C, pleotelson distal tip, ventral view. D, uropod, left side, lateral view. E. Pleotelson and pleonite 5, lateral view. Scale bar = 0.5 mm.

Lateral tergal plates of pereonites 2–4 absent, 5–7 absent. Sternal processes absent. Typhlosole intermediate, ventral invagination 'Y' shaped; hindgut caecae absent.

Pleonites in lateral view much deeper than pereonites, with large ventrolateral plates, basal region of pleopods not visible; pleonite 1 pleura distinctly shallower than pleurae of pleonites 2–5. Pleonites in dorsal view 2–3 respective lengths less than half the length of pleonite 5, pleonite 4 length equal to or more than half the length of pleonite 5, 1–4 relative lengths unequal, pleonite 4 length greater than pleonites 1–3, 1–4 width 0.4 composite length in dorsal view. Pleonites 1–5 respective dorsal length ratios relative to maximum width – 0.46, 0.46, 0.46, 0.57, 1.2; depth ratios relative to pereonite 7 depth, respectively – 0.97, 1.18, 1.26, 1.23, 1.1.

Pleotelson lateral length 0.15 body length, greater than depth, 1.38 depth; dorsal length 2.1 width; depth 0.93 pereonite 7 depth. Median dorsal ridge absent; lateral dorsal ridges absent. Telsonic region or tailpiece distinct – reflexed dorsally, not trilobed – forming medial lobe only; robust sensillate setae present, 4 altogether; elongate pappose setae present; posterior margin of pleotelson smooth. Dorsal uropodal ridge absent. Ventral margin anterior to uropods with stout setae, posterior marginal seta larger than anterior adjacent setae, 4 robust setae altogether.

Antennula length 0.1–0.11 body length in male (N=2), 0.09 body length in female, with 7–8 articles in male (N=4), with 8 articles in female. No articles divisible into one large or two small articles. Article 4 shorter than article 3. Article 5 length 1.36 width. Article 6 length 1.47 width. Aesthetascs tiny, 1–2 each on articles 5–6, 2–3 on articles 7–8. Terminal article globular, shorter than penultimate article, length1.0, width, 0.05 antennular length. Penultimate article sub-equal or shorter than other articles; broad and flattened.

Antenna length 0.58 body length in male (N=2), 0.52 body length in female. Flagellum length 0.67–0.71 total antenna length in male (N=2), 0.7 total antenna length in female, with 23–31 articles in male, with 31 articles in female. Propodal article 1 present, forming thin ring, scale on propodal article 3 absent. Article 5 longer than article 4, article 6 shorter than articles 4 and 5.

Mouthfield clypeus broad and laterally indented at mandibular fossae, width 0.69 head width. Labrum ventrally semicircular in anterior view, approximately same width as clypeus. Paragnaths laterally rounded, with narrow distomedial projections, with distomedial clump of setae, elongate setae on lateral margins and thickened medial base covered with fine spinules.

Mandible palp length 0.85 mandible length; article 3 with 10–11 setae, setae finely setulate; lacking cuticular hairs; combs absent; articles 1–2 with groups of long setae on dorsolateral margins and 2 long setae on ventral margin of article. Incisor processes thin, resembling denticulate spines, width near thickness. Left incisor process with 2 cusps, distally sharp and narrow, with dentate ridge near level of lacinia mobilis. Left lacinia mobilis with 3 cusps (2 distally, 1 on anterior surface). Right incisor process with 1 cusp. Right lacinia mobilis absent. Spine rows on linear pedunculate projection between incisor and molar processes, distal part on projection raised above proximal part. Left spine row with 9 spines, 9 bifurcate, none on margin between pedunculate projection and molar, first spine not separated from remainder of spine row. Right spine row with 10 spines, 8 bifurcate, none on margin between pedunculate projection and molar. Molar process distally broad with sharp blade-like projection on posterior margin, heavily keratinised, wider than long; triturating surface lightly ridged, with no teeth, many tiny fine setae on blade-like posterior margin.

Maxillula medial lobe length 0.58 lateral lobe length; width greater than lateral lobe, width 1.11 lateral lobe width; with 10 pappose setae; with 2 'accessory' setae, both setae placed

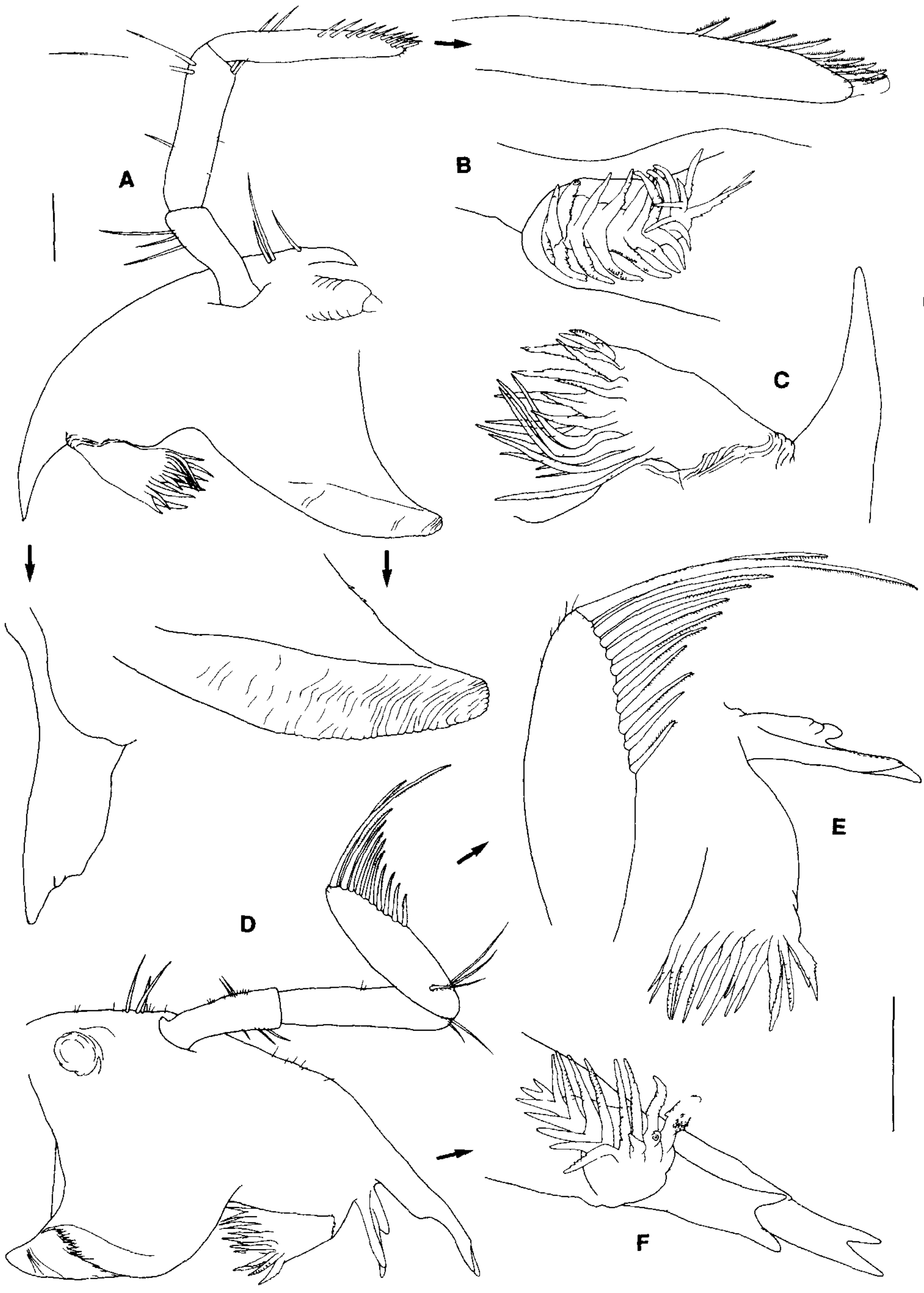

Fig. 4 Copulatory male, AM P52733 A-C, right mandible, dorsal view, spine row in medial and lateral views, respectively D-F, left mandible D, dorsal view, E, spine row and, lacinia mobilis in ventral view, F, spine row, lacinia mobilis and incisor process in medial view Scale bar = 0 1 mm

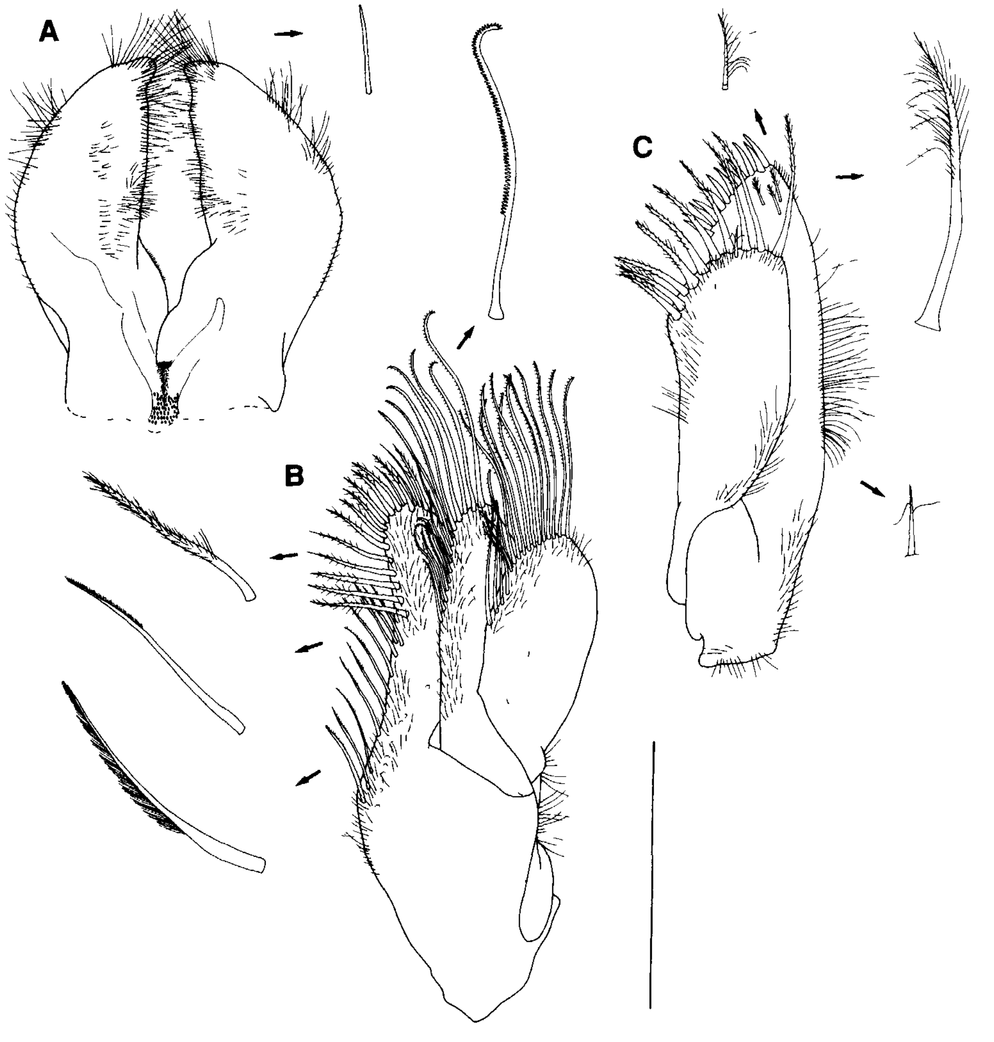

Fig. 5 Copulatory male, AM P52733. A, paragnaths. B, maxilla with enlargements of setae C, maxillula, with enlargements of setae Scale bar = 0.5 mm

centrally, 'accessory' setae simple; no short, weakly setulate setae on distal tip. Lateral lobe with 11 denticulate robust setae, 5 smooth robust setae, plumose setae on ventral face present, 2 altogether.

Maxilla lateral lobes subequal in length; with bidenticulate setae on distal tips and on medial margin. Inner lateral lobe with 15 long, bidenticulate setae. Outer lateral lobe wider than inner lateral lobe; with 16 long, bidenticulate setae. Medial lobe width 0.93 outer lateral lobe width; proximal and distal setal rows separated by gap; setae in ventral basal rows with single row of fine setules; setae in dorsal basal row plumose inserting on laterally curving ridge; setae in distal row of 2 types, ventral row with teeth and row of fine setules, dorsal row of long simple distally blunt setae. Medial lobe proximal portion smoothly continuous with distal portion.

Fig. 6 Copulatory male, AM P52733. Maxilliped. A, ventral view. B, endite, distal tip with enlargement of setae. C, dorsal view showing receptaculi and dorsal setal row. Scale bar = 0.1 mm.

Maxilliped epipod length 1.56 width; distal tip truncate; distal marginal setae fine and in fringe; fine cuticular combs absent; ventral surface setae absent. Endite length 0.34 total basis length; distal tip with approximately 44 subdistal biserrate setae on ventral surface;

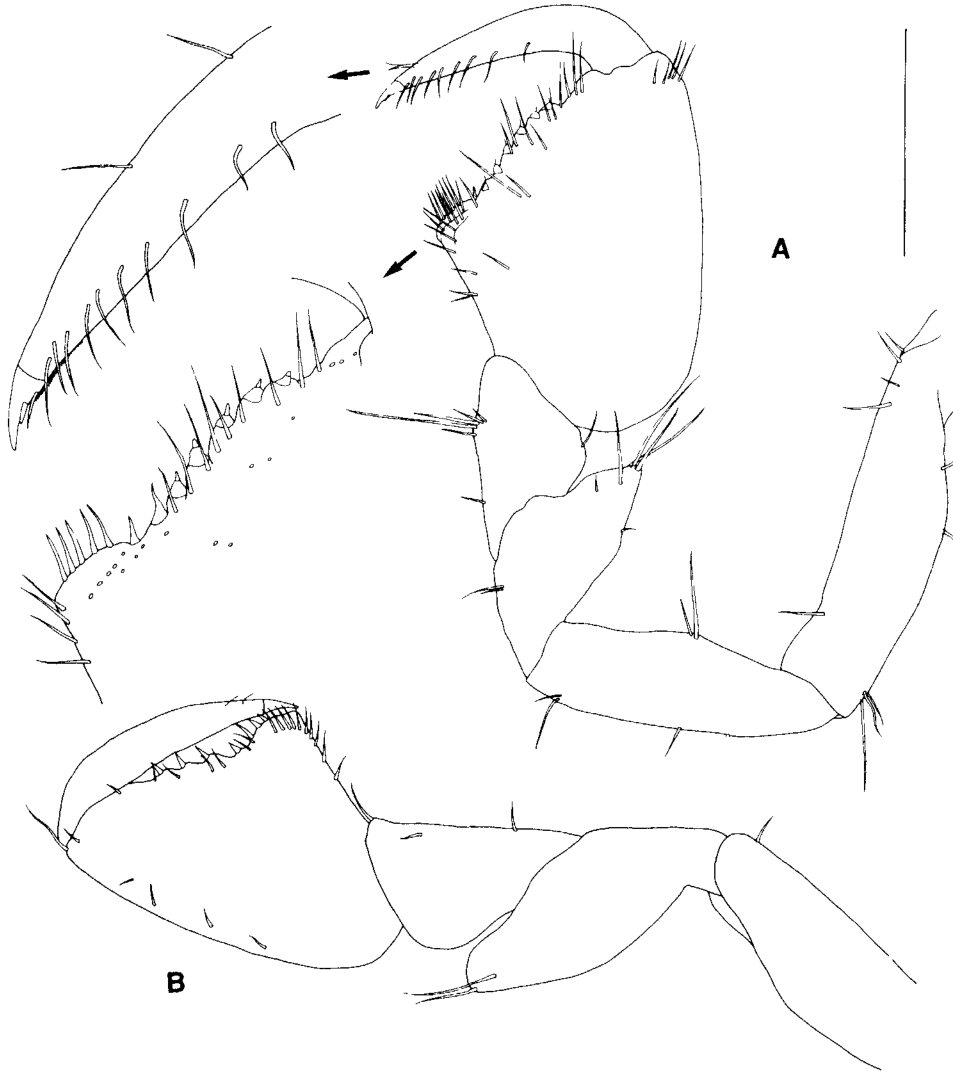

Fig. 7 Pereopod I. A, Copulatory male, AM P52733 with enlargement of palm and distal dactylus. B, preparatory female lectotype, Canterbury Museum. Scale bar = 0.5 mm.

medial margin with 2 coupling hooks on left side, 2 on right side; dorsal ridge with 15 large, distally denticulate, plumose setae. Palp insertion on basis with no lateral plumose setae, no medial plumose setae, no medial simple setae; ventral surface with no subdistal smooth setae, no subdistal biserrate setae, without other setal types. Palp length 1.2 basis length, width across articles 2–3 2.33 endite width; article 4 length 1.88 width, shape oblong; article 5 length 3.21 width, 0.92 article 4 length.

Pereopods ischium dorsal margin with single elongate robust simple seta absent.

Pereopod I length 0.27 body length in male, 0.23 body length in female. Dactylus subequal to palm in male, length 1.07 palm length, subequal to palm in female, length 1 palm length. Dactylus dorsal margin lacking dense group of elongate setae; ventral margin with no short stout setae in male, with no short stout setae in female; midlength spine-like projection

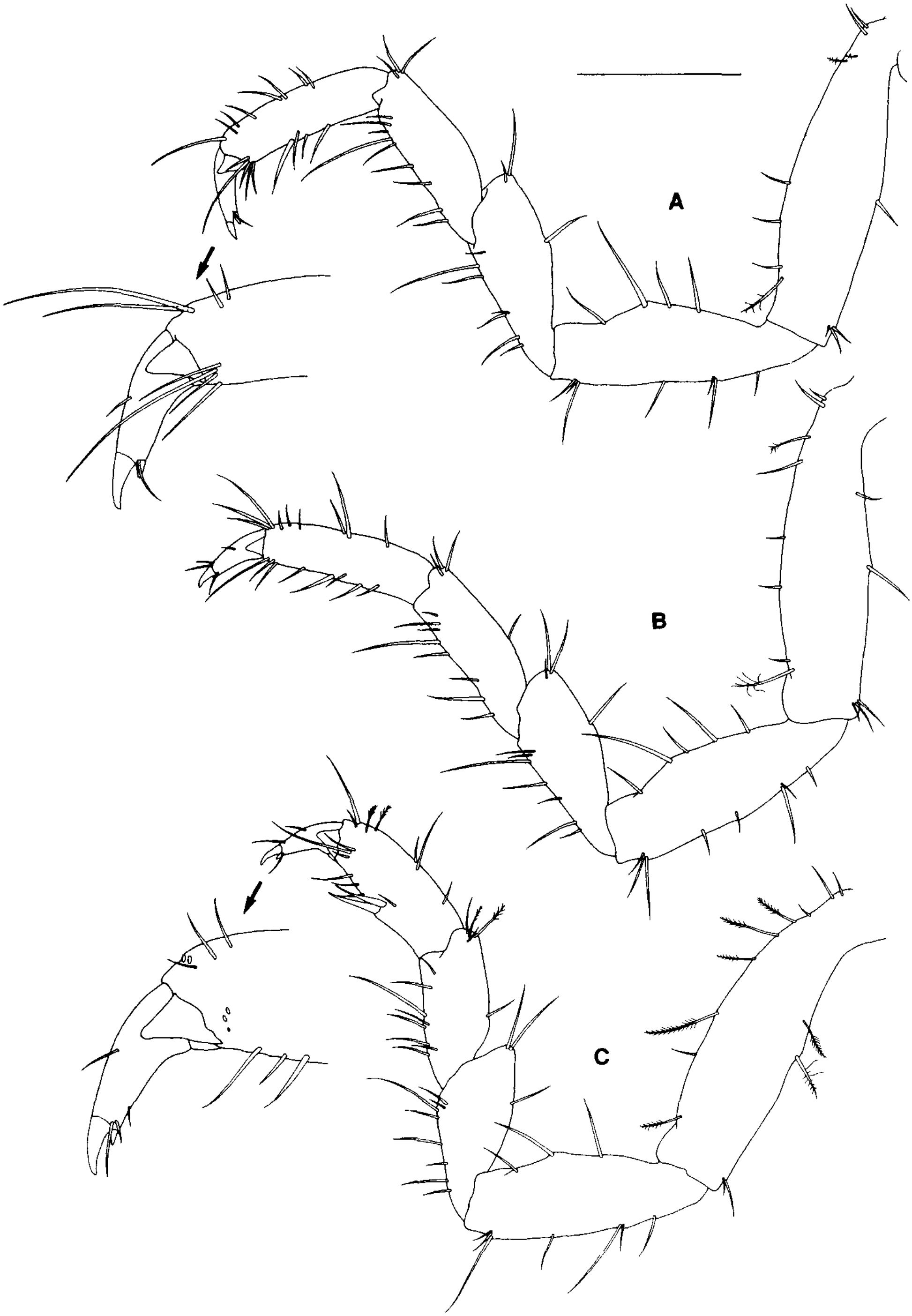

Fig. 8 Copulatory male, AM P52733. A-C, Pereopods II –IV, lateral view. Scale bar = 0 5 mm.

absent, distal cuticular fringe present, fringe length 0 22 total dactylus length in male, 0 32 total dactylus length in female, claw length 0 11 dactylus length in male, 0 15 dactylus length in female, with 1 distal accessory claw, embedded in ventral margin of large claw, accessory spines present, 16 altogether (approximately), tiny, occurring ventrally in row Propodus length in male 0 24 pereopod length, 1 35 width, 0 16 pereopod length, 1 width in female Propodus dorsal margin proximal region in male protruding beyond distodorsal margin of carpus, female not protruding Propodal palm in female concave, with spine like projections absent, stout denticulate setae absent, stout robust simple setae present, conical, elongate broad based setae present, 5 altogether, low conical setae on ridge absent Merus dorsal margin projection shelf-like and U-shaped in both male and female, with numerous elongate fine simple setae Basis length 4 width in male, 3 25 width in female, dorsal setae in male absent, in female absent, ventrodistal margin with 1 elongate seta in male, with 1 elongate seta in female, setae shorter than ischium, anteroproximal surface without dense group of setae

Pereopods II-III respective lengths 0 28, 0 28 body length in male, 0 26, 0 27 body length in female In male dactylus shorter than propodus, dactylus respective lengths 0 45, 0 42 propodus length In female dactylus shorter than propodus, dactylus respective lengths 0 43, 0 38 propodus length Dactylus distal accessory claw present, positioned distally under main claw, robust roughly third length of primary claw, respective primary claw lengths in male 0 3, 0 29 dactylar length, in female 0 36, 0 36 dactylar length Dactylus spines on ventral margin absent Propodus respective lengths 0 15, 0 15 pereopod length in male, 3 8, 3 5 width in male, 0 12, 0 13 pereopod length in female, 2 33, 2 67 width in female, articular plate present, broad based setae present, sparse, 2 in male and in female, in male longest seta approximately 0 25 propodus length, in female longest seta approximately 0 25 propodus length Carpus respective lengths 0 13, 0 13 pereopod length in male, 3 8, 3 5 width in male, 0 14, 0 12 pereopod length in female, 2 67, 2 33 width in female, broad based setae absent Basis respective lengths 0 30, 0 29 pereopod length in male, 3 65, 3 62 width in male 0 31, 0 32 pereopod length in female 3 6, 3 8 width in female, dorsal ridge angular in cross section and produced but not forming distinct plate, with scattered fine setae and penicillate setae positioned both proximally and distally

Pereopod IV not sexually dimorphic (male propodus slightly more robust than in female) Length 0 27 body length in male, 0 24 body length in female Penicillate setae present in both sexes, in male occurring on dorsal margin of basis, in female occurring on dorsal margin of basis Dactylus subequal to propodal palm, with distal accessory claws or spines in both sexes, one half length of primary claw in male or more, one half length of primary claw in female or more Propodus length in male 0 14 pereopod length, 2 34 width, female 0 11 pereopod length, 3 width, distal width less than palm width, 0 75 palm width, articular plate on posterior side of limb present, shorter than dactylar claw in male, shorter than dactylar claw in female, with 2 broad based setae on ventral margin in male present, none distinctly larger than others, no broad based setae on female ventral margin Carpus length 0 14 pereopod length in male, 0 11 pereopod length in female, with no broad based setae on ventral margin in male or in female Ischium posterodistal margin with 2 setae in male 2 setae in female Basis length 4 1 width in male, 3 8 width in female, dorsal ridge in cross section rounded, male with 8 setae, positioned along ridge, female with 7 setae, positioned along ridge

Pereopods V-VII respective lengths 0 27, 0 36 0 36 body length in male, 0 29, 0 35 0 33 body length in female Penicillate setae present on dorsal ridge of basis Dactylus respective claw lengths 0 33, 0 33, 0 45 dactylar length in male, 0 38, 0 35, 0 32 dactylar length in female, distal accessory claws absent, spines absent Propodus respective lengths 0 11, 0 15,

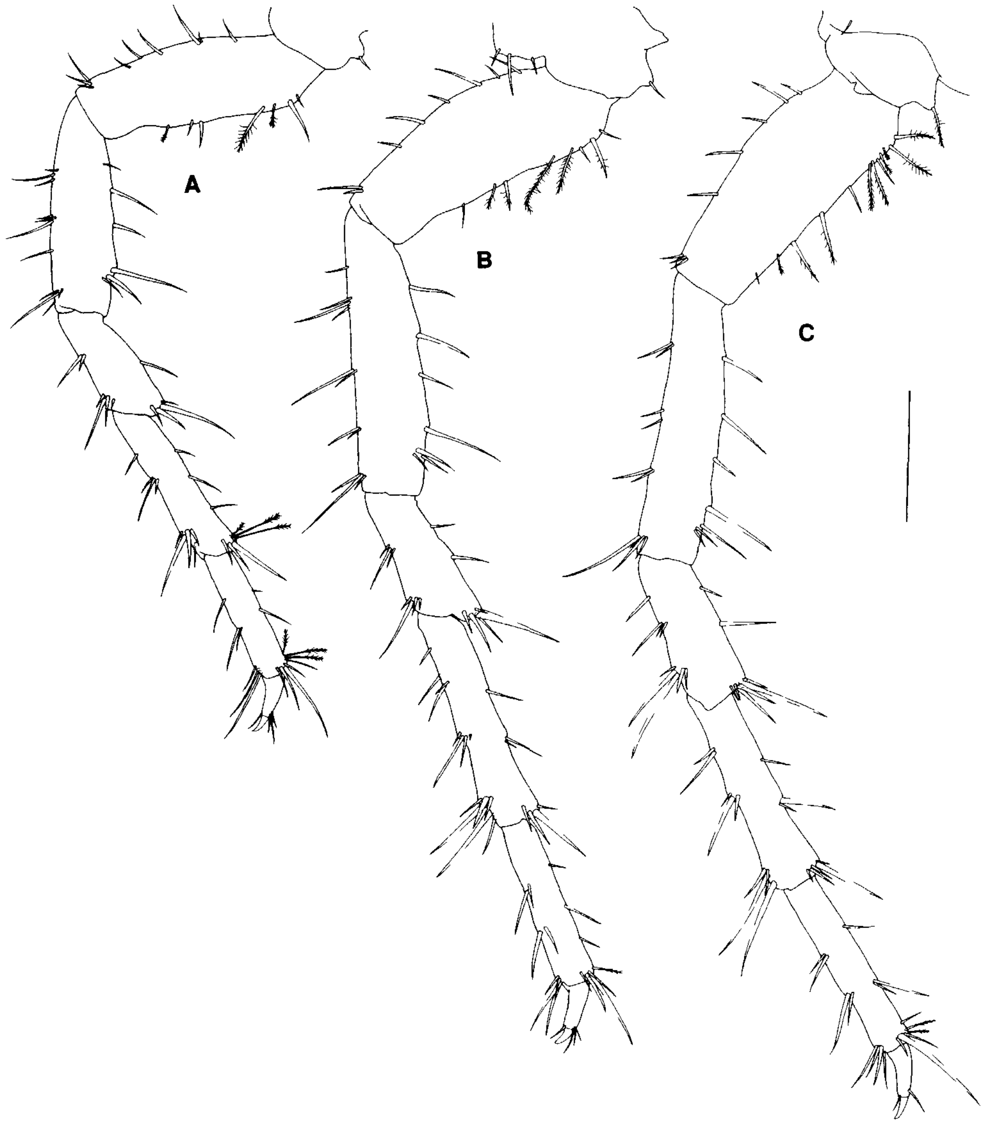

Fig. 9 Copulatory male, AM P52733 A-C, Pereopods V-VII, lateral view Scale bar = 0 5 mm

0 17 pereopod length in male, articular plate on posterior side of limb present, distal margins with 4 elongate robust setae Carpus respective lengths 0 2, 0 2, 0 18 pereopod length in male, 0 17, 0 18, 0 18 pereopod length in female Basis respective lengths 2 88, 2 96, 2 75 basis width in male, dorsal ridge not distinctly separated from basis shaft, in cross section angular, with 3–6 setae (+3 penicillate), positioned along ridge

Penes straight, length 0 32 body width at pereonite 7, extending past midline and onto pleonite 1, smooth, lacking setae, distally tubular, distal tip rounded

Pleopods I-V respective lengths 0 12, 0 11, 0 1, 0 08, 0 07 body length in male Exopods I-V respective lengths 3 4, 3, 2 7, 2 1, 1 7 width in male, exopod I uniarticulate, exopods II-V biarticulate, II-V proximal article distolateral lobes shorter than distal article, respective

Fig. 10 Copulatory male pleopods, ventral view AM P52733 A, pleopod I B C, Pleopod II D F pleopods III V Scale bar =0 1 mm

lengths of distal articles 0.32, 0.32, 0.33, 0.35 exopod length in male, lateral proximal lobes present on exopods II-V, medial proximal lobes present on exopods II-V. Endopods all unilobed, endopods I-V respective lengths 4.5, 3.2, 2.5, 2.1, 2.1 width in male 0.7, 0.75, 0.68, 0.69, 0.76 exopod length in male, male endopods I-V without marginal setae, female endopods I-V without marginal setae. Protopods II-V with small medial projections, protopods III-V with lateral epipods (male). Male pleopod I exopod broadest proximally, distal margin rounded, lateral margin rounded, dorsal surface lacking setae. Male pleopod II endopod appendix masculina curved, ventral shape of cross section of proximal half of shaft concave (forming an elongate trough), basal musculature pronounced. distal tip broadly rounded without tiny rounded denticles, marginal setae only occurring distally, 3 setae altogether length 0.61 pleopod length, distal tip extending near to distal margin of endopod. Male pleopod II endopod proximal article distal tip rounded. Male pleopod II exopod distal segment longer than wide, lateral margin proximally linear.

Uropod total length 1.1 pleotelson length in male, 1 pleotelson length in female. Protopod length 3.88 width in male, 4 width in female, 0.65 uropod total length in male. 0.59 uropod total length in female. Protopod distomedial row of closely spaced setae absent. Protopod dorsolateral margin setae robust and simple, robust spinose setae on distoventral margin absent. Rami distal tips pointed, exopod cross-sectional shape round, endopod dorsally or laterally flattened. Endopod shorter than protopod, subequal to or longer than exopod, dorsal margin robust seta present, placed midlength, with 1 robust seta in male, 1 robust seta in female, spines or spurs on dorsal margin absent. Exopod length 0.78 endopod length in male, 0.71 endopod length in female, not sexually dimorphic, robust setae on dorsal margin present, 2 robust setae in male, 2 robust setae in female.

Remarks. After Nicholls' (1944) revision, *Phreatoicus* was reduced to only two species, *Phreatoicus typicus* and *P. orarii* Nicholls, 1944. Nicholls (1944) was vague about the differences between *P. orarii* and *P. typicus*, and he had not seen identified types nor males of *P. typicus*. One has to take some latitude with the descriptions by both authors, but more so with Chilton's because he had not seen many different phreatoicideans at the time of his original descriptions. Nevertheless, *P. orarii* Nicholls appears to be valid, even though we have not seen specimens of this species (types of which are not available at any Australian or New Zealand Museum. pers. comm. G. Poore (Mus. Victoria), and M. Walker (Canterbury Mus.). In creating the diagnosis of *P. typicus*, we also included differences from *Neophreatoicus assimilis* (Chilton, 1894). Among the phreatoicideans described from New Zealand, these three species are similar in body form and pleotelson shape, and occupy the same habitat.

The question of whether *Neophreatoicus* is distinct from *Phreatoicus* is left for a larger analysis of the family Phreatoicidae. Species of *Notamphisopus* Nicholls, 1944 are less similar to *Phreatoicus* and *Neophreatoicus* in having a more robust, setose body and strongly developed lateral lobes on the pleotelson, as well as having a more normal mandible. Comparisons using the DELTA database program INTKEY identified 86 putative differences between *P. typicus*, *P. orarii* and *N. assimilis*, from which the diagnosis of *P. typicus* was abstracted. Generic characters were not distinguished from species characters in the diagnosis and measurements that differed between the three taxa were not used. *Phreatoicus typicus* lacks well defined lateral lobes on the tailpiece of *P. orarii*, allowing the two species to be easily separated. Moreover, the mandibles of *P. typicus* are rotated anteriorly, much more so than in any other New Zealand species, and have thin, spine like incisor processes. *P. typicus* also differs from *P. orarii* and *Neophreatoicus assimilis* owing to its short straight penes and a maxillular median lobe that has 10 pappose setae (only 4 in *Neophreatoicus assimilis*).

ECOLOGY

Phreatoicus typicus and water conditions

A large variation in sample sizes of *P typicus* was observed No specimens were collected from Well 1 or Well 11, Well 2 yielded 3, 38 and 82 specimens, seven collections from Well 4 ranged from 1–62 specimens, 2, 4 and 26 specimens were taken from Well 8, and two samples from Well 10 produced 2–3 specimens

Chemical and microbial contamination of the wells fluctuates over time (Martin & Noonan 1977, Close 1984), partly due to oxidation pond irrigation patterns These wells represented a gradient in groundwater contamination based on chemical and microbial data (Martin & Noonan 1977, Close 1984), as well as the abundance of groundwater crustaceans (Sinton 1984, Fenwick in prep) Well 1 was relatively uncontaminated compared with the others, and Well 11 was the least contaminated of the downstream wells Chemical data indicated that Well 4 was more contaminated than Well 2 Sample sizes of crustaceans in Well 2 were generally larger than Well 4, but Well 2 may have suffered periodic mass kills (Sinton 1984, Fenwick in prep) Wells 8 and 10, which yielded few *P typicus* specimens, appear somewhat intermediate in contamination, but were not included in the physicochemical analyses (Fenwick in prep)

The groundwater parameters (Table 1) are extracted from Fenwick (in prep) The data show that groundwater temperatures varied slightly with season from 12 5° C in January to 10 5° C in June, with no differences between wells Suspended loads in the well water varied widely within and between wells, but were lower in the more contaminated wells Frequent flushing by oxidation pond effluent may have caused the loss of fines from soils surrounding Wells 2 and 4 Variation in pH was minimal in all wells, except Well 2 The usual range was 6 5–6 8 at the uncontaminated well (Well 1), but *P typicus* apparently tolerated wider fluctuations (6 2–7 3) at the contaminated wells Similarly, dissolved oxygen concentrations at the upstream well were high (6 66–8 11 g m ^{3}), but lower (3 67–7 57 g m ^{3}) at the contaminated sites where *P typicus* was more abundant Dissolved and total organic carbon concentrations were also higher in the contaminated wells where *P typicus* was more abundant

P typicus was most abundant where concentrations of coliform bacteria were high (Table 1, Wells 2–4, mean = 5275–9735 cells 100 ml ^{1} water) Concentrations of coliform bacteria in these wells were almost 20 times greater than concentrations in water from the uncontaminated well in which *P typicus* was infrequently found (Well 1, mean – 381 cells 100 ml ^{1} water) Five-day biological oxidation demands (BOD_5) for each well were, however, similar between wells (Table 1), with mean values for each well at all times falling within the range 0 04–0 06 g m ^{3}

Differences in concentrations of six other chemical species amongst the wells at Templeton (Table 1) also provide some insight into physico-chemical tolerances of *P typicus* Chloride concentrations ranged between 9 5 and 20 4 g m ^{3}, and *P typicus* was confined to locations where concentrations exceeded 16 g m ^{3} (Wells 2 and 4) Similarly, wells containing *P typicus* were those with higher concentrations of nitrate nitrogen (mean concentrations > 7 12 g m ^{3}, Wells 2 and 4), total Kjeldahl nitrogen (mean concentrations above 200 g m ^{3}) and dissolved reactive phosphorus (frequent above 10 g m ^{3})

These observations show that *P typicus* tolerates considerable contamination of the groundwater, where organic carbon and bacterial counts are elevated above those of relatively uncontaminated groundwater Nevertheless, this species may be limited to fairly clear water where average suspended sediment loads are less than 42 g m ^{3} These data support, however, the proposition that *P typicus* may favour sites with elevated organic loads in the groundwater

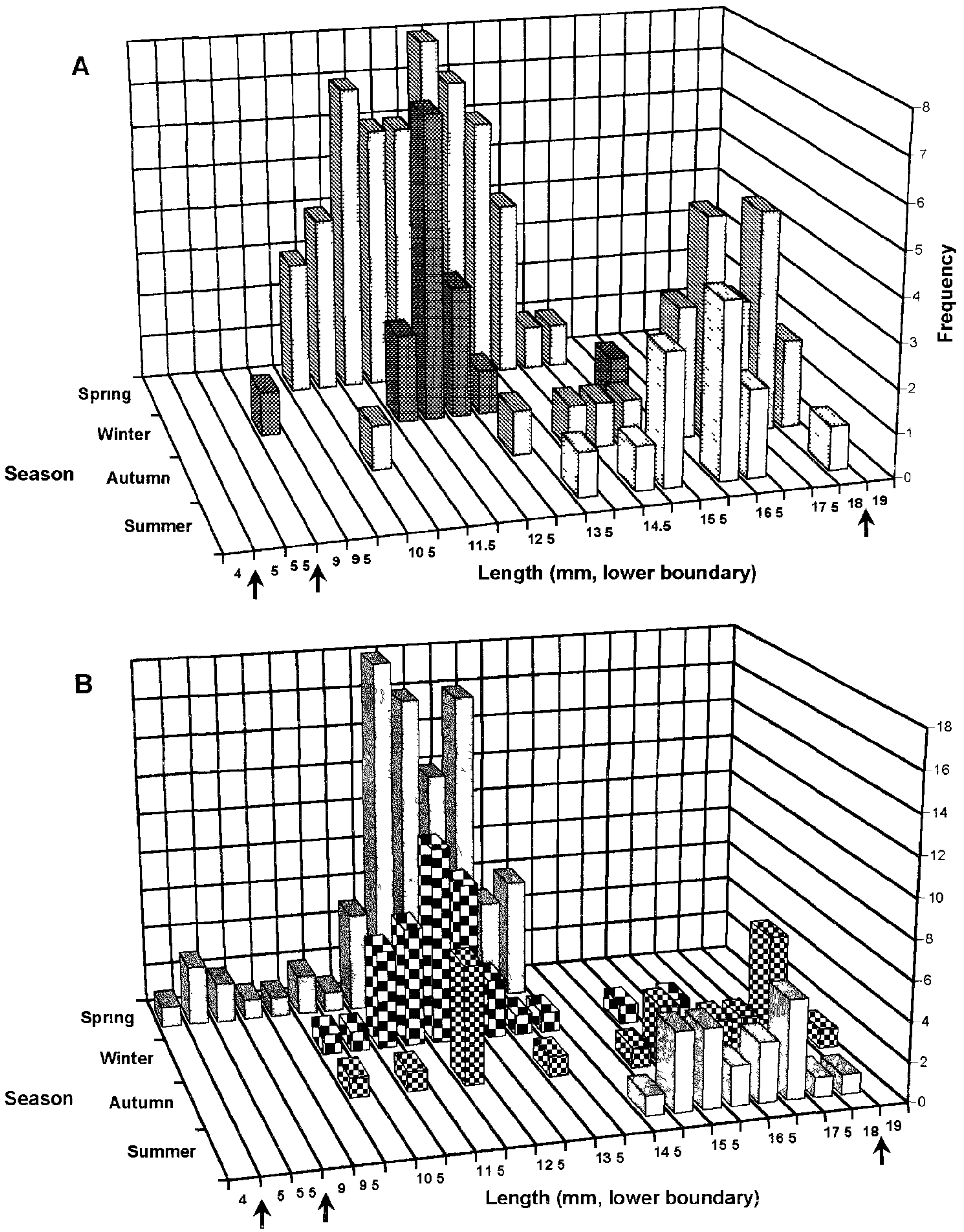

Fig. 11 Seasonal size frequency distributions of all specimens pooled from all wells. A, Males B, Females and Juveniles Arrows indicate hiatuses in length scales

Gut analyses of *P. typicus* (Fenwick in prep) showed that *P. typicus* specimens had ingested clay particles up to 35 µm in diameter. The majority of gut material, however, comprised fine (< 1 µm) organic particles, and bacterial densities were approximately halved as these particles passed from the foregut to midgut. These observations, combined with data from feeding experiments, suggest that *P. typicus* feeds predominantly by ingesting fine particulate material but may also browse films from the surfaces of larger (>300 μm) particles, albeit considerably less efficiently (Fenwick in prep) Several characteristics of the mouthparts seem consistent with fine particles comprising the diet

1 The medial surface of the gnathopodal propodus (with dactyl closed) in both sexes is shaped into a scoop that seems appropriate for moving sediment
2 All mouthparts are extensively setose, and many of these setae are arranged in distinct rows
3 Many of the setae are differentiated (variously plumose, pappate, biserrate) in ways that may enhance their effectiveness in handling fine particles
4 The rudimentary mandibular incisor, poorly developed lacinia mobilis and finely ridged molar (Fig 4) all suggest that tearing, shredding and scraping are not part of *P typicus*' feeding These morphologies are more consistent with a microphagous lifestyle

Table 1 Ranges and means of physico-chemical and biological factors for four Templeton wells, November 1985 – August 1986 Samples for different factors were taken at different times Values for some factors are means of two (*2) or five (*5) replicates from each sampling time

Factor	Well Number			
	1	2	4	11
Total *Phreatoicus typicus* collected during sampling program	0	121	118	0
Temperature °C	10 5–12 5	10 5–12 0	10 5–12 5	10 5–12 5
Suspended load (g m^{-3})*5	29–609	0–60	6–159	60–127
mean, sd (n=6)	192 7, 210 8	12 7, 23 4	42 2, 57 8	100 2, 24 8
pH (Gallenkamp pH stick)	6 5–6 8	6 3–7 3	6 2–6 4	6 2 6 6
mean, sd (n=5)	6 6, 0 11	6 6, 0 39	6 3, 0 06	6 4, 0 15
O_2 (g m^{-3})(modified Winkler)*2	6 66–8 11	3 67–7 57	3 79–6 54	3 90–8 44
mean, sd (n=9)	7 26, 1 19	5 73, 1 16	5 86, 0 95	6 08, 1 36
Total organic Carbon (g m^{-3})*5	1 88–3 53	2 22–4 81	1 52–5 62	2 13–5 34
mean, sd (n=42–44)	2 57, 0 21	3 56, 0 31	3 63, 0 46	3 49, 0 35
Dissolved organic C (g m^{-3})*5	1 05–3 41	1 92–4 86	2 12–4 65	2 11–4 84
mean, sd (n=39)	1 96, 0 53	3 24, 1 03	3 21, 0 82	3 12, 0 86
BOD_5 (g m^{-3})*2	0 02–0 17	0 01–0 19	0 01 0 16	0 01–0 17
mean, sd (n=8–9)	0 05, 0 02	0 06, 0 02	0 04, 0 02	0 06, 0 02
Total coliforms (cells 100 ml^{-1})	2–1510	200–16000	100–38000	4 37
mean, sd (n=4)	381, 752	5275, 7325	9735, 18844	19, 17 5
Faecal coliforms (cells 100 ml^{-1})	0–80	35–2320	14–130	0–11
mean, sd (n=4)	20 0, 40 0	723 8, 1070	46 0, 56 1	4 5, 5 5
Chloride (g m^{-3})	8 1–13 7	10 1–27 4	10 8–26 0	14 6–26 0
mean, sd (n=13)	9 46, 1 52	20 35, 5 79	16 25, 4 29	17 81, 3 10
Total Kjeldahl Nitrogen (mg m^{-3})	54–350	117–294	145–435	127–354
mean, sd (n=13)	152 5, 75 1	200 5, 55 2	234 5, 87 67	200 2, 64 5
Nitrate Nitrogen (g m^{-3})	3 6–6 9	4 8 10 9	5 7–9 1	6 6–11 1
mean, sd (n=13)	5 22, 1 16	8 15, 1 70	7 12,1 11	8 12, 1 23
Ammonia Nitrogen (mg m^{-3})	12–68	9–38	7–44	7–58
mean, sd (n=13)	29 2, 16 6	14 7, 10 4	22 3, 13 1	24 1, 15 6
Total Phosphorus (mg m^{-3})	28–316	6–64	10–300	17 181
mean, sd (n=13)	113 5, 86 1	28 2, 19 0	69 9, 75 1	64 9 52 2
Dissolved reactive P (mg m^{-3})	1–31	4–23	3–41	2–45
mean, sd (n=13)	9 15, 8 75	10 23, 5 93	12 92, 10 30	7 50, 5 03

5 *P typicus* specimens appear to be unable to swim and do not move rapidly, indicating that they are neither predatory nor mobile scavengers

Therefore, the presence of this species at sites contaminated by organic effluent and bacteria is not unexpected *P typicus* may play a key role in contaminant removal and quality maintenance of groundwaters in Canterbury (Fenwick in prep)

Life history

Sample intervals and sizes differed because the observations on size frequency of *P typicus* were made coincidentally to a ecological survey that was not designed for this purpose The low frequencies of juveniles and brooding females in the samples is, therefore, likely to be a sampling error The following discussion was derived from patterns observed in the body length data (Table 1, Table 2, Figs 11, 12)

Sexual maturity in males, indicated by the presence of well-developed penes, may have been reached at a body length of approximately 10 mm, although few animals below this size were collected Size frequency analysis of males (Fig 11A) shows that the largest individuals (> 16 mm) were present only during the summer (December-January) and autumn (March-April) Medium sized males (11–16 mm), comprising at least two instars, appeared in the wells during winter (May-July) and peak in abundance in spring (September)

Size frequencies showed a similar pattern of change in females (Fig 11B and Table 2), although separate, more discrete distributions indicated more instars than were evident from males Females collected in December-January (Fig 11B, 12B, summer) appeared to comprise two instars with modal size classes of 17 mm and 15 mm, all bearing preparatory 2 (95 percent) or full oostegites (5 percent – 1 specimen) These two instars were designated as cohort 1 Both instars were present in autumn (March-May, 94 percent with preparatory 2 oostegites) but have increased in size to modes of 15 5 mm and 17 5 mm During autumn, an additional instar (designated cohort 2) first appeared at a modal size of 11 5 mm (Fig 11B) In winter (June-August), cohort 1 was represented by only a few small individuals, with cohort 2 dominating the population (Figs 11B, 12B, winter) At this time, 71 percent of cohort 2 females bore preparatory 2 oostegites and the cohort spanned at least two instars No animals in cohort 1 were present in September (spring, Fig 11B, 12B) and preparatory 2 females predominate within cohort 2 A new cohort was represented by 5 mancas in the 5 5–6 0 mm size class in spring samples (September, fig 11B) A single 4 5 mm long manca recorded in this period appeared to be dislodged from a brood pouch

Breeding appeared to be annual, starting in early spring, probably August-November, and continuing through the summer Broods were probably released in late spring (October-November), and perhaps also later in the summer (a single large brooding female, length

Table 2 Frequencies (in %) of *Phreatoicus typicus* at each reproductive state in each season

Reproductive status	Season Summer Dec-Jan	 Autumn March-May	 Winter June-Aug	 Spring Sept
Cohort 1 females (>15 0 mm body length)				
Females, no oostegites	0	0	0	0
Preparatory 1	0	6 3	50 0	0
Preparatory 2	95 2	93 8	50 0	0
Full oostegites	4 8	0	0	0
Sample size (n)	21	16	2	0
Cohort 2 female (11 0–14 5 mm body length)				
Females, no oostegites	0	0	0	15 4
Preparatory 1	0	100 0	29 4	28 2
Preparatory 2	0	0	70 6	53 8
Full oostegites	0	0	0	2 6
Sample size (n)	0	8	34	78

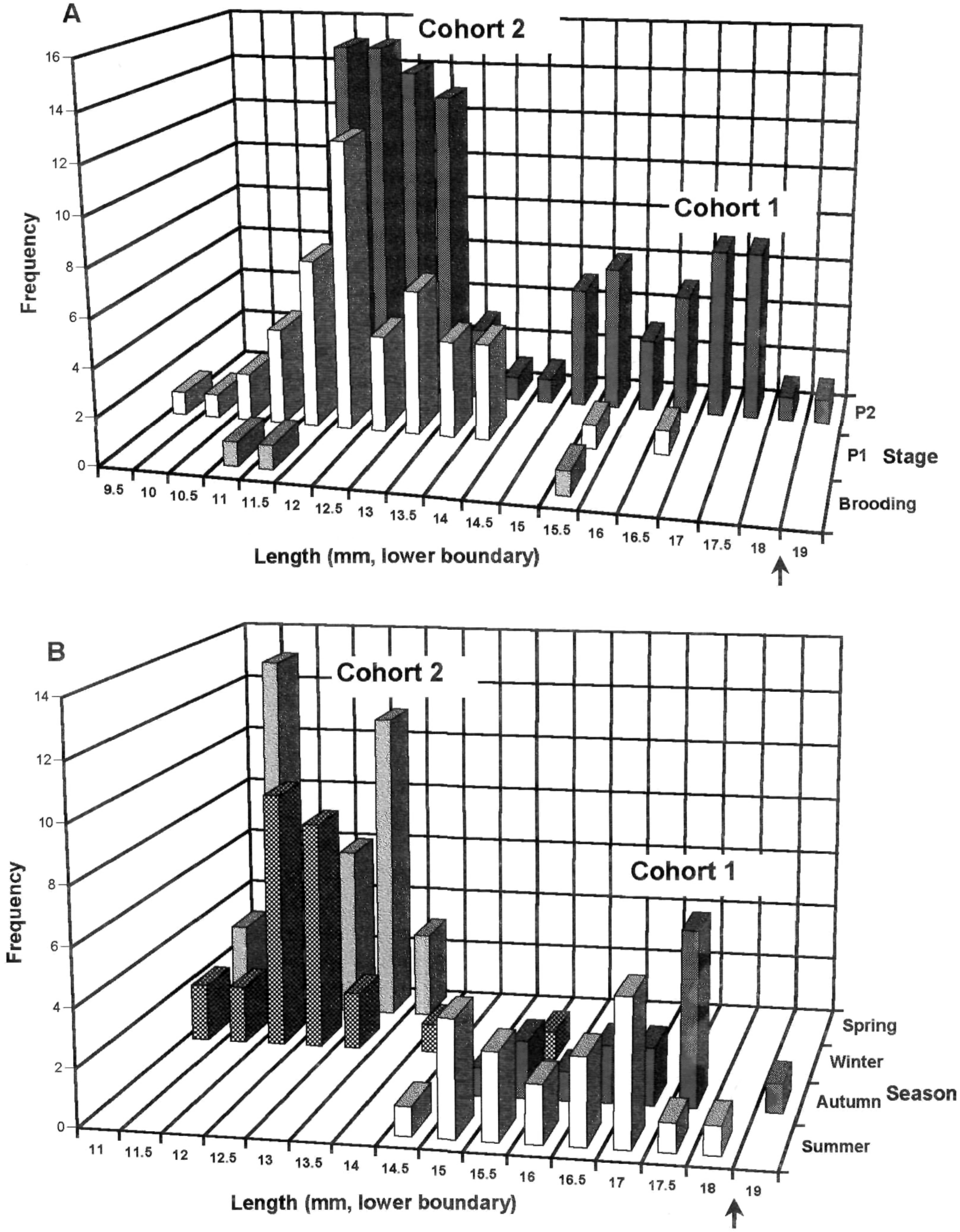

Fig. 12 Females whose reproductive status was identifiable, data pooled from all wells. A, all adult females in separate stages, pooled over all sampling dates. B, Preparatory stage 2 females only, sorted by season. Arrows indicate hiatuses in length scale.

15 8 mm, was captured in December 1985, see Table 2) Several broods being released during spring and summer would account for at least two instars appearing in the cohorts Brooding females may avoid open spaces such as wells, because they are rare in the samples Small juveniles also appeared to remain in interstitial microhabitats, avoiding larger spaces such as wells until they have grown to lengths of 12–14 mm and after surviving the winter season At this size, males appear to be sexually mature and most females have preparatory 1 oostegites, indicating that they are mature and approaching breeding After winter, cohort 1 disappears from the samples Cohorts thus could represent year classes, because the largest adults do not survive through the winter season *P typicus* appears to become reproductive around the age of one year, and females could breed up to three times, attaining a total body length of almost 20 mm before disappearing from the population This pattern is similar to that seen in the Australian phreatoicid *Crenoicus buntiae*, another species known to be iteroparous (Wilson & Ho 1996)

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REFERENCES

Banarescu P 1990 Zoogeography of fresh waters *General distribution and dispersal of freshwater animals* Vol 1 Aula-Verlag, Wiesbaden, Germany 511 pp (208 maps)

Close, M E 1984 Factors influencing the chemical quality of groundwater downstream of a sewage disposal area – Templeton, New Zealand *Water & Soil Miscellaneous Publication No 69* 47–61

Chilton C 1883 Notes on, and a new species of subterranean Crustacea *Transactions of the New Zealand Institute 14* 87 92, pl 4

Chilton, C 1894 The subterranean Crustacea of New Zealand with some general remarks on the fauna of caves and wells *Transactions of the Linnean Society of London (2nd Series Zoology) 6(2)* 163 284, pls 16–23

Dallwitz, M J 1980 A general system for coding taxonomic descriptions *Taxon 29* 41–46

Dallwitz, M J , Paine, T A , Zurcher, E J 1993 DELTA User's Guide A general system for processing taxonomic descriptions, 4th edition Canberra, CSIRO Division of Entomology

Fenwick, G D [In prep] Organic carbon pathways in the Canterbury groundwater ecosystem and the role of phreatic crustaceans

Golterman, H L 1970 *Methods for Chemical Analysis of Fresh Waters*. I B P Handbook No 8 Blackwell Publications, London

Maciolek, J A 1962 Limnological organic analyses by quantitative dichromate oxidation *Research Report United States Fisheries and Wildlife Service 60* 1–61

Martin, G N , Noonan, M J 1977 *Effects of Wastewater Disposal by Land Irrigation on Groundwater Quality of the Central Canterbury Plains* Water & Soil Technical Publication 7 Ministry of Works and Development, Wellington 25 pp

Nicholls, G E 1943 The Phreatoicoidea Part I The Amphisopidae *Papers and Proceedings of the Royal Society of Tasmania 1942* 1–145

Nicholls, G. E. 1944: The Phreatoicoidea. Part II. The Phreatoicidae. *Papers and Proceedings of the Royal Society of Tasmania 1943*: 1–156.

Sheppard, E. M. 1927: Revision of the family Phreatoicidae (Crustacea), with a description of two new species. *Proceedings of the Zoological Society of London 1927(pt. 1)*: 81–124.

Sinton, L. W. 1984: The macroinvertebrates in a sewage-polluted aquifer. *Hydrobiologia 119*: 161–169.

Sinton, L. W.; Close, M. E. 1983: *Groundwater Tracing Experiments*. Publication No. 2 of the Hydrology Centre, Christchurch. 37 pp.

Stebbing, T. R. R. 1888: *Report on the Amphipoda collected by H.M.S. Challenger during the years 1873–1876*. Vol. 29. (*In series*: C.Wyville Thomson, J. Murray (series eds.) *Report on the Scientific Results of the Voyage of H.M.S. Challenger During the Years 1873–76*.) Eyre & Spottiswoode, London. xxiv + 1737 pages. (210 pls)

Stebbing, T. R. R. 1893: *A History of Crustacea – Recent Malacostraca*. The International Scientific Series, no. 74. Kegan, Paul, Trench, Trübner & Co. Ltd., London. 466 pp.

Thomson, G. M.; Chilton, C. 1886: Critical list of the Crustacea Malacostraca of New Zealand. *Transactions and Proceedings of New Zealand Institute Zoology 18*: 141–159.

Wilson, G. D. F.; Ho, E. L. 1996: *Crenoicus* Nicholls, 1944, (Crustacea, Isopoda, Phreatoicidea): Systematics and biology of a new species from New South Wales. *Records of the Australian Museum 48*: 7–32.

Wilson, G. D. F.; Johnson, R. [in press]: Ancient endemism among fresh water isopods (Crustacea, Phreatoicidea). *Transactions of the Royal Society of New South Wales*.

Wilson, G. D. F.; Keable, S. J. [in press]: A new genus of phreatoicidean isopod (Crustacea) from the North Kimberley Region, Western Australia. *Zoological Journal of the Linnean Society, London*.

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