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# *Quinquelaophonte Aurantius* sp. nov., a new harpacticoid species (Copepoda: Harpacticoida: Laophontidae: *Quinquelaophonte*) from New Zealand

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## ABSTRACT

The new species *Quinquelaophonte aurantius* sp.nov. is described, based on specimens collected in Portobello Bay, New Zealand. The species is distinguishable for having long fine setules in the anal operculum distal edge, a breadth ratio of caudal rami length above 3.5, and a rudimentary antenna abexopodal spine. This new species differentiates from *Q. parasigmoides* and *Q. wellsii* on the following autapomorphs; short spine-like outer seta in segment 2 of females P3 endopod and the partial reduction of setae in spines from male P3 and P4, longer V-shaped caudal rami, an almost non-existent terminal portion of the antenna exopod with short lateral setae. Phylogenetic analyses demonstrate the position of *Quinquelaophonte* within the family Laophontidae.

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## Introduction

The genus *Quinquelaophonte* (Wells et al. 1982) has 12 described species: *Q. quinquespinosa* (Sewell 1924), *Q. bunakenensis* (Mielke 1997), *Q. koreana* (Lee 2003), *Q. wellsii* (Hamond 1973), *Q. prolixasetae* (Walker-Smith 2004), *Q. candelabrum* (Wells et al. 1982), *Q. capillata* (Wilson 1932), *Q. longifurcata* (Lang 1965), *Q. parasigmoides* (Bozic 1969), *Q. varians* (Bjornberg 2010) and *Q. aestuarii* (Sciberras et al. 2014). To date, *Q. candelabrum* is the only species of *Quinquelaophonte* described in New Zealand (Wells et al. 1982), and is one of the most common harpacticoids found in intertidal mud and fine sand sediments in estuaries and harbours.

As part of a nationwide sampling, the presence of an undescribed second species of *Quinquelaophonte* inhabiting the same substrata was identified. This species presents a

**Table 1.** Known locations of *Quinquelaophonte candelabrum* and *Q. aurantius* sp. nov. in New Zealand. Numbers correspond to locations shown in Figure 9.

	Location	Coordinates	Date & Collector (both species unless stated)	Habitat and qualitative abundance	
				<i>Q. candelabrum</i>	<i>Q. aurantius</i>
<b>North Island – east coast</b>					
1	Houhora Harbour	34°47' S 173° 06' E	5 January 1978 JBJ Wells	Abundant in fine quartz sand with much silt and high density of NZ cockle, <i>Austrovenus stutchburyi</i> .	
2	Taipa, Doubtless Bay, Orura River estuary	35°00' S 173° 28' E	3–4 January 1978 JBJ Wells	Abundant in fine quartz sand with much silt and high density of cockles. Common in drier sand without cockles. Rare in mud.	Common in drier sand without cockles.
3	Mangonui Harbour	35°00' S 173° 32' E	6 January 1978 JBJ Wells	Rare in mud among mangroves.	
4	Uruti Bay, Bay of Islands	35°17' S 174° 08' E	10 January 1978 JBJ Wells	Common in muddy sand with NZ cockles.	
5	Frenchmanms Swamp, Waikare Inlet, Bay of Islands	35°17' S 174° 10' E	10 January 1978 JBJ Wells	Common in muddy sand among mangrove roots.	
6	Stevens Point, Whangarei Harbour	35°46' S 174° 22' E	17 January 1984 JBJ Wells	Common in muddy sand among mangroves; rare in silty coarse sand.	
7	Whangateau Harbour	36°19–22' S 174° 67–77' E	17–25 January 1978 JBJ Wells	Abundant or common in cockle beds; common in fine silty sand with pipis ( <i>Paphiesaustralis</i> ); rare in mud.	
8	Orewa River estuary	36°35' S 174° 42' E	13 December 1981 GRF Hicks	Rare in silty sand.	
9	Orukwai Point, TeAtatu, Waitemata Harbour	36°50' S 173° 30' E	14 January 1984 JBJ Wells	Abundant in silty sand; rare in mud.	
10	Tamaki River estuary, Waitemata Harbour	36°51' S 174° 53' E	12 December 1981 GRF Hicks	Common in silty sand; rare in mud.	
11	Hobson Bay, Waitemata Harbour	36°52' S 174° 48' E	18 June 1981 BC Coull	Rare in mud.	
12	Kauaeranga River estuary, Thames	37°08' S 175° 33' E	14 December 1981 GRF Hicks	Abundant in thick layer of silt over fine to medium sand.	
13	Athenree, Tauranga Harbour	37°27' S 175° 58' E	19 January 1984 JBJ Wells	Common in silty sand with cockles.	
14	TePuna estuary, Tauranga Harbour	37°40' S 176° 02' E	19 January 1984 JBJ Wells	Common in silty sand with cockles.	
15	Whareroa Point, Tauranga Harbour	37°40' S 176° 11' E	25 August 1981 JBJ Wells	Rare in silty sand on upper shore.	
16	Waimapu estuary, Tauranga Harbour	37°43' S 176° 10' E	19 January 1984 JBJ Wells	Common in silty sand with cockles.	
17	Port Ohope, Ohiwa Harbour	37°59' S 177° 06' E	20 January 1984 JBJ Wells	Rare in muddy sand on upper shore.	
18	Kutarere, Ohiwa Harbour	38°02' S 177° 08' E	20 January 1984 JBJ Wells	Common to abundant in muddy sand.	
19	Uawa River estuary, Tolaga Bay	38°23' S 178° 19' E	22 January 1984 JBJ Wells	Rare in very muddy sand and in clay.	

(Continued)

**Table 1.** Continued.

	Location	Coordinates	Date & Collector (both species unless stated)	Habitat and qualitative abundance
<b>North Island – west coast</b>				
20	Rawene, Hokianga Harbour	35°24' S 174° 10' E	16 January 1984 JBJ Wells	Common in sandy mud among mangroves.
21	Kaipara Harbour	36°15–22' S 174° 06–11' E	20 November 1981 DE Bennett	Fine sand; abundant in areas with much silt, rare in areas with little silt.
22	Wood Bay, Manakau Harbour	36°57' S 174° 40' E	14 January 1984 JBJ Wells	Common in sandy mud with cockles.
23	French Bay, Manakau Harbour	36°57' S 174° 40' E	12 December 1981 GRF Hicks	Rare in thin mud overlying fine sand.
24	Manurewa, Manakau Harbour	37°01' S 174° 53' E	13 January 1984 JBJ Wells	Very rare in muddy sand.
25	Waiuku, Manakau Harbour	37°15' S 174° 44' E	13 January 1984 JBJ Wells	Common in sandy mud.
26	Raglan Harbour	37°48' S 174° 52' E	2 January 1982 JBJ Wells	Abundant in fine sand with varying quantities of silt.
27	Kawhia Harbour	38°04' S 174° 49' E	2 January 1982 JBJ Wells	Rare in fine sand with clay.
28	Pauatahanui Inlet, Porirua Harbour	41°06' S 174° 54' E	22 January 1985 JBJ Wells	Common in mud among <i>Juncus maritimus</i> marsh.
29	Motukaraka Point, Pauatahanui Inlet, Porirua Harbour	41°06' S 174° 54' E	19 December 1984 JBJ Wells	Common in mud.
30	Brown's Bay, Pauatahanui Inlet, Porirua Harbour	41°13' S 174° 53' E	10 December 1984 JBJ Wells	Rare in fine silty sand among gravel.
31	Onepoto Arm, Porirua Harbour	41°08' S 174° 50' E	7 February 1985 JBJ Wells	Rare in fine silty sand and in mud.
<b>South Island – east and south coasts</b>				
32	Pakawau Inlet, Golden Bay	40°35' S 172° 41' E	9 February 1982 GRF Hicks	Rare in fine silty sand with cockles.
33	Motueka, Moutere Inlet	41°06' S 173° 01' E	10 February 1982 GRF Hicks	Rare in firm mud.
34	East Mahakipawa Arm, Pelorus Sound	41°10' S 173° 50' E	24 February 1982 GRF Hicks	Rare on soft mud.
35	Monaco, Waimea Inlet, Tasman Bay	41°16' S 173° 09' E	7 February 1982 GRF Hicks	Abundant in fine silty sand.
36	Nelson Haven, Tasman Bay	41°16' S 173° 17' E	6 February 1982 GRF Hicks	Common in compacted mud.
37	Avon-Heathcote estuary, Christchurch	43°31–33' S 172° 42–44' E	<i>Q. candelabrum</i> – 12 February 1983 GRF Hicks 3 December 2008 T Stringer <i>both species</i> – 28 August 1985 JBJ Wells	Abundant in fine silty and muddy sand with cockles, middle and lower shore; common in drier sand on upper shore; rare in mud.
38	Portobello Bay, Otago Harbour	45°50' S 170° 39' E	<i>Q. candelabrum</i> – 16–18 January 1979 JBJ Wells April–September 1980 GRF Hicks 28 April 1981	Common in muddy sand. Common in muddy to fine sand.

(Continued)

**Table 1.** Continued.

	Location	Coordinates	Date & Collector (both species unless stated)	Habitat and qualitative abundance
			BC Coull <i>both species</i> – 14 October 2009 T Stringer 16 June 2016 M Charry	
39	Papanui Inlet, Otago Peninsula	45°51' S 170° 41' E	3 February 1983 GRF Hicks	Rare in fine sand on lower shore.
40	Mokomoko Inlet, New River Harbour, Invercargill	46°28' S 168° 20' E	3 February 1983 GRF Hicks	Rare in muddy fine sand.
41	Bluff Harbour	46°35' S 168° 21' E	3 February 1983 GRF Hicks	Rare in muddy fine sand.
	<b>South Island – west coast</b>			
42	Ongawanga Creek, Whanganui Inlet	40°35' S 172° 38' E	9 February 1982 GRF Hicks	Common in muddy fine sand.
43	Anaweka River estuary	40°47' S 172° 18' E	19 May 1985 FM Cllimo	Common in silty sand with cockles.

smaller distribution than *Q. candelabrum* (Table 1, Figure 9). *Quinquelaophonte aurantius* sp. nov. is easily cultured in the laboratory and their sensitivity to pollutants has been validated for estuarine sediment toxicity testing (Stringer et al. 2012a; Stringer et al. 2014). In this study, we describe this new harpacticoid copepod species of the genus *Quinquelaophonte*, obtained from field samples collected at Portobello Bay, in Dunedin, New Zealand.

## Materials and methods

### *Specimens collection and treatment*

Specimens were collected from sediment samples in Portobello Bay, Dunedin (45° 50'14.3"S170°39'25.9E"). Sediment samples were gently sieved out with a 100-µm plastic mesh, and fixed in 4% formalin before being transferred to 70% ethanol for storage. Specimens were cleared in lactic acid, dissected in water, mounted in Reyne's Medium and ringed with clear nail varnish for identification. Drawings were made with a camera lucida tube on a Zeiss Universal microscope equipped with Nomarski differential interference contrast microscopy. Terminology of tagma and appendages follows Huys & Boxshall (1991). In this paper, 'medial' signifies 'towards the middle or centre of the animal or of the structure being described'. P1–P4 refers to the 'swimming' legs and P5–P6 to the legs modified for reproductive purposes. Individual 'segments' of rami are numbered from proximal to distal (i.e. exopod–1, exopod–2, exopod–3). Setal formula of P1–P4 is given in the simple Langian form (Lang 1934). The total length of individuals was measured from the base of the rostrum to the apex of the caudal rami. Mean length is expressed ±1SD. The wide variation in length represents the difference between extremely contracted and fully relaxed individuals. This mean value probably is considerably smaller than the true mean of a collection of living adults.

## Material examined

Type specimens were deposited in the Auckland Museum, New Zealand. Holotype: adult female preserved in ethanol (reg. no. MA73574, Auckland Museum). Allotype: adult male preserved in ethanol (reg. no. MA73575, Auckland Museum). Paratypes: 4 females – 1 preserved in ethanol and 3 dissected and mounted on slides (reg. no. MA73576, Auckland Museum); 5 males – 2 preserved in ethanol and 3 dissected and mounted on slides (reg. no. MA73577, Auckland Museum).

## DNA extraction, sequencing, and phylogenetic analyses

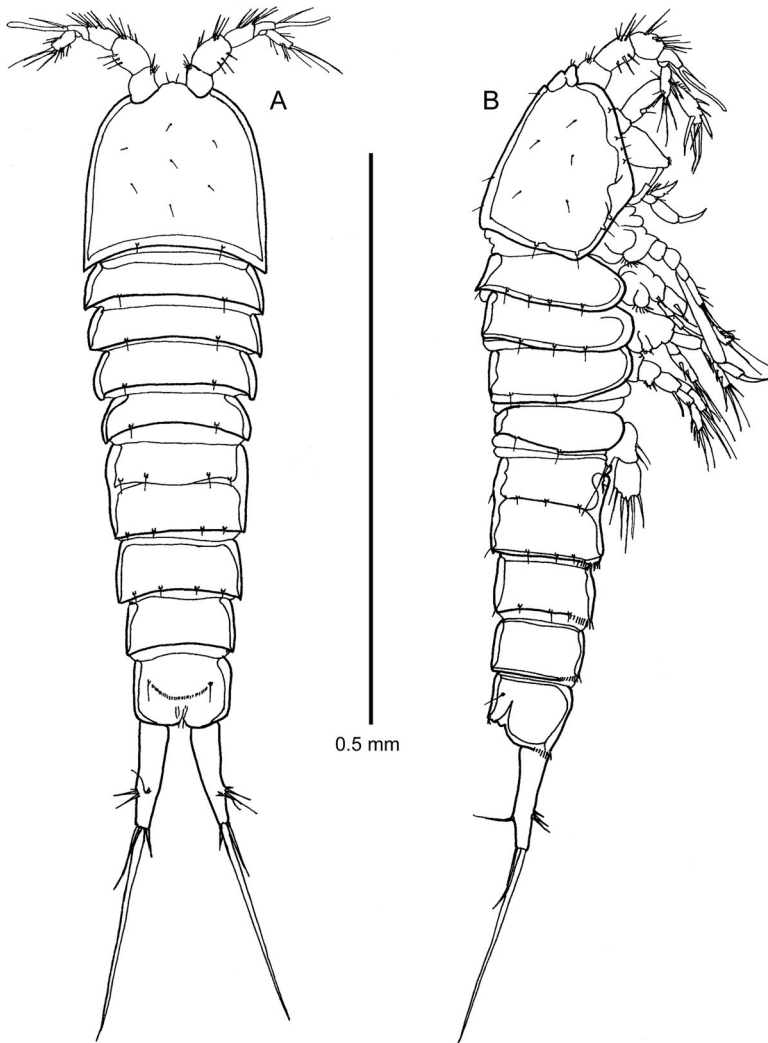
Total genomic DNA was extracted from 100 pooled adult copepods using a PowerSoil DNA isolation kit (Qiagen, Hilden, Germany) following the manufacturer's protocol. DNA extractions were quantified using a NanoPhotometer (Implen, Munich, Germany) to check for DNA quantity and quality (260/280 ratio), and stored at  $-20^{\circ}\text{C}$  until further analysis. An approximately 700 bp section of the cytochrome c oxidase subunit I gene (COI) was amplified using the primers LCO1490 and HCO2198 (Vrijenhoek 1994). The polymerase chain reaction (PCR) amplifications were carried out in 50  $\mu\text{l}$  reaction volumes containing; 25  $\mu\text{l}$  of MyTaq<sup>TM</sup> 2x PCR master mix (Bioline, MA, USA), both forward and reverse primers 0.4  $\mu\text{M}$  and template DNA (ca. 50–150 ng). Thermocycling conditions consisted of an initial denaturing step of  $95^{\circ}\text{C}$ , 4 min, followed by 40 cycles of  $94^{\circ}\text{C}$ , 1 min;  $50^{\circ}\text{C}$ , 1 min;  $72^{\circ}\text{C}$ , 90 s; with a final extension step of  $72^{\circ}\text{C}$ , 10 min. An approximately 1800 bp section of the 18S ribosomal DNA gene region (rDNA) was amplified using the primers EukA and EukB (Medlin et al. 1988). PCRs were made up as described above with thermocycling conditions of initial denaturing step of  $94^{\circ}\text{C}$ , 2 min, followed by 30 cycles of  $94^{\circ}\text{C}$ , 30 s;  $56^{\circ}\text{C}$ , 1 min;  $72^{\circ}\text{C}$ , 90 s; with a final extension step of  $72^{\circ}\text{C}$ , 10 min. Amplification products were purified using AxyPrep PCR cleanup kits (Axygen, California, USA) and sequenced in both directions, using the PCR primers, by an external contractor (Genetic Analysis Services, University of Otago, Dunedin). Forward and reverse sequences were aligned using Geneious v8.1.5 (Kearse et al. 2012) and conflicts resolved by manual inspection.

The 18S rDNA sequence from *Q. aurantius* was aligned with publicly available Harpacticoida 18S rDNA sequences (Yeom et al. 2018) from GenBank using the ClustalW algorithm (Thompson et al. 1994) in Geneious. For subsequent analyses, sequence data matrices were truncated to 1695 bp. Bayesian analyses were carried out in Geneious using MrBayes 3.1.2 (Ronquist et al. 2012) using the evolutionary model (general time reversible with gamma-distributed rate variation across sites and a proportion of invariable sites, GTR + G + I). Analyses of alignments were carried out in two simultaneous runs with four chains each  $2.1 \times 10^6$  generations, sampling every 1000 trees. A 50% majority-rule consensus tree was drawn from the last 1000 trees. All final split frequencies were  $<0.01$ .

## Results

**Taxonomy.** *Quinquelaophonte aurantius* sp. nov. (Figures 1–8).

**Etymology.** The specific name alludes to the latin word for orange (aurantius), in reference to the species body's colour when alive.



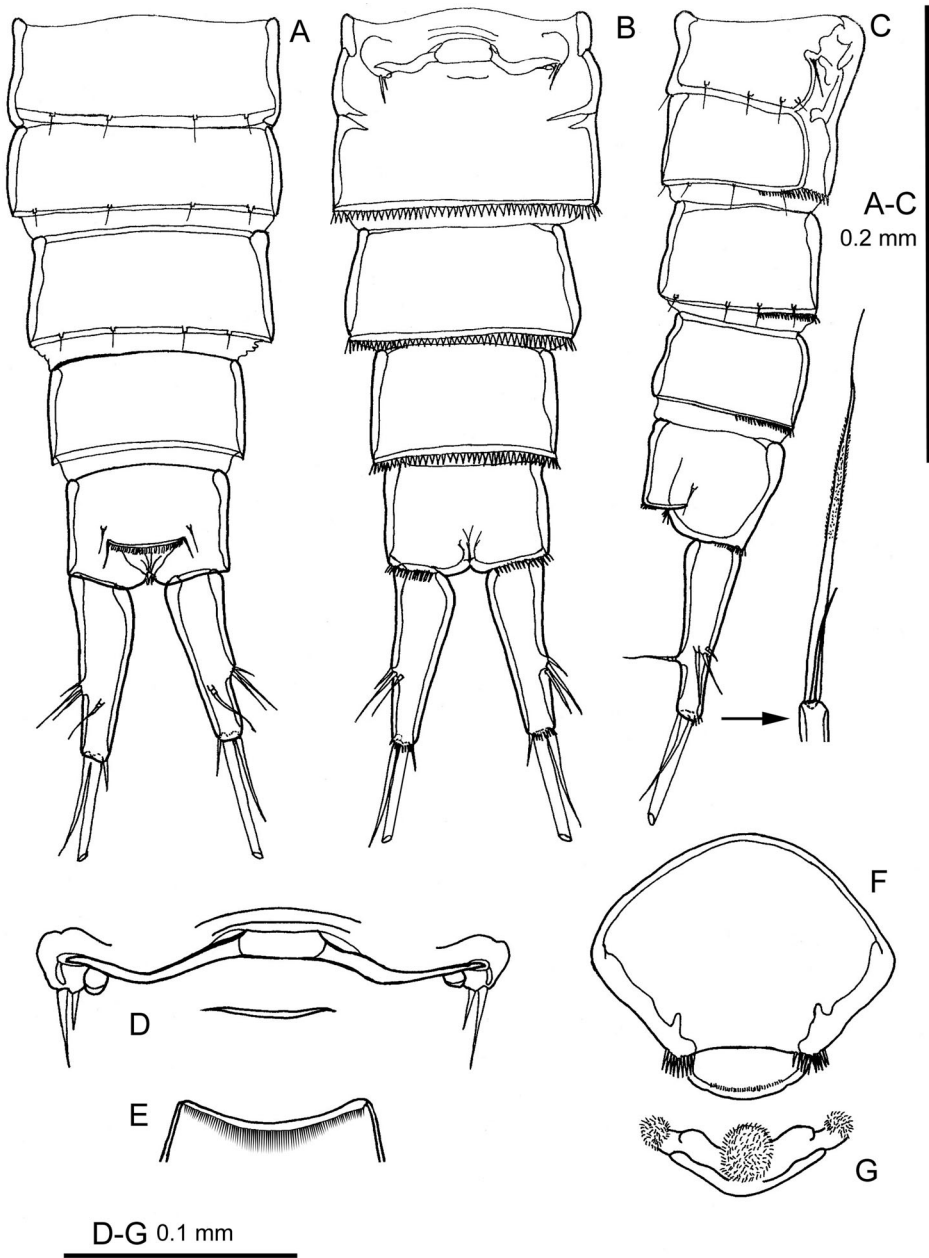
**Figure 1.** *Quinquelaophonte aurantius* sp. nov. female: **A–B**, habitus dorsal and lateral.

**Type location.** Portobello Bay, Otago Harbour, New Zealand (Table 1, location 38).

**Diagnosis.** Body surface almost naked, without a comprehensive cover of minute setules, denticles or pustules; anal operculum with long fine setules; caudal ramus almost four times as long as maximum breadth; female antennule 6-segmented; antenna abexopodal seta spine-like and small; P1 exopod-2 with two setae and three spines; P1 endopod-2 with minute accessory seta; exopod-3 of female P3 and P4 with six setae and spines; female P5 exopod with six setae; male P5 with a total of five setae. Adult length: Females: 608–842  $\mu\text{m}$ ; mean  $737 \pm 55 \mu\text{m}$  ( $n = 34$ ). Males: 632–808  $\mu\text{m}$ , mean  $715 \pm 49 \mu\text{m}$  ( $n = 23$ ).

### **Female description**

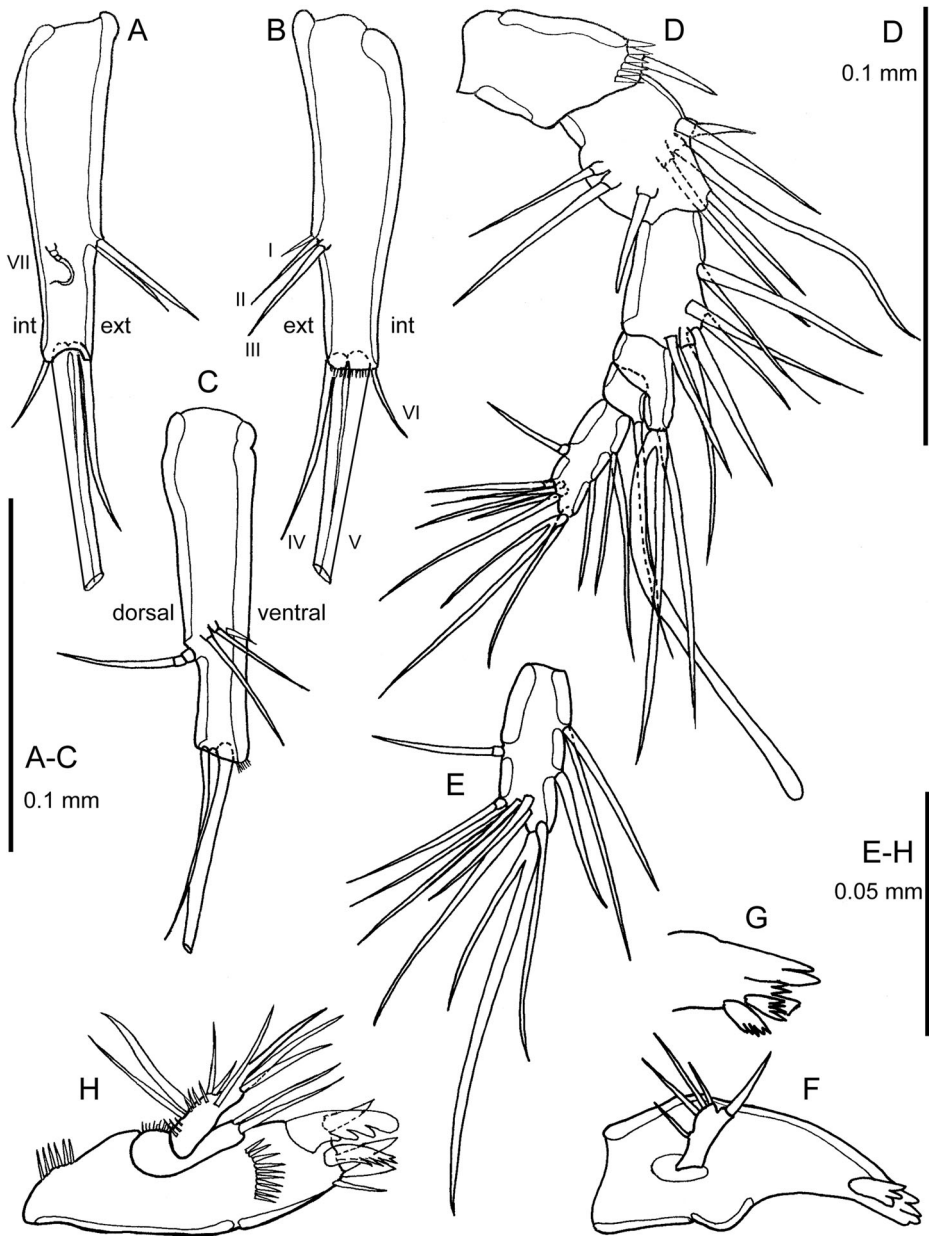
**Habitus.** (Figure 1A–B): almost cylindrical. Urosome slightly tapering posteriorly. Somites well demarcated from each other. Hyaline frill broad on cephalic shield but



**Figure 2.** *Quinquelaophonte aurantius* sp. nov. female: **A–C**, urosomites 2–6 dorsal, ventral and lateral; **D**, P6 and genital field; **E**, anal operculum; **F**, labrum; **G**, paragnaths.

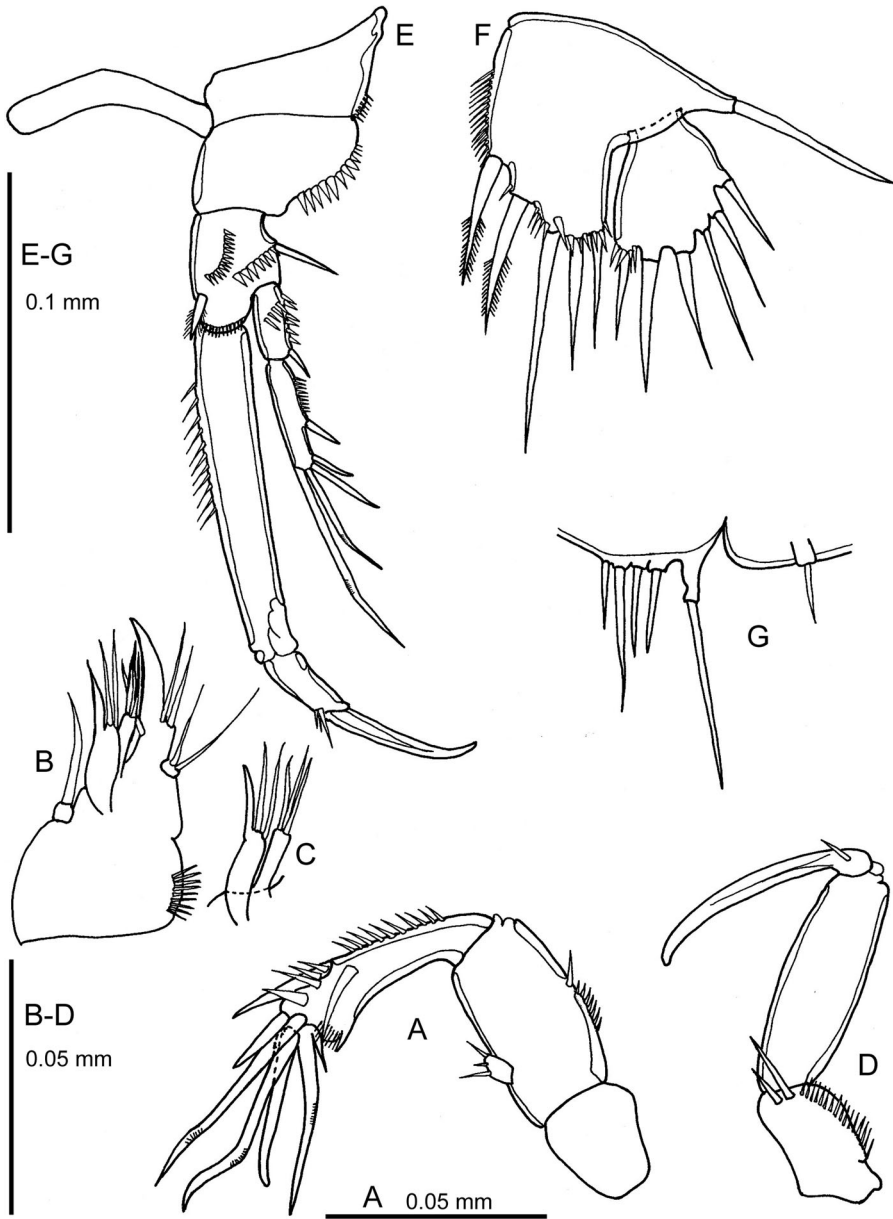
rudimentary elsewhere. Rostrum small, fused to cephalic shield, with two sensilla. Urosomites 2–3 fused to form a genital double somite (Figure 2A–C). Outline of urosomite-2 obvious in dorsal view. Junction between the two somites marked by a prominent dorsal and lateral chitin ridge bearing sensilla that ventrolaterally extends anteriorly and posteriorly as though marking the ventral margin of the pleura. Anal operculum (Figure 2E) well developed, semilunar, margin heavily chitinised, clothed with fine





**Figure 3.** *Quinquelaophonte aurantius* sp. nov.. female: **A–C**, right caudal ramus dorsal, ventral and outer lateral; **D**, antennule; **E**, antennule segment 6 in posterior view; **F**, mandible; **G**, mandible gnathobase in another orientation; **H**, maxillule. [int = internal; ext = external].

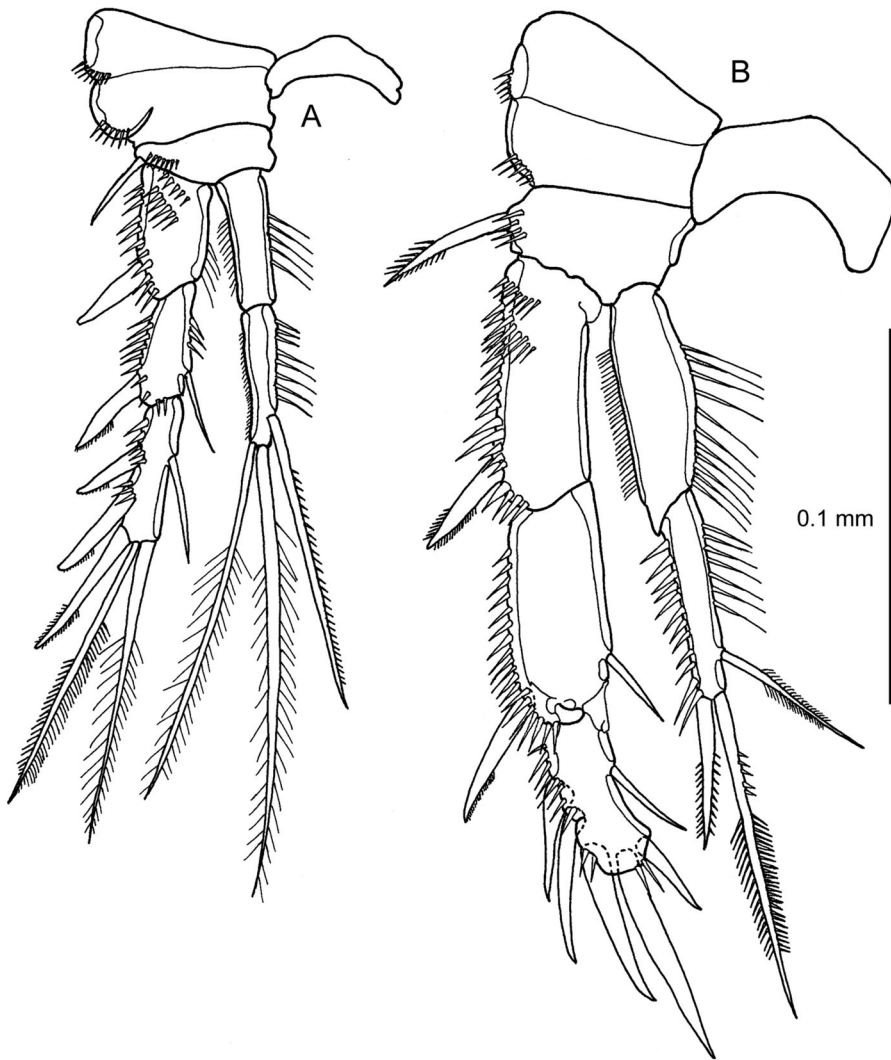
setules and flanked each side by a sensillum. Posterior margin of all somites (including urosomite–2) except urosomites 5–6 with several sensilla on small pedestals. Ventral and ventrolateral posterior margins of urosomites 3–6 a row of small spinules. Dorsal posterior margin of all urosomites without spinules. Almost all body surfaces with a thin layer (about 2 $\mu$ m) of mucus in which a large number of minute particles are entrapped.



**Figure 4.** *Quinquelaophonte aurantius* sp. nov.. **A–F**, female: **A**, antenna; **B**, maxilla; **C**, maxilla, distal endites; **D**, maxilliped; **E**, P1 and intercoxal sclerite; **F**, P.5; **G**, male P5.

Generally, the body surface without apparent surface ornamentation except for some sensilla on the cephalic shield.

**Genital field.** (Figure 2D): The pair of P6 widely separated; each with two short setae. Adjacent and medial to the P6 is a small lobe that possibly conceals the gonopore. Copulatory pore not displaced posteriorly and possibly hidden beneath a central chitin ridge.

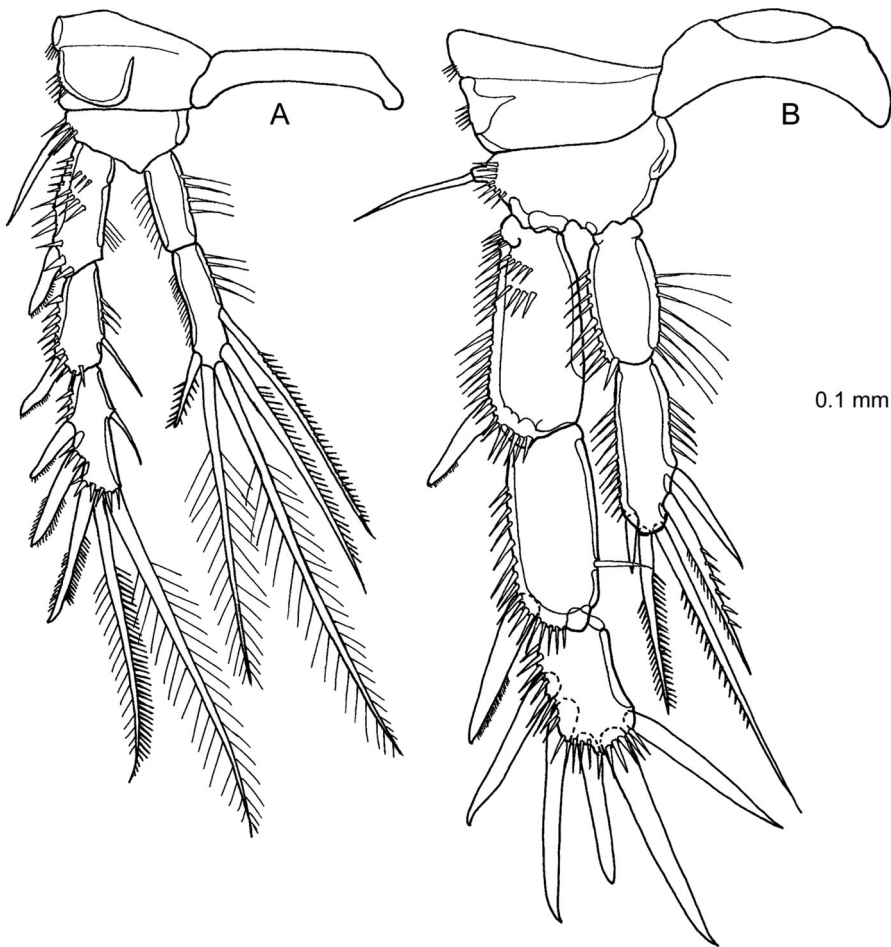


**Figure 5.** *Quinquelaophonte aurantius* sp. nov. **A–B**, P2 and intercoxal sclerite, female and male.

This central region is linked on each side to the P6 region by a tubular structure whose medial portion is somewhat enlarged and may be the receptaculum seminis.

**Labrum.** (Figure 2F) **and paragnaths** (Figure 2G): Labrum very large and very prominent in lateral view of whole animal (Figure 1B). Paragnaths complex, with two minutely setulose lateral knobs and a large similarly setulose central knob.

**Caudal ramus.** (Figure 3A–C): cylindrical, slightly conical, with the inner margin convex proximally; maximum length 3.5–3.8 times as long as maximum width; seven setae. Origins of setae I–III closely adjacent about two-thirds along the inner margin. Seta I rudimentary. Setae IV and V with a common base. Seta IV short and very slender. Seta V 2–3 times as long as the ramus, without a cleavage plane; middle portion set all round with minute setules only just visible under high magnification (x1825) Nomarski optics



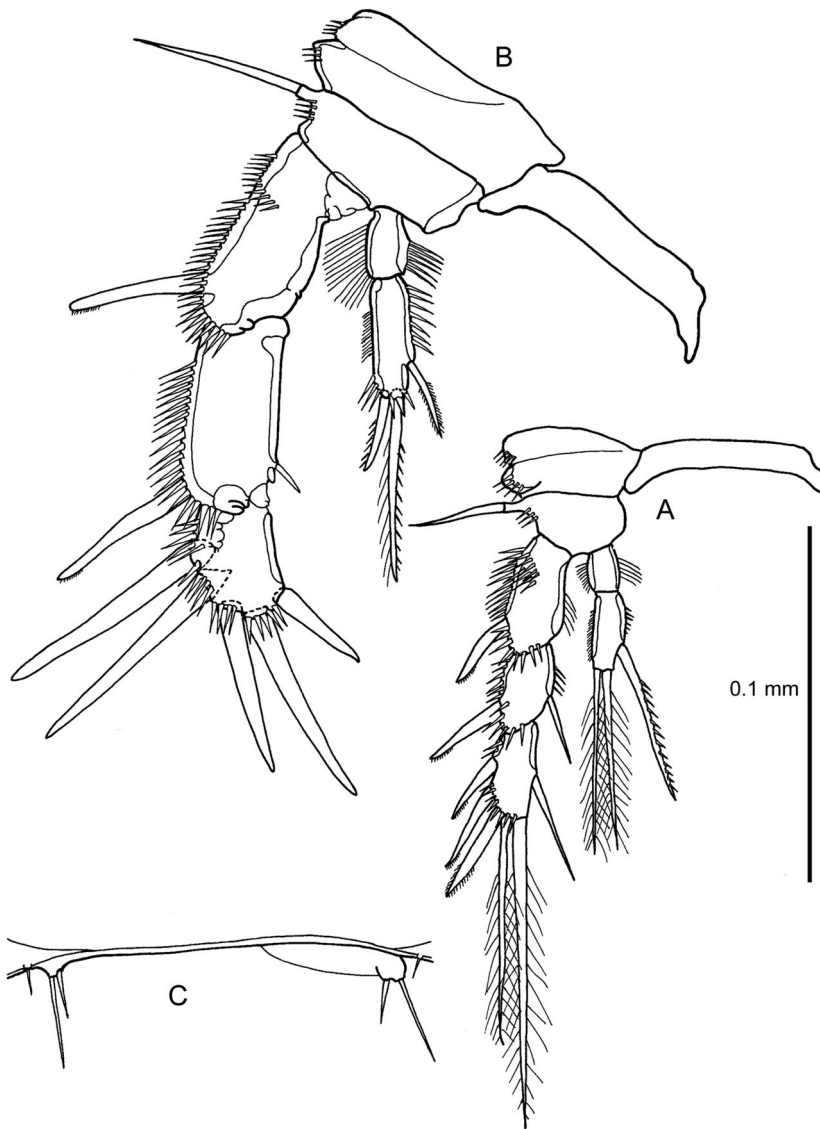
**Figure 6.** *Quinquelaophonte aurantius* sp. nov. **A–B**, P3 and intercoxal sclerite, female and male (note comment in text on setation of male exopod-3).

(Figure 2C). Seta VI at inner distal corner, very short. Seta VII well developed, biarticulate at its base, borne on a pedestal just distal to the origin of setae I–III.

**Antennule.** (Figure 3D–E): short, six-segmented. Segment four has a terminal aesthetasc fused basally with a long seta and accompanied by another long seta in a trithek. Segment six with a terminal trithek similar to that on segment four, although the aesthetasc is very fine and delicate. Setal formula: 1–[1], 2–[8], 3–[7], 4–[2 + aesthetasc], 5–[1], 6–[11 + aesthetasc].

**Mandible.** (Figure 3F–G): with a strongly chitinised, but relatively simple gnathobase consisting of five short blunt teeth, three of which appear to be on a distinct plate. Palp a single element, exopod and endopod not recognisable but represented by one and three setae respectively; basis with one terminal seta.

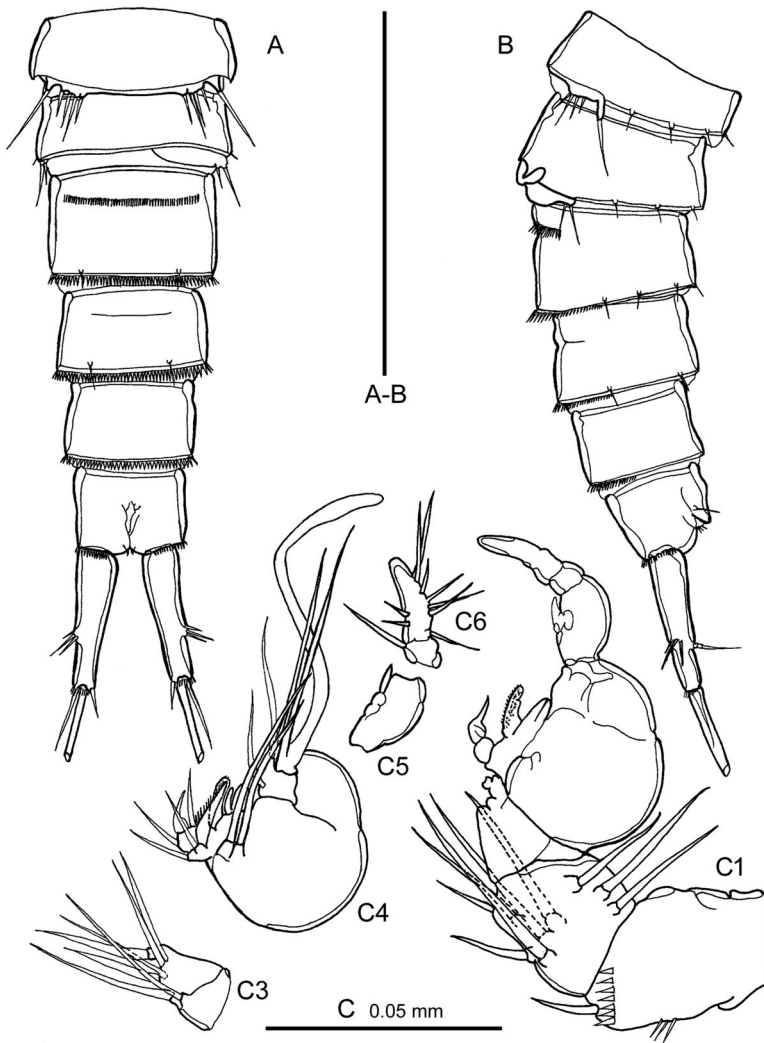
**Maxillule.** (Figure 3H): arthrite with five terminal teeth and a subterminal lateral spinule; posterior surface with a row of spinules, but without setae. Coxa distinct, with two long



**Figure 7.** *Quinquelaophonte aurantius* sp. nov. **A–B**, P4 and intercoxal sclerite, female and male (note comment in text on setation of male exopod-2 and -3); **C**, male, pair of P6.

terminal setae. Basis endite with three setae. Rami absorbed into basis. Endopod with three setae. Exopod with two setae.

**Antenna.** (Figure 4A): large and robust. Allobasis with a small abexopodal spine like seta that is not much longer than the adjacent spinules. Endopod-2 with two stout spines on inner margin, one of which is displaced medially and some extremely large, stout spinules distally; terminally with two claw-like spines and three weakly geniculate spines, the outer sharing a common base with a very small spine. Exopod reduced to one very small segment with three-minute terminal setae.

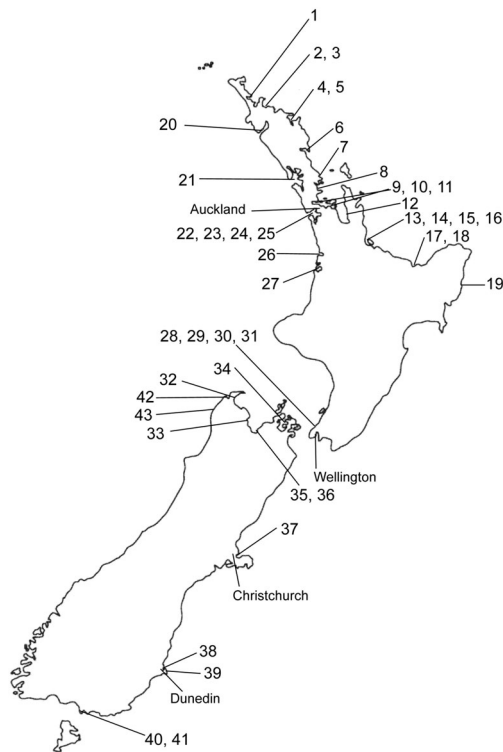


**Figure 8.** *Quinquelaophonte aurantius* sp. nov. male: **A–B**, urosome ventral and lateral; C1, antennule (setation shown only for segments 1–2) [C3, segment 3; C4, segment 4; C5, segment 5; C6, segments 6–7]. (Note that C3–C6 are figured in a slightly different orientation from their equivalents in C1).

**Maxilla.** (Figure 4B–C): syncoxa compact, with three endites; proximal endite with 1 seta, distal endites each with three elements. Basis with a fused terminal pinnate claw with two setae at its base on the inner side and one on the outer side. Endopod recognisable (in some specimens it appears to be distinct from the basis) with two setae.

**Maxilliped.** (Figure 4D): long and slender, prehensile. Syncoxa with two setae. Basis unornamented. Endopod a long claw with a minute seta at its base.

**PI.** (Figure 4E): The pair of P1 widely separated by a long slender intercoxal sclerite. Prae-coxa large and prominent; with small spinules at the outer distal corner. Coxa much broader than long, outer side rounded and ornamented with strong spinules. Basis



**Figure 9.** Known locations of *Quinquelaophonte* spp. in New Zealand (see [Table 1](#) for details).

narrow, much longer than broad, with origin of exopod considerably proximal to that of endopod. Outer margin with a stout spine. Inner spine spinulose, subterminal and originating slightly medial to inner margin. Anterior surface of basis with outer and medial antero-posterior rows of stout spinules. Distal margin above origin of endopod ornamented with small spinules. Exopod two-segmented and extends to about halfway along endopod-1. Exopod-2 almost twice as long as exopod-1. Exopod-1 with a distal outer spine and ornamented with stout spinules along outer edge and in a proximal transverse row on anterior surface. Exopod-2 with two weakly geniculate setae terminally and three outer spines. Endopod elongate, prehensile, two-segmented. Endopod-1 about four times as long as endopod-2. Endopod-1 with long fine setules on proximal part of inner margin. Endopod-2 terminally with a long claw, a minute seta and two small spinules.

**P2.** ([Figure 5A](#)): the pair of P2 separated by a slender intercoxal sclerite that is shorter than that of the other legs. Praecoxa large and prominent but suture with coxa less well defined than in P1. Praecoxa with spinules at outer distal corner. Coxa with spinules at outer distal corner; sclerotisation of outer margin continues medially in an arc. Basis narrow, especially on outer side, with a short row of stout spinules around the origin of the stout outer spine. Exopod with three, endopod with two segments; endopod extends beyond the end of exopod-2. Exopod segments approximately equal in length but progressively more slender; outer distal corner of exopod-1 and -2 produced as a rounded projection; outer margin of segments densely ornamented with long stout spinules; proximal anterior surface of exopod-1 with two

diagonal rows of stout spinules. Endopod segments approximately equal in length, elongate, slender; inner margin ornamented with very long fine setules; outer margin of endopod-1 with extremely fine setules, that of endopod-2 with minute spinules.

**P3.** (Figure 6A): differs from P2 only in the longer intercoxal sclerite, a narrower and less well-defined praecoxa, slightly different proportions of exopod and endopod segments and the presence of five setae and spines on endopod-2.

**P4.** (Figure 7A): intercoxal sclerite of similar proportions to that of P1 and P3. Praecoxa similar to P3. Coxa as P2-P3. Basis as P2-P3 but with outer side projecting as a long pedestal. Exopod slightly shorter and endopod much shorter than P2-P3. Endopod extends only halfway along exopod-2. Exopod-1 considerably longer than exopod 2 or 3. Endopod-2 almost twice as long as endopod-1. Ornamentation of rami as P2-P3.

**P5.** (Figure 4F): the pair of P5 are separate. Basis and endopod fused as a baseoendopod. Outer side of basis expressed as a narrow pedestal with a slender seta. Endopod lobe well developed; ornamented with fine setules on inner margin and spinules on distal margin. Exopod not fused to basis, only slightly longer than endopod lobe; broadly triangular in shape, making it difficult to be certain which setae are on the inner, outer and distal margins; inner distal corner with spinules. Baseoendopod with two bipinnate spines and three setae, exopod with six short plain setae.

**Variability.** was noted in body length. Caudal ramus seta V varied relative to urosome length; in females of similar body length this seta varied between being almost as long as the entire urosome (excluding caudal ramus) to being equal only to urosomites 3-6.

**Male Description.** The male differs from the female in the following aspects:

**Habitus.** (Figure 8A-B): urosomites 2-3 not fused and without trace of ventral pleura margins. Venter of urosomite-3 with a proximal row of fine setules situated in a shallow groove. Urosomite-4 with a similar groove but without ornamentation.

**Antennule.** (Figure 8C-G): chirocerate; nine segments, with segments 2-3 and 5-6 fused together. The major articulation is between segments 6 and 7. Segments 5-6 form a very large and bulbous unit, with small traces of its amalgamation from two precursors visible on the outer margin. The portion distal to segments 5-6 comprises three segments that are poorly demarcated from each other. The visible line of demarcation between segments 7 and 8 is very weak and that between segments 8 and 9 is variably present or incomplete. Aesthetasc on segment four shares a common base with a long seta in an acrothek; another long seta originates on an adjacent but distinctly separate pedestal. Inner margin of segment four has a large minutely spinose digitate pad. Immediately distal to this pad is a bifid lobe; proximal to the pad is a large stoutly spinulose structure, a small seta and a pedestal with a small acutely pointed hyaline structure. A similar structure appears on segment five. While it is possible these structures have been derived from setae they are excluded from the setal formula. Setal formula: 1-[1], 2-3-[9], 4-[7], 5-[10 + spiniform process + aesthetasc + hyaline structure], 6-[0], 7-[1], 8-9-[10].

**P2.** (Figure 5B): much longer and more stoutly built than female. Intercoxal sclerite broader in proximal-distal axis than in the female. Protopod similar to female except



that the coxa lacks a medial sclerotised arc and inner margin of basis appears to be more heavily chitinised. Ornamentation of rami as female except that the setules and spinules on the outer margin of the endopod are much stronger. Exopod-3 very strongly chitinised, especially around the origin of the outer and terminal spines, where the segment margin is extended so that the spines appear to be set into deep sockets. Terminal setae represented by very stout spines in the male. Exopod-3 linked to exopod-2 by a flexible membrane at inner proximal corner that enables exopod-3 to be swivelled inwards through approximately 90°. Endopod less modified. Endopod-1 less cylindrical than in female, inner margin convex; outer distal corner a unguiform projection. Inner seta of endopod-2 much shorter than in female and outer seta replaced by a much shorter plumose spine. Outer margin of endopod-2 with strong spinules.

**P3.** (Figure 6B): similar to P2 in general build; junction between exopod-2 and -3 similarly modified. Endopod not extending to the end of exopod-2; relatively shorter and much more robust than in female. Endopod-2 setae much shorter than in female; outer seta replaced by a very short stout spine. Outer distal corner of endopod-1 not unguiform. Inner seta much reduced in size on exopod-2 and -3, and usually absent from exopod-3 (in 10 males examined this seta was only present on the right leg in one and on the left in two; never present on both legs).

**P4.** (Figure 7B): similar to P2 in general build; junction between exopod-2 and -3 similarly modified. The two proximal outer spines of exopod-3 very long. Endopod-2 more cylindrical than in female but with a rounded base and apex; all setae much shorter and outer seta replaced by a spinulose spine. Outer distal corner of endopod-1 not unguiform. Inner seta of exopod-2 rudimentary or absent (it was present on the left leg of all 10 males examined, but on the right leg in only one). Nine of the 10 males examined lack an inner seta on exopod-3; in one male a rudimentary seta was present on the right leg only (this is the same male that has a seta on the right P3 exopod-3). Setal formula for male P1-P4 swimming legs (Figures 4E-7A) (Table 2).

**P5.** (Figure 4G): reduced to a long outer pedestal (the remnant of the basis) bearing a long seta and four small inner pedestals each bearing a seta (there is no evidence to indicate whether these are rudiments of the exopod or endopod or a mixture of both).

**P6.** (Figure 7C): left P6 represented by a broad but shallow articulated genital lappet bearing two setae at its outer margin. Right P6 reduced to two small pedestals fused to somite margin, each bearing a seta.

**Table 2.** Summary setal formula for male and female *Q. aurantius* sp. nov. P1-P4 swimming legs.

	Male		Female	
	Exopod	Endopod	Exopod	Endopod
P1	0. 0.2.3.	0. 0.2.0.	0. 0.2.3.	0. 0.2.0.
P2	0. 1. 1.2.3.	0. 1.2.0.	0. 1. 1.2.3.	0. 1.2.0.
P3	0. 1. 1*.2.3.	0. 2.2.1.	0. 1. 1.2.3.	0. 2.2.1.
P4	0. 1*. 1*.2.3.	0. 1.2.0.	0. 1. 1.2.3.	0. 1.2.0.

\* These setae may be present or absent.

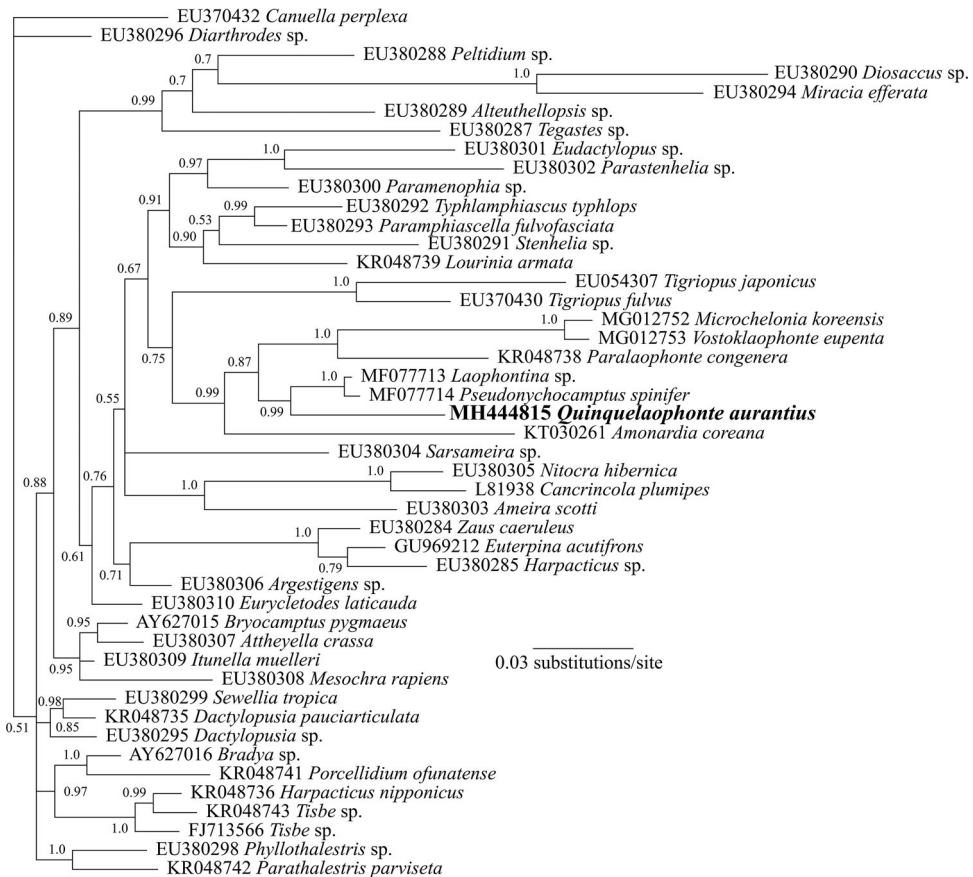
**Variability.** was noted in body length, relative length of caudal ramus seta V (of a similar order to that in the female), the level of reduction of setation in P3 and P4 and the degree of segmental fusion in the antennule.

**Habitat distribution.** *Quinquelaophonte aurantius* is widespread in the Otago Harbour, and at Taipa in Doubtless Bay (Table 1; sites 2 and 38). Habitat preferences has been correlated to finer sediments (mud to medium sand particles <500  $\mu\text{m}$ ), and upper tidal reaches with pH between 8 and 8.8 (Stringer et al. 2012b).

**Remarks.** Reference DNA sequences obtained from adult copepods of *Q. aurantius* have been deposited in GenBank as follows: COI (MH444814) and 18S rDNA (MH444815).

### Phylogenetic analyses

The phylogenetic tree based on the nuclear 18S rDNA gene (Figure 10) shows that currently available sequences from genera of the family Laophontidae (*Paralaophonte*, *Pseudonychocamptus*, *Laophontina*, *Microchelonia*, *Vostoklaophonte*) group together with the sequence from *Q. aurantius* with very high support (87% Bayesian posterior probability)



**Figure 10.** Phylogenetic analysis of *Q. aurantius* sp. nov. from Portobello Bay, New Zealand, and other Harpacticoida species showing alignment of partial 18S rDNA sequences using Bayesian analyses. Values at nodes represent Bayesian posterior probability support. Scale bar is substitutions per site.

(Yeom et al. 2018). In particular, the analysis suggests a close relationship between *Quinquelaophonte*, *Pseudonychocamptus* and *Laophontina*.

## Discussion

Analysis of all *Quinquelaophonte* species shows that *Q. aurantius* is most similar to *Q. parasigmoides* and *Q. wellsii* in major structures. Regarding the geographic distribution, species *Q. parasigmoides* is known only from marine beach sand on Réunion Isle (Indian Ocean, east of Madagascar) and *Q. wellsii* from saline lakes in South Australia. Ten females and ten males of *Q. aurantius* were examined for variability of structural characters. Based on the descriptions provided for *Q. parasigmoides* and *Q. wellsii*, there appear to be four autapomorphs for male *Q. aurantius*. Three relate to the partial reduction of setae and spines in the male P3 and P4. However, a number of other structural differences between these three species are shown on Table 3. Phylogenetic analyses demonstrate the position of *Quinquelaophonte* within the family Laophontidae.

**Table 3.** Characters of *Q. aurantius* sp. nov. compared with *Q. parasigmoides* and *Q. wellsii*. \* =Autapomorph. <sup>(a)</sup> 5 setae on both legs in 7 of the 10 individuals examined; 5 on left and 6 on right in 1 of 10; 6 on left, 5 on right in 2 of 10; <sup>(b)</sup> 1 female (of 2 examined) without seta on second segment on both legs; <sup>(c)</sup> 1 female (of 2 examined) with two inner setae on left leg only; <sup>(d)</sup> Exp. 2 inner seta: present on left leg of all 10 individuals; only on 1 of 10 on right leg; <sup>(e)</sup> Exp. 3 inner seta: 9/10 seta absent; 1/10 seta rudimentary on right leg only.

Characters	<i>Q. aurantius</i>	<i>Q. parasigmoides</i>	<i>Q. wellsii</i>
Caudal ramus length/breadth ratio	3.5–3.8	3.0	2.7
Anal operculum distal edge	long fine setules	naked	naked
Antenna abexopodal spine	rudimentary*	unknown	well developed
Antenna exopod, shape	terminal portion almost non-existent; lateral 2 setae short; terminal seta long, setose	terminal portion long; lateral 2 setae long; terminal seta long, setose	terminal portion long; lateral 2 setae long; terminal seta spinose
P1 female; endopod seg. 2, apical setae/spine length	outer spine very long; inner seta minute	outer spine very long; inner seta minute	both very long
P3 female; exopod seg. 3, setae and spines	6 (1.2.3)	6 (1.2.3)	7 (2.2.3)
P3 female; endopod seg. 2, outer seta	short, spine-like	unknown	long fine seta
P4 female; exopod, setae and spines	0.1.123	0.1.123	0.0–1 <sup>b</sup> .123
P4 female; exopod 3, inner seta	long	long	short and weak
P4 female; endopod seg. 2, setae	1.2.0	1.2.0	1–2 <sup>c</sup> .2.0
P5 female basendopod shape	inner edge almost straight; innermost seta very close to 2nd seta	inner edge almost straight; innermost seta very close to 2nd seta	inner edge convex; innermost seta well separated from 2nd seta
P5 female exopod shape	broad, 'v'-shaped	broad, 'v'-shaped base	oval shaped base
P5 female exopod, length/breadth ratio	1.5–2	<1.5	<1.5
P2 male; endopod seg. 2, outer terminal seta length	very long cf. Inner seta	very long cf. Inner seta	all 3 setae more or less same length
P3 male; exopod seg. 3, setae and spines	5 or 6 (0–1*.2.3) <sup>a</sup>	6 (1.2.3)	6 (1.2.3)

Despite the distribution similarity between *Q. aurantius* and *Q. candelabrum* in New Zealand, different morphological characteristics are evident on the urosomite, the antennule and the shape of the seta V. Unlike *Q. aurantius* males, the two rows of fine setules in the proximal part of the venter are not situated in a groove in the somite surface of *Q. candelabrum* (Figure S1). Further, the urosomite 4 does not have a ventral groove. Another main difference lies on the male antennule, where segments 5–6 and 7–9 are completely fused, and the distal digitate element on the digitate spine is extremely long (Figure S2). Last, seta V in *Q. candelabrum* has a pipette like shape, while *Q. aurantius* sp. nov. has a pronounced V shape in both sexes.

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