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A new anchialine shrimp of the genus *Procaris* from Christmas Island: the first occurrence of the Procarididae in the Indian Ocean (Crustacea: Decapoda: Caridea)

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Abstract

A fifth species of the anchialine shrimp genus *Procaris* is described from Christmas Island, northeast Indian Ocean. This marks the first record of the Procarididae from the Indian Ocean. The closest known congeneric species, and the only other known from the Indo-West Pacific region, is *P. hawaiiana* Holthuis, 1973, from Hawaii. The new species can be separated from other described species by its angular fifth abdominal pleuron, having the medial eye lobe longer than the lateral, and by having a distolateral tooth on the scaphocerite. A cladistic analysis suggests the new species is sister to the clade containing the Pacific, *P. hawaiiana*, and the Atlantic *P. chacei*.

Key words: Anchialine, Procarididae, *Procaris*, Indian Ocean, new species, Christmas Island

Introduction

The family Procarididae includes a group of aberrant shrimps apparently restricted to anchialine caves in both the Atlantic and Indo-Pacific Oceans, but until the publication of the present paper, no species of the Procarididae has been known from the Indian Ocean. Two genera are recognised, *Procaris* Chace & Manning, 1972, and the monotypic *Vetericaris* Kensley & Williams, 1986. All are relatively poorly known. Four species have been placed in *Procaris*: *P. ascencionis* Chace & Manning, 1972, *P. chacei* Hart & Manning, 1986, and *P. mexicana* Sternberg & Schotte, 2004, from the Atlantic region; and *P. hawaiiana* Holthuis, 1973, from the Central Pacific. The discovery of a new species in the Indian Ocean is therefore of particular interest. The present species is known only from

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a single specimen found in an anchialine cave on the Australian Territory of Christmas Island in the eastern Indian Ocean.

Christmas Island is the tip of an isolated seamount rising 4.5 km from the ocean floor in the Wharton Basin of the Indian Plate. It is part of a chain of volcanoes that formed from the mid-Cretaceous starting about 80 Ma. It is the only one to be exposed above sea-level. Grimes (2001) reviewed what is known of the geomorphology, geology and genesis of the cave systems on the island. "The basaltic core of Christmas Island is encased in a series of limestones dating from the Eocene to the Recent and eustatic changes have produced a series of marine terraces ... near the coast seawater intrudes beneath the freshwater within the karstic limestone ... so forming an anchialine collar around the island. The saltwater interface caves are strongly tidal." (Humphreys & Eberhard 2001).

Previous authors have commented on the extremely conservative morphology of *Procaris* species. The present species is no exception to this finding and is very similar to the four earlier described species, each of which are still known only from their respective type localities. A detailed description, based on the single incomplete specimen, appears unnecessary and the following abbreviated description describes mainly the characters of taxonomic importance. The specimen is deposited in the collections of the Western Australian Museum, Perth (WAM).

Abbreviations: CL, postorbital carapace length.

Taxonomy

Procarididae Chace & Manning, 1972

Procaris Chace & Manning, 1972

Procaris Chace & Manning, 1972: 6; Holthuis, 1993: 21.

Type species: *Procaris ascensionis* Chace & Manning, 1972, by original designation and monotypy. Gender feminine.

Procaris noelensis sp. nov.

(Figs 1–3)

Procaris n. sp. — Humphreys & Eberhard, 2001: 64, 66 (not pl. 2 on p. 65, which is presumed to be *Antecaridina lauensis* (Edmondson) (Atyidae))

Undescribed procarid sp. — Jones & Morgan, 2002: 211 (not colour picture on this page which is presumed to be *Antecaridina lauensis* (Edmondson) (Atyidae)).

Material examined

Holotype, 1 spec., sex undetermined, CL 5.3 mm (partly dissected), WAM C 35817 (field number BES 5807), Runaway Cave, c. 1.5 km south from the North East Point of Christmas Island.

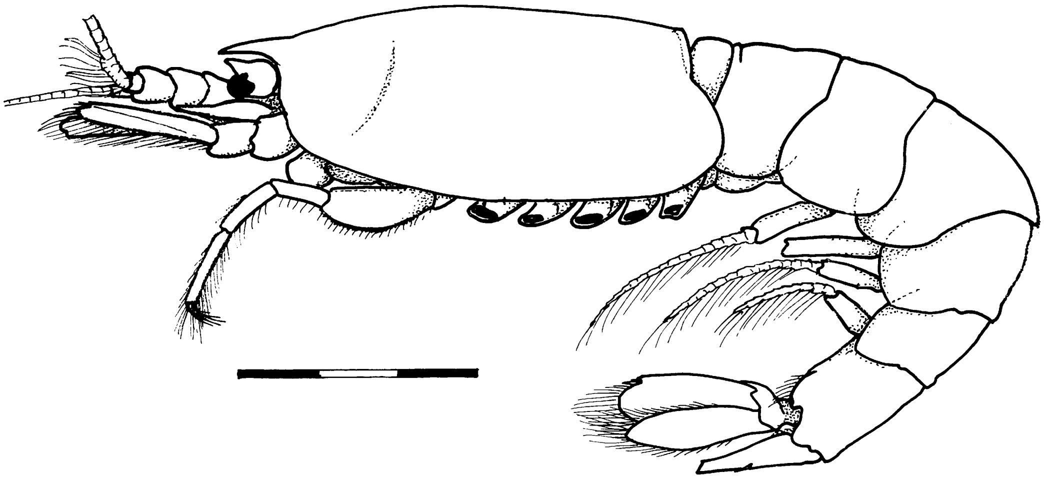

FIGURE 1 *Procaris noelensis* sp. nov., holotype, Christmas Island. Scale bar in millimeters.

Diagnosis

Rostrum slightly exceeding both lobes of eye, carapace with distinct cervical groove, eye lobes well developed with medial lobe longer than lateral, stylocerite reaching to middle of second segment peduncle, carpocerite exceeding scaphocerite, scaphocerite with small distolateral tooth, first and second pereiopods with ischial spines well developed, third abdominal tergite posterodorsally produced, reaching to about middle of fourth segment, fifth abdominal pleuron posteroventrally angular, sixth abdominal segment with posteroventral angle posteriorly produced, rounded.

Description

Generally in a rather fragile state. All pereiopods detached, six preserved, including both pairs of first and second pereiopods. Thoracic exopods all detached except on the left second maxilliped; the left third maxilliped still attached; distal half of telson missing.

Carapace (Fig. 1) smooth, without spines, with oblique cervical sulcus, without cardiac notch, anterolateral angle obtusely rounded, not produced, not emarginate.

Rostrum (Fig. 2A, B) triangular, acute, slender in lateral, narrow in dorsal views, ventrally concave, without dorsal or ventral carina, toothless, exceeding level of distal end of medial eye lobe.

Ophthalmic somite simple, without median process or pigment spot. Eye (Fig. 2A, B, C) half covered dorsally by anterior margin of carapace, fully exposed laterally; eyestalks proximo-medially ankylosed, immobile; short, bilobed, medial lobe longer than lateral, conoidal, unpigmented, lateral lobe shorter, hemispherical, well pigmented, cornea not facetted.

Antennule (Fig. 2D) with peduncle robust, proximal segment subcylindrical, about 1.6 times longer than central width, without ventromedial tooth, very obliquely articulated with intermediate segment, stylocerite long, acute, slender in dorsal view, broad in lateral view, reaching to near distal margin of intermediate peduncular segment, statocyst small, poorly developed, without statolith; intermediate segment as long as wide, medial length subequal to medial length of proximal segment; distal segment slightly longer than intermediate segment with rounded setose lobe distally between flagella; flagella as in other *Procaris* species.

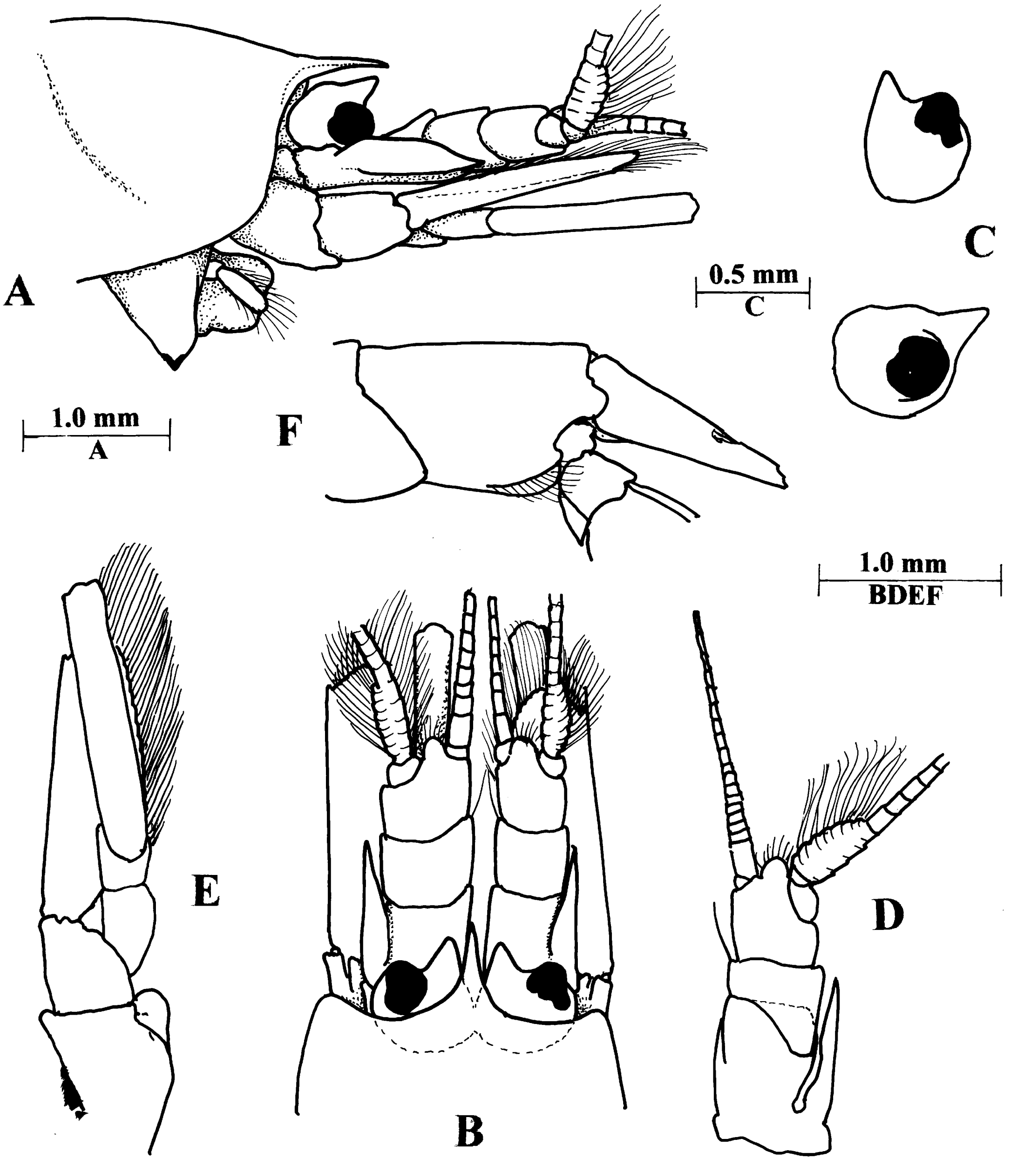

FIGURE 2 *Procaris noelensis* sp. nov., holotype, Christmas Island. Anterior carapace and appendages, lateral. B, same, dorsal. C, eye, upper, dorsal; lower, lateral. D, antennule. E, antenna.

Antenna (Fig. 2E) with coxal segment exposed, robust, with large rounded antennal gland tubercle medially, basicerite stout, laterally unarmed, ischiocerite and merocerite linear, short, subequal, carpocerite subcylindrical, 5.5 times longer than central width, 1.8 times longer than combined ischio-merocerite length, well exceeding distal end of scaphocerite lamella; scaphocerite (Fig. 3A) well developed, 2.5 times longer than maximal width at 0.3 of length, tapering distally, anterior margin broadly rounded, lateral margin straight, with small acute tooth (Fig. 3B) at about 0.92 of lamella length; flagella missing.

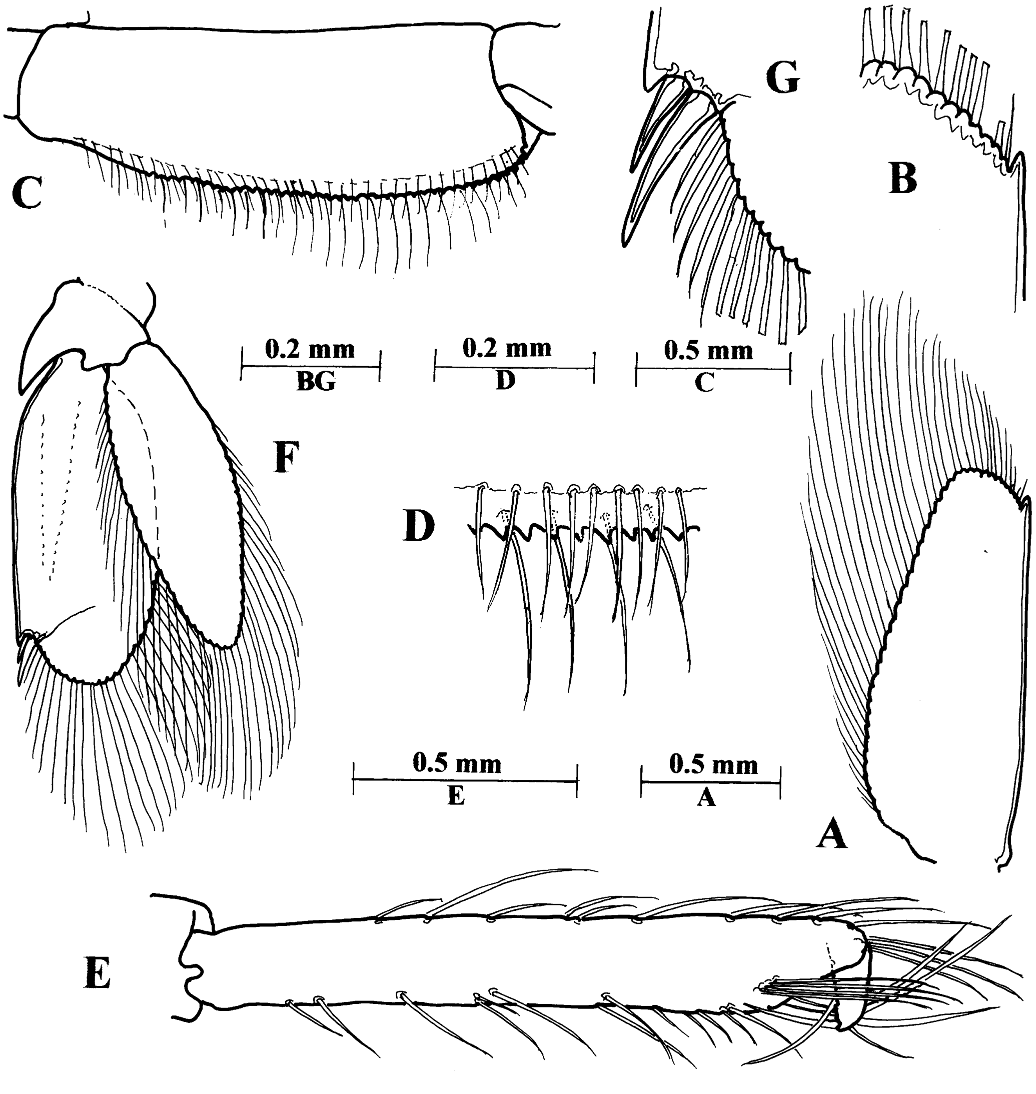

FIGURE 3 *Procaris noelensis* sp. nov., holotype, Christmas Island. A, scaphocerite. B, same, distlateral angle. C, third maxilliped, ischium, distal edge to left. D, same, cutting edge. E, third pereiopod (?), propod and dactyl. F, uropods. G, same, posterolateral exopod.

Epistome (Fig. 2A) strongly protuberant, semi-globular, glabrous, laterally exposed.

Mouthparts. Not dissected.

Third maxilliped similar to other *Procaris* species, reaching distally to end of antennular peduncle; ischium lamelliform (Fig. 3C) about 4.0 times longer than proximal width, expanding slightly distally, ventral edge uniformly serrate throughout most length, with small acute teeth (Fig. 3D).

Pereiopods generally as in other *Procaris* species. The three anterior pairs of pereiopods have well developed spines on the ventral ischia, about 0.225 mm long or about 0.18 of the ischial length; bases without acute tooth proximodorsally; dactyls of anterior pereiopods held in strongly flexed position, forming feebly sub-chelate mechanism (Fig. 3E).

Abdomen smooth, third segment posterodorsally produced, extending over anterior half of fourth segment with abdomen extended, pleura of first four segments rounded, fifth angular, sixth segment (Fig. 2F) about 0.3 of CL, 1.75 times longer than anterior depth, posterolateral angle large, rounded, posteroventral angle small, posteriorly produced, rounded, ventral margin strongly setose.

Telson: anterior portion presents no special features; posterior part broken away.

Pleopods similar to other *Procaris* species.

Uropods (Fig. 3F) similar to other *Procaris* species, protopod posterolaterally acute, exopod with posterolateral angle dentate and bispinose (Fig. 3G), diaeresis obsolete.

Etymology

From *Noel* meaning Christmas, and thus named after the type locality of Christmas Island.

Habitat

Only recorded from a single female collected in Runaway Cave (Cave CI-2 of Humphreys & Eberhard 2001). Runaway Cave is a tidally influenced freshwater/ anchialine habitat. It is presumed to be connected to two adjacent anchialine caves, an un-named cave CI-54, and The 19th Hole (CI-19), and together probably form a single anchialine system. *Procaris noelensis* will thus presumably be found to be spread more widely through the cave systems. Within Runaway Cave, *P. noelenis* co-occured with a hippolytid shrimp *Parahippolyte* (? *P. uvea* Borradaile, 1899), and an atyid shrimp *Antecaridina lauensis* (Edmondson).

Within the wider cave system (CI-2, CI-19, CI-54) the identified aquatic fauna includes: Scyllidae indet. (Polychaeta); *Nerilla* sp. (Archiannelida: Nerillidae); *Microceratina martensi* Namiotko *et al.* (Ostracoda: Cytheruridae); *Danielopolina* sp. (Thaumatocyprididae: Halocyprida) (Humphreys & Danielopol in press); *Nitocrella*/ *Nitokra* complex (Harpacticoida: Ameiridae); *Bryocyclops muscicola* (Menzel) (Cyclopoida: Cyclopinidae); a new copepod genus (Calanoida: Arietellidae); *Leucothoe* sp. (Amphipoda: Leucothoidae); Alpheidae indet. (Decapoda); *Parahippolyte* (? *P. uvea* Borradaile) (Decapoda: Hippolytidae); *Antecaridina lauensis* (Edmondson) (Decapoda: Atyidae); *Macrobrachium lar* (Fabricius) (Decapoda: Palaemonidae); Gobioidae indet. (Pisces: Perciformes); unidentified Eleotridae (Pisces: Perciformes) (see Humphreys & Eberhard, 2001; Namiotko *et al.*, 2004); ?*Eleotris fusca* (Forster, 1801) (Eleotridae) (Humphreys & Eberhard 2001; Namiotko et al. 2004).

In general, according to Humphreys & Eberhard (2001), the cave waters are all well oxygenated (dissolved oxygen >73% saturated) and the pH (7.65±0.41, N=13), with the marine caves having salinities ranging from 0.39–16.5 g L^{-1} TDS (sea water c. 36 g L^{-1} TDS). Specific physico-chemical measurements for Runaway Cave, and the adjacent The 19th Hole, are presented in Table 1. Runaway Cave is brackish with salinities ranging from about 9–18 ppt. No measurements deeper than 2 m were taken so it is not known if deeper waters become suboxic as reported for many other anchialine systems (Sket 1996; Humphreys 1999; Iliffe 2000).

TABLE 1. Physical and chemical parameters of groundwaters from Runaway Cave where *Procaris noelensis* was found, and from an adjacent cave of the same anchialine system. Measurements were taken on 5–6 April 1998. Data reproduced from Namiotko *et al.* (2004).

Cave		Dissolved oxygen		Conductivity	Temperature	pH
		mg dm^{-3}	%	mS cm^{-1}	°C	
Runaway Cave (CI-2)	surface	7.06	97.7	5.5	26.9	7.99
	2 m depth	6.67	96.6	8.1	26.5	7.50
The 19th Hole (CI-19)	surface	6.60	94.0	31.2	27.0	7.60
	2 m depth	5.05	73.0	34.4	27.4	7.35

Systematic position

All the *Procaris* species are extremely conservative in morphology, however by comparison with published descriptions, *P. noelensis* appears to have at least two unique apomorphies: 1) the proximal segment of the first antenna lacks the distal dorsomedial notch that other species possess; and 2) the ventral edge of the ischium of the third maxilliped is finely serrate. This character is not noted in other species, and although it looks feebly serrate on the figure for *P. hawaiiana* given by Holthuis (1973, fig 5b), this is not mentioned in the text.

Following Sternberg & Schotte (2004) we have undertaken a cladistic analysis to try to understand the relationship of *P. noelensis* to the other described species, and especially to investigate if there is any emergent biogeographic pattern. One may intuitively expect a sister relationship between the Indian and Pacific Ocean species given that this is a broadly recognised marine biogeographic province. But this may be difficult to ascertain with certainty as Sternberg & Schotte (2004: 521) state: 'Each *Procaris* species ... appears to be a mosaic of character states found in the other taxa; species differences are due then to specific character state combinations as opposed to the presence of apomorphies.' *Vetericaris* is used as the outgroup, being the only other genus known in the Procarididae.

Our character list for the parsimony analysis is based on that of Sternberg & Schotte (2004) and the data matrix is presented in Table 2.

1. Rostrum — not reaching medial concavity of eye (0), reaching medial concavity of eye (1); overreaching medial concavity (2).
2. Eyes — median lobe longer (0); lateral lobe equal to or longer than median lobe (1).
3. Stylocerite — overreaching antennal segment 2 (0); not overreaching antennal segment 2 (1).
4. Antennal scale tooth — present (0); absent (1).
5. Cervical sulcus — absent (0); weak (1); distinct (2).
6. Third abdominal somite cap — absent (0); not reaching middle of fourth somite (1); reaching to middle of fourth somite (2); reaching beyond middle of fourth somite (3).
7. Posteroventral margin of fifth somite — narrowly rounded (0); broadly rounded (1); angular (2).
8. Ratio of length of sixth abdominal somite to telson — c. 1.5 (0); c. 1.4 (1); c. 1.25 (2); c. 1.75 (3).

TABLE 2. Data matrix used in the parsimony analysis. Character states are explained in the text.

Character	12345678
Vetericaris	00000000
P. ascensionis	10012223
P. chacei	21101222
P. hawaiiana	21101311
P. mexicana	10112111
P. noelensis	2010222?

As Sternberg & Schotte (2004) have already stated, a difficulty with this analysis is the paucity of characters relative to the number of taxa, which is a reflection of the conservative morphology of *Procaris* species. In the case of *P. noelensis* this is exacerbated by the fact that the sixth abdominal segment to telson ratio character could not be scored due to the broken telson on the sole example of *P. noelensis*.

Again, following Sternberg & Schotte (2004), character states were coded to maximise hierarchical resolution given a limited number of characters, and thus do not necessarily fully reflect all observable differences between individual species. However, Sternberg &

Schotte (2004) commented that when they recoded characters to reflect all possible differences, the tree obtained was unchanged.

For the present analyses we used NONA 2.0 (Goloboff 1997) through Winclada 1.00.08 (Nixon 2002) using settings mult*n=25, with 1000 replications, and 10 starting trees per replication, all characters were treated as unordered. An exhaustive search was undertaken on the unordered series. Two equally parsimonious trees were produced with lengths of 17 steps, CI = 0.88, and RI = 0.66 — identical tree statistics to the two unordered trees derived by Sternberg & Schotte (2004). One tree showed poor resolution; the other is the preferred tree presented here (Fig. 4) using only unambiguous changes. Non-homoplasious synapomorphies are represented by solid black circles. Using all characters as ordered, again two trees resulted — in one the position of *P. noelensis* as sister group of *P. chacei* + *P. hawaiiana* is the same as the preferred tree. The preferred tree is essentially similar in topology to the unordered tree of Sternberg & Schotte (2004: fig. 4B). This places *Procaris ascensionis* as basal and thus sister to all other species. *Procaris mexicana* is sister to the rest based on the single synapomorphy that the stylocerite does not overreach the second segment of the antennal peduncle. *Procaris noelensis* is sister to *P. chacei* and *P. hawaiiana* based on the single synapomorphy of the rostrum overreaching the medial concavity. Finally, *P. chacei* and *P. hawaiiana* are sister to each other based on two synapomorphies: eyes with the lateral lobe equal to or longer than the median lobe; and a weak cervical sulcus.

Procaris ascensionis is the most geographically isolated species in the genus, and perhaps this in some part helps explain its apparent phylogenetic distance from the other species. Sternberg & Schotte (2004) suggested that the split between Atlantic and Pacific *Procaris* species would have occurred after the emergence of two Atlantic clades: *P. ascencionis* + *P. mexicana* on the one hand, and the proto-*P. chacei/P. hawaiiana* ancestor. However, the discovery of *P. noelensis* representing an Indian Ocean split basal to the clade containing *P. chacei* and *P. hawaiiana* makes the biogeographic interpretation more difficult. Hopefully, the discovery and description of additional *Procaris* species, such as potentially two undescribed species from Fiji (J. Short pers. comm., 2000), will add new data to better understand the evolution within this genus. Hart *et al.* (1985) and Maciolek (1983) have already speculated that the distribution of *Procaris* could be much more extensive than currently known, with gene flow over great distances occurring via semi-continuous populations distributed among shallow submerged ‘crevicular’ habitats. Boxshall (1989) proposed that the mid-oceanic ridge islands may form a continuous route of dispersal around the globe, but as Humphreys & Eberhard (2001) have pointed out, there is no simple connection between the crevicular system of mid-oceanic ridges and hot spot islands such as Christmas Island.

The restriction of *Procaris* species to anchialine systems, is a strong indication that *P. noelensis* is a relic (*sensu* Humphreys 2000) that has survived by using the Christmas Island karst system as a refugium. Kensley & Williams (1986) have already suggested this concept to explain the occurrence of decapod procaridids in other anchialine systems. The view is further supported by the fact that procaridids have always been found living sympatrically with one or more species of atyid shrimps, another ancient caridean lineage.

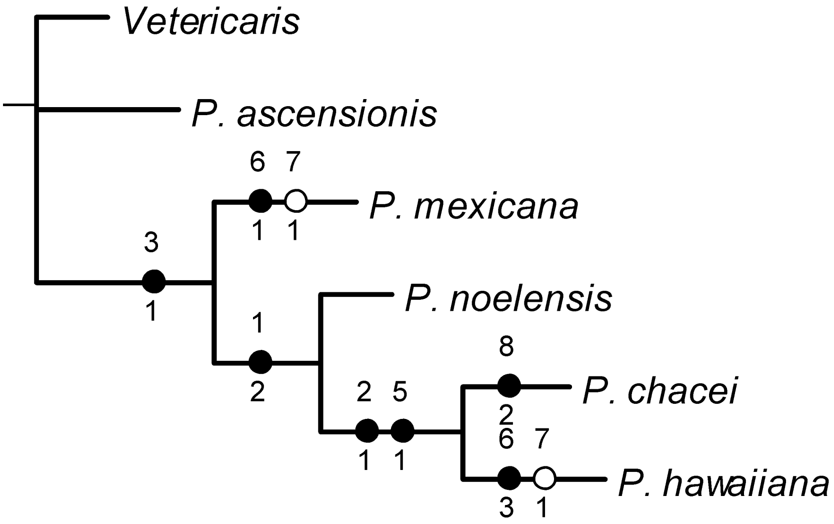

FIGURE 4 The preferred of the two most parsimonious trees; character states marked with solid black circles are non-homoplasious and unambiguous changes. All unsupported nodes are shown collapsed.

Key to known *Procaris* species

1. Fifth abdominal pleuron posteroventrally angular. 2
- Fifth abdominal pleuron posteroventrally broadly rounded. 4
2. Lateral eye lobe longer than medial. .... *P. chacei*
- Medial eye lobe longer than lateral. 3
3. Scaphocerite without distolateral tooth. .... *P. ascensionis*
- Scaphocerite with distolateral tooth. .... *P. noelensis*
4. Eye lobes subequal. .... *P. hawaiana*
- Medial eye lobe longer than lateral. .... *P. mexicana*

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