

*VARGULA ANNECOHENAE*, A NEW SPECIES OF BIOLUMINESCENT OSTRACODE  
(MYODOCOPIDA: CYPRIDINIDAE) FROM BELIZE

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A B S T R A C T

A new species of bioluminescent ostracode, *Vargula annecohenae*, from Belize is described on the basis of morphology and mating displays. At night, male *V. annecohenae* ostracodes produce an elaborate species-specific display in order to attract females. These displays occur as a series of rapid flashes in an upward direction, above shallow grassbeds.

INTRODUCTION

Males of many species of Caribbean cypridinid ostracodes produce elaborate species specific bioluminescent displays for courtship (Morin and Cohen, 1991; Cohen and Morin, 1993). These ostracodes produce their own luciferase and luciferin in separate glands in the light organ, and secrete these molecules from a series of nozzles on the upper lip (Huvad, 1993). Upon contact with the sea water, a bright blue luminescence is produced. Over 60 species of luminescent cypridinids that engage in this courtship behavior have been discovered in the Caribbean (Morin and Cohen, 1988; Morin and Cohen, 1991; Cohen and Morin, 1993; Cohen and Morin, 2003). These displays occur nightly over specific reef microhabitats. Intraspecific variation in the components of the signaling behavior is low. Diversity of signaling species in a reef area can be quite high, however, and most species are highly endemic to specific islands or regions (Morin, 1986; Morin and Cohen, 1991). A taxonomic description of a new species, *Vargula annecohenae*, from Belize with details of the behavioral displays is given here. *V. annecohenae* is in the F-Group (or Phot-Group) of Cypridinidae, a group to be described as a new genus (Cohen and Morin, in prep; Phot-Group in Cohen and Morin, 2003).

MATERIALS AND METHODS

Methods for observing, recording and collecting the specimens were similar to those previously described (Cohen and Morin, 1986, 1989, 1993; Morin and Cohen, 1988). Specimens were collected either in discrete traps or sweep nets while they produced their bioluminescent courtship displays, or small baited funnel traps. Light amplified videos (Morin and Cohen, 1988) of the luminescent displays were simultaneously (or independently) recorded during the displays. The videos were analyzed on a frame by frame basis (see Morin and Cohen, 1988 for details) and processed using APL/Statgraphics computer programs. Relative distances between pulses recorded on the video were converted into absolute distances from in situ measurements. The temporal data represent the lower limits of the actual durations of the pulses (Cohen and Morin, 1989). The lowest temporal resolution is 33 ms (1 video frame). The captured specimens were measured, fixed, preserved and microscopically analyzed (by both light and

scanning electron microscopy) according to the methods of Cohen and Morin (1986). SEM studies were carried out on a Cambridge 360 scanning electron microscope at the University of Southern California (see Cohen and Morin, 1997).

Holotypes and paratypes are deposited in the Natural History Museum of Los Angeles County, California (LACM). SEM materials are deposited in the Smithsonian Institution, Washington, D. C. (USNM). All specimens are in alcohol except for limb and SEM (dry) slides as indicated in specimen list. Abbreviations listed under type material are: discretos = samples from single displays collected in individually numbered velcro-sealed discrete nets; sweeps = samples collected with hand net from several displays; [VV] = paratypes which are voucher specimens of the video recordings of specific displays.

Glossary of Terms

General.—L=length, Ht=height, D=dorsal, V=ventral, M=medial, Lat=lateral, RT=right, LT=left, W=width; additional terms as in Morin and Cohen (1988) and Cohen and Morin (1989, 1993), and designation of setae by letters and numbers shown in figures therein. Terms describing the copulatory (eighth) limb as described in Cohen and Morin (1993). Nozzles of the upper lip are the same as the glandular pegs or processes of Kornicker (1975:111). Measurements are as in Cohen and Morin (1993).

SYSTEMATICS

*Vargula annecohenae* n sp.

Diagnosis.—Valve size: Relatively small for F-Group [male: L = 1.56-1.70 mm, mean = 1.62 ± 0.03 mm, Ht = 0.98-1.04 mm, mean = 1.02 ± 0.02 mm, ratio of L:Ht = 1.56-1.65, X = 1.60, n = 45; female L = 2.01-2.05 mm, mean = 2.02 ± 0.02 mm, Ht = 1.32-1.42 mm, mean = 1.39 ± 0.05 mm, ratio of L:Ht = 1.42-1.52, X = 1.46, n = 4]. Valve shape (Figs. 1A, B, 2A): Oval, male posterodorsal margin sloped as much as anterodorsal margin, males with low rather pointed projecting keel extending almost to midheight of valve. Infold (Fig. 1C): Male rostral row with 13-20 setae [5 males] plus 0-1 anterior and 1-5 setae posterior to row; anteroventral row with 22-38 (usually 22-32) [2-4 along incisor, 3 males] plus 0 setae anterior and 2-11 setae posterior to row; LT ventral infold with 2-3 and posteroventral infold with 0 setae. Female rostral row with about 17-22 setae [4 females] plus 0-2 anterior and 5-9 setae posterior to row; anteroventral row with about 32-39 setae

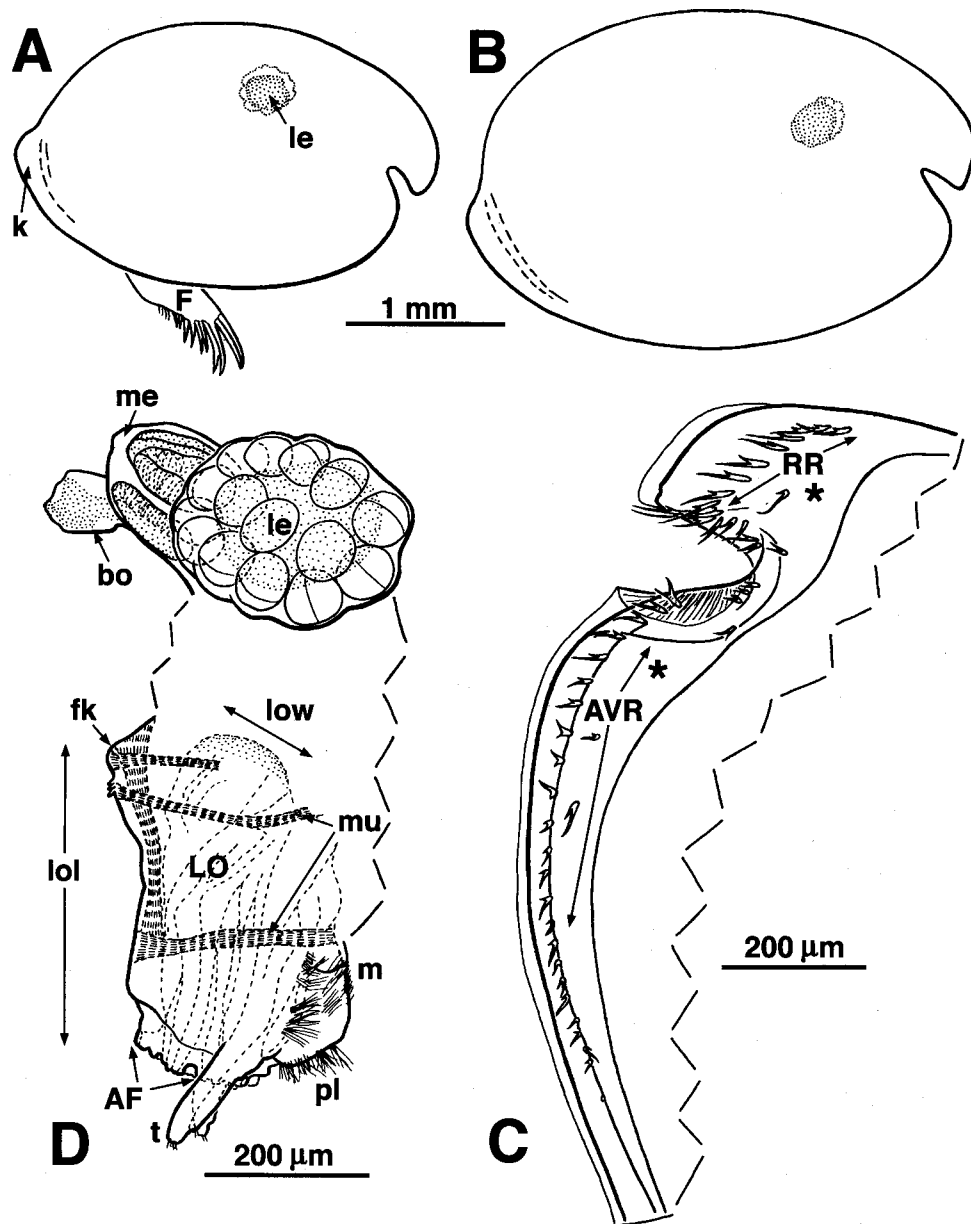


Fig. 1. *Vargula annecohenae*: A, male BZ09078.1-A: RT Lat external view of animal (showing lateral eye, furca, and caudal list [stippled]). B, female (tentatively assigned to this species) BZ02066.1-B: C, RT anterior view of infold. D, LT view of anterior of body showing lateral eye, medial eye, Bellonci organ, and upper lip. AF = anterior field, AVR = anteroventral row of setae, bo = Bellonci organ, fk = frontal knob, le = lateral eye, LO = light organ, lol = light organ length, low = light organ width, m = mouth, me = medial eye, mu = muscle, pl = posterior lobe, RR = rostral row of setae, t = tusk.

plus 11-23 posterior to row. Furca (Figs. 1A, 2A, B): Ratio of L first:second furcal claw = about 1.1. Upper lip (Figs. 1D, 3A, B, D): Central row with about 13 nozzles (anterior 2 together), pegs and ridges with total of about 24-26 nozzles (3-6/peg). D Lat field near mouth with only 2 nozzles (Fig. 3D). Male first antenna (Fig. 2A): V seta of article 4 L = 0.5-0.6% of Valve L ( $n = 5$ ), total small suckers on b- and c-setae = 12-21 [includes 3-5 on proximal c-seta,  $n = 5$ ]. Second antenna (Fig. 2A): Number of tooth-like spines on seta of second exopodial article in males = 5-8 [mean =  $6.9 \pm 0.7$ ,  $n = 6$ ]. Mandible (Figs. 2A, 4A-C, 5D): D d-setae of 2nd endopodial article extending almost to 3<sup>rd</sup> endopodial article; terminal article with rather straight claws

with slightly bent tips, VM claw about 96-100% L of D Lat claw [mean =  $99 \pm 3\%$ ,  $n = 5$ ]; tip of d-seta unlike that of b- and c-setae, thinned to pointed thread-like tip with subterminal papilla, d-seta L about 80-86% D claw in males [mean =  $82 \pm 3\%$ ,  $n = 5$ ], c-seta about 70% L of VM claw [mean =  $71 \pm 2\%$ ,  $n = 5$ ; one shallow water specimen was 85%]. Fourth limb (Fig. 4D): One (a-3, the second longest) of 4 lateral a-setae of second endopodial article with thin but blunt tubular tip, other 3 setae with more pointed tips and subterminal minute papilla; d-1-claw about 70-80% L of d-3-seta ( $n = 4$ ), smallest c-seta (c-1) with or without teeth ( $n = 4$ ). Fifth limb: L of posterior-most seta of endite III about 2.1-2.4 X L of smallest seta [second posterior seta bare,

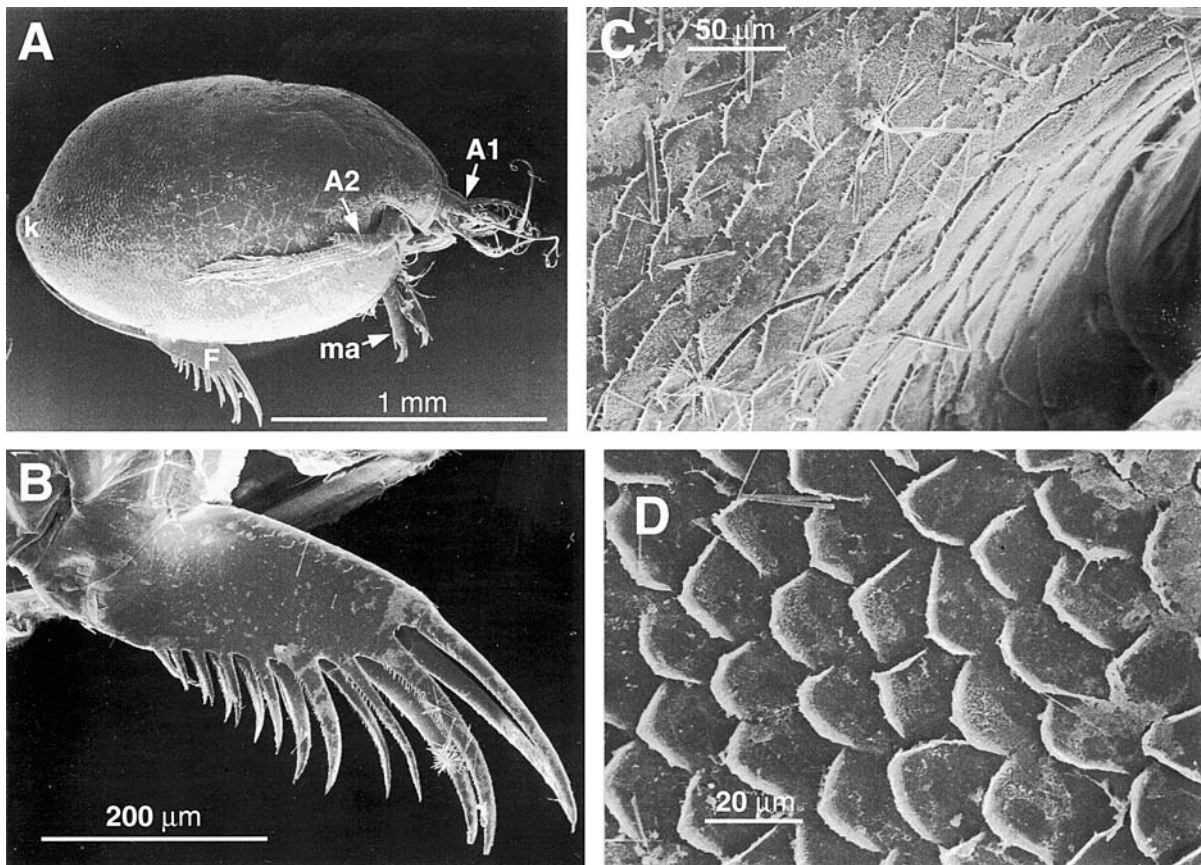


Fig. 2. *Vargula annecohenae*: A, male BZ05078.1-D: external view showing first antenna, second antenna, mandible, and furca. B, male BZ05078.1-E: furca. Male BZ05078.1-E: C, exterior view of valve surface near incisure. D, exterior view of posterior valve surface. A1 = first antenna, A2 = second antenna, F = furca, k = keel, ma = mandible.

$n = 3$ ]; longest a-claw on second article about 0.4-0.5% of valve L [ $n = 3$ ]; inner corner of fifth article with group of small spines possibly on small process [ $n = 5$ ]. Seventh limb: Total setae in males = 7-12 (includes 3 terminal peg setae,  $n = 4$ ). Male copulatory [eighth] limb (Figs. 4E-G, 5A-C): Outer lobe: hood with or without very small rounded or triangular hump-like central peak and thinned weak rather rounded or triangular flap-like tip; 3 ringed, bare thumb setae [ $n = 5$ ] at base of hood next to prominent long stout sclerotized thumb; 2 or 3 more proximal ringed, bare setae. Inner lobe: distal cleft area with small bare triangular tooth [on finger branch] and thinner, almost straight, basally bent bare claw of about same L [on setal branch, claw = about 0.6-0.8% of valve L]; 6-9 ringed, bare setae. Central lobe: stout, posterior, with 3 stout slightly ringed, spinous setae. Eye size (Fig. 1A, D): Lateral eye male diameter 0.26-0.30 mm,  $X = 0.28 \pm 0.13$  mm [range = 0.32-0.34 mm], ratio of lateral eye diameter:valve L 0.16-0.19 mm, mean =  $0.17 \pm 0.01$  mm [range = 0.16-0.19,  $n = 44$ ], medial eye male L = 0.13-0.15 mm [ $n = 4$ ].

**Holotype.**—LACM cat. no. CR 1988-152.1, male, L = 1.65 mm, limbs on slide, remainder in alcohol; sample no. BZ09078.1, specimen A; collected at lagoon W of Carrie Bow Cay, Belize; 9 July 1988; caught by A. Cohen from display above grass bed of ~4.6 m depth; grass bed mainly *Thalassia* in sand; collected at night by discrete trap net

through upward flashing display of *V. annecohenae*, which was videotaped.

**Paratypes.**—All Belize. Habitats, depths, and displays as indicated under General Biology (Note: label for species in field notebooks is “GP”).

Carrie Bow Cay. Males: Grassbed discretives: BZ09078.1, 9 July 1988, A. Cohen,  $n = 1$  (limb slide b, [VV]), LACM cat. no. CR 1988-152.2. BZ05078.1, 5 July 1988, A. Cohen and J. G. Morin,  $n = 3$  (limb slide a, LACM CR 1988-406.1, limb slide b, LACM CR 1988-406.2, limb slide c, LACM CR 1988-406.3 [limb slide c with paratype ostracode limbs, plus nicothoid copepod]; SEM mounts a, b, c, d, e, f [USNM]). Grassbed sweeps: 00BZ0705.03, 5 July 2000, E. Torres, D. G. Valdez, A. Cohen,  $n = 2$  (preserved in ethanol), LACM cat. no. CR 2000-028.1, male limb slide a and body plus valves (ethanol), LACM cat. no. CR 2000-028.2. Females: Grassbed trap: 00BZ0705.03, 5 July 2000, E. Torres, D. G. Valdez, A. Cohen,  $n = 2$  (preserved in ethanol), LACM cat. no. CR 2000-028.1.

**Additional Material.**—From San Pedro Lagoon, Ambergris Cay. Males and females (designated as GF in field notebooks): Grassbed baited trap sample: BZ02066.1, 2 June 1986, J. G. Morin,  $n = 3$  (1 female, 2 males) [male limb slides a, b [LACM cat. no. CR 1986-709.1]]. Grassbed

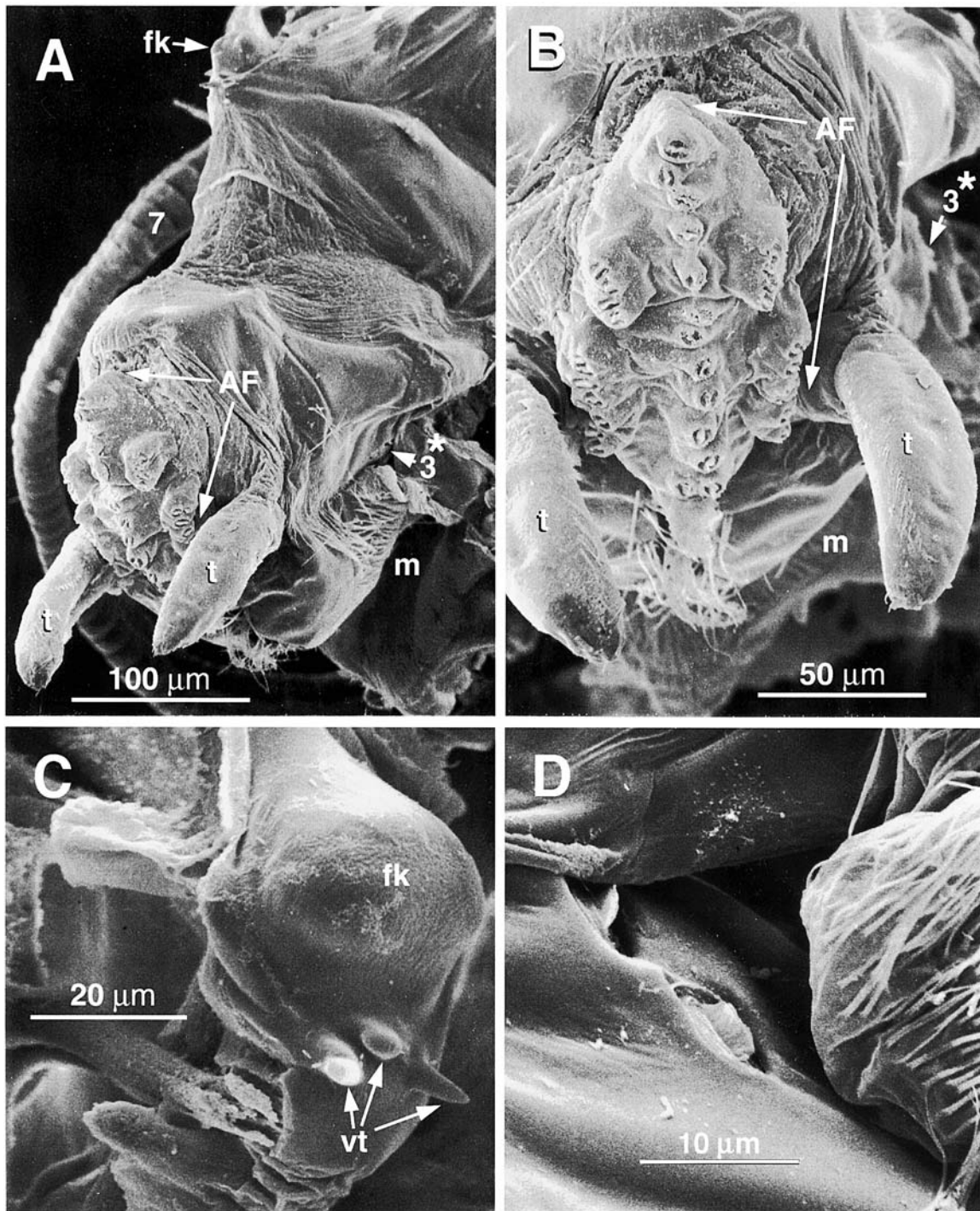


Fig. 3. *Vargula annecohenae*: Male BZ05078.1-C: A, B, upper lip showing anterior field, tusks and dorsal lateral field. Male BZ05078.1-A: C, frontal knob. D, dorsal lateral field. AF = anterior field, fk = frontal knob, m = mouth, t = tusks, 3 = dorsal lateral field, 7 = seventh limb, vt = ventral teeth, \* = diagnostic character.

sweeps through flashing display: BZ31056.5, 31 May 1986, A. Cohen,  $n = 1$  male (2 limb slides, a [LACM cat. no. 1986-710.1]).

**Etymology.**—This species is named in honor of Dr. Anne C. Cohen, expert in the field of ostracode taxonomy and systematics, and our frequent collaborator as well as mentor to the senior author.

**Geographical distribution.**—*Vargula annecohenae* is known from Carrie Bow Cay, Belize (16°48'09.4"N, 88°04'56.2"W). Additional specimens that are tentatively assigned to this species were collected at Ambergris Cay, Belize (17°55'12"N, 87°57'33"W).

**Habitat.**—*Vargula annecohenae* occurs in grassbeds (*Thalassia testudinalis* and *Syringodium filiforme*) to the

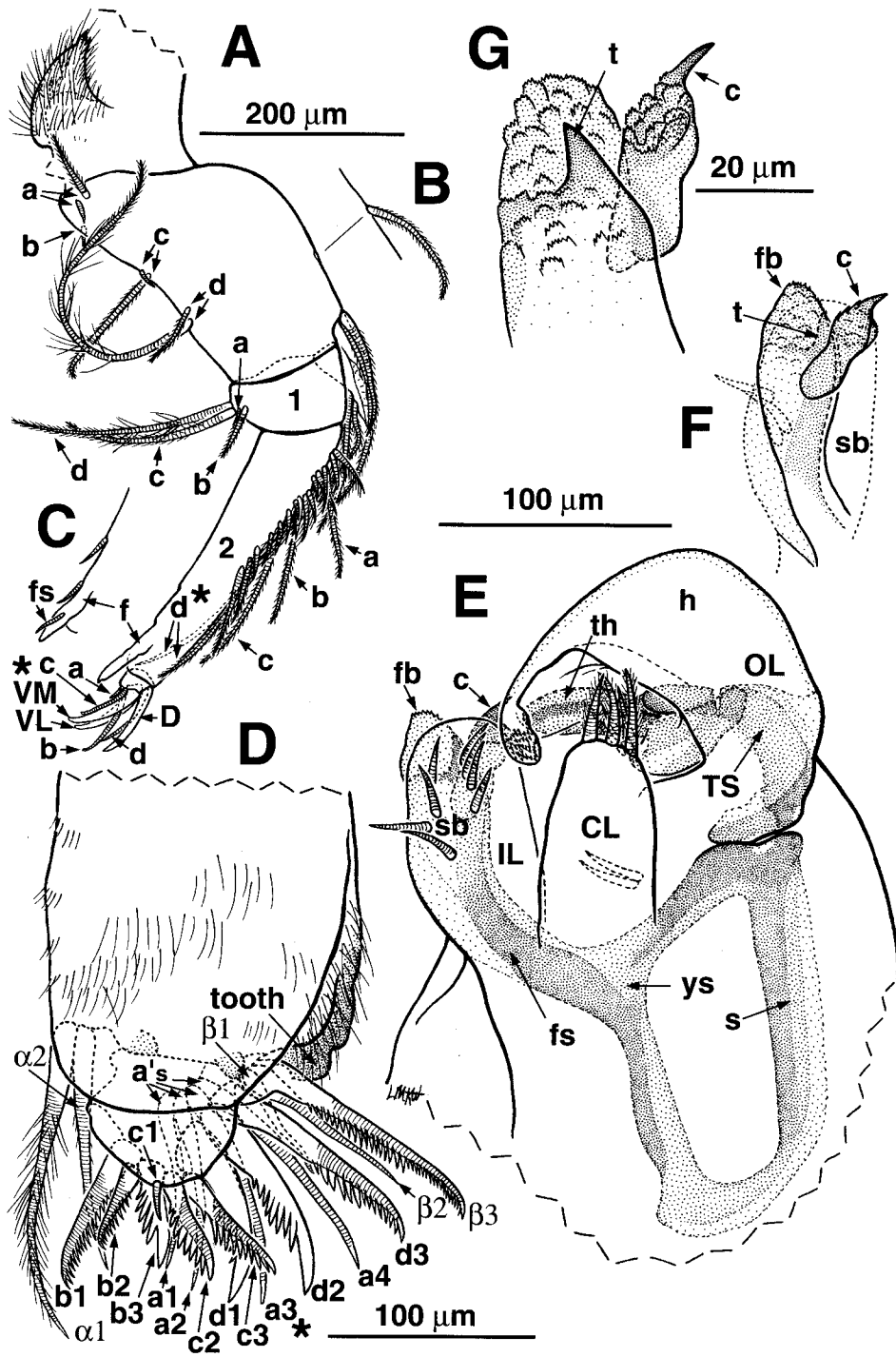


Fig. 4. *Vargula annecohenae*: Male BZ09078.1-A: A, LT mandible (ventral setae of basis lettered, first 2 endopodial articles numbered, and setae and claws labeled; medial view). B, proximal D seta of mandibular basis. C, male BZ09078.1-A: Lat view of finger and V setae of second endopodial article of mandible. D, male BZ05078.1-B: medial view of tip of RT fourth limb (tooth = cutting tooth of first article, distal setae lettered and numbered), distal setae lettered and numbered. E, male BZ09078.1-B: posterior view of left copulatory limb. F, male BZ09078.1-A: part of distal inner lobe of copulatory limb showing finger branch with tooth; also claw from cleft of setal branch. G, male BZ09078.1-B: distal inner lobe of copulatory limb showing claw on cleft of setal branch (branch indicated by dashed line); finger branch (tooth indicated by dashed line). c = claw, CL = central lobe, fb = finger branch, fs = finger sclerite, h = hood, IL = inner lobe, OL = outer lobe, s = strut, sb = setal branch, t = tooth, th = thumb, ts = thumb setae, TS = thumb sclerite, ys = Y-sclerite, \* = diagnostic character.

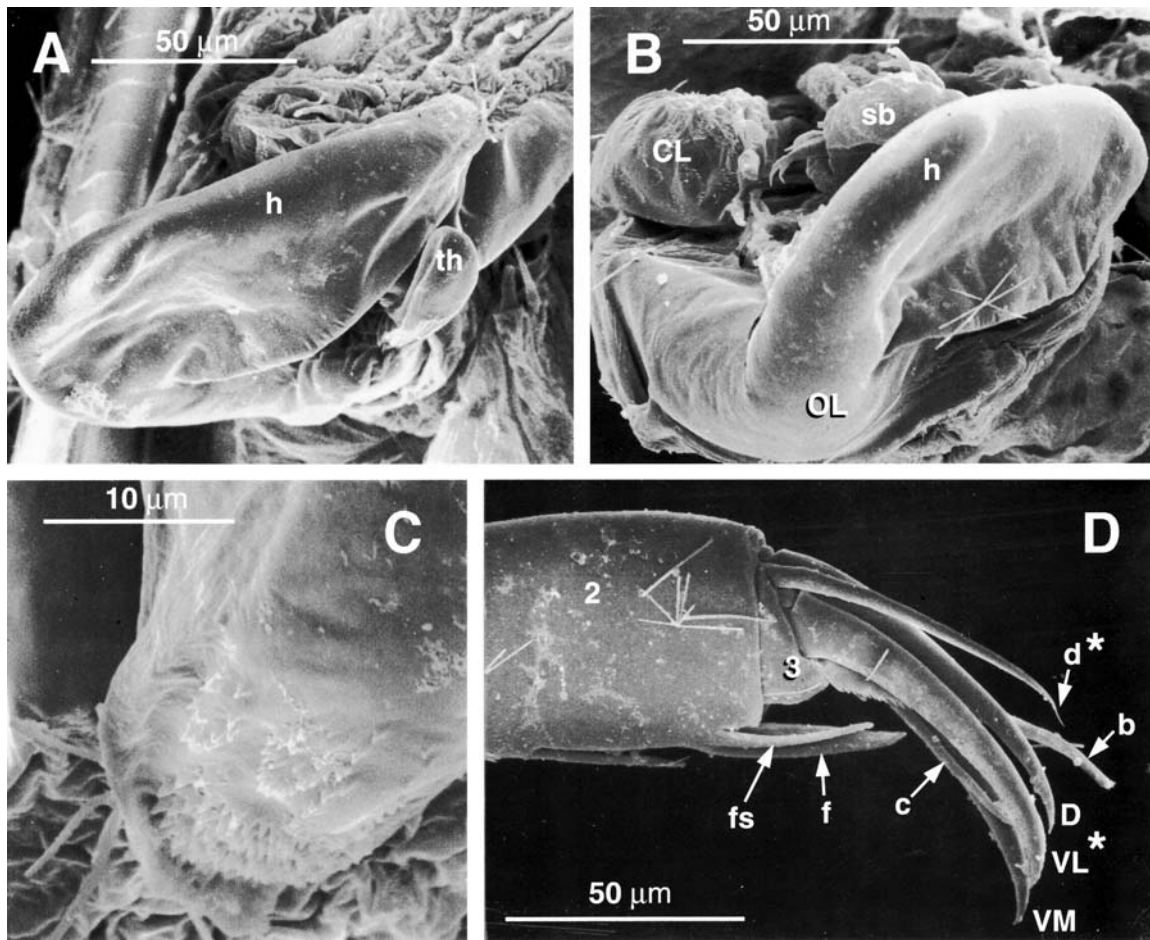


Fig. 5. *Vargula annecohenae*: A, male BZ05078.1-A: ventral anterior view of right copulatory limb showing hood and thumb of outer lobe. B, male BZ05078.1-C: ventral posterior view of left copulatory limb showing hood, central lobe and setal branch of inner lobe. C, male BZ05078.1-A: hood tip of copulatory limb. D, male BZ05078.1-E: lateral view of tip of second endopodial article of right mandible, articles numbered, terminal setae lettered. CL = central lobe, D = dorsal lateral claw, h = hood, f = finger, fs = finger seta, IL = inner lobe, OL = outer lobe, sb = setal branch, th = thumb, VL = ventral lateral claw, VM = ventral medial claw, \* = diagnostic character.

west of barrier islands in the lagoon, at about 4-5 m depth and from about 12-20 m off shore of the south side of the boat dock on the south west side of Carrie Bow Cay, at 1-2 m depth. Their day habitat is presumably in sand or in the axils or roots of the grasses. Specimens are attracted to carrion (fish carcasses).

**Bioluminescent Displays, Behavior and Ecology.**—Males of *Vargula annecohenae* produce upward displays, consisting of 9-13 pulses per display. Their displays commence 2-10 cm above the substrate (occasionally to 30 cm) at 45 min post sunset [ $\sim +1.9$  crep (Nielsen, 1963)]. The displays consist of 3 bright longer pulses (initial shortening phase), followed by a trill of 6-10 dimmer, quick pulses. The length of the train of the displays is 50-70 cm. The train ends at a location no more than 1.5 m above the substrate. The initial pulse duration is about 0.25-0.5 s, while the trill pulse duration is  $\sim 100$  ms. The interpulse interval is approximately 0.5 s, with a shortened interpulse distance from about 10-15 cm down to  $\sim 1$  cm. The displays begin to taper off at about 45 to 50 min ( $\sim +3.8$  crep) after they commence, but

it is uncertain how much longer they continue. No co-occurring species were detected. *Vargula annecohenae* are fairly abundant, with many displays within visual range at one time. However, entrainment of the signals is weak. No periodicity of the displays was detected. The distances between displays usually appeared to be about 0.5 m or more, but sometimes two signals occurred within a few cm of each other. From 27 discrete samples, a mean of 1.26 males were captured per display. A mean of 2.13 males were captured in sweeps ( $n = 39$ ).

**Color of Living Ostracodes.**—*Vargula annecohenae* show no valve pigment, and are mostly transparent (slight amount of color around heart region). The gut is cream-pink in color, while the eyes are maroon-brown. The light organ is army green-brown; bar shaped and slightly concave anteriorly.

**Light Organ Field Data.**—Light organ (LO) length =  $0.11 \pm 0.02$  mm [ $n = 45$ , range = 0.08-0.14], LO height =  $0.29 \pm 0.02$  mm [ $n = 45$ , range = 0.24-0.32], ratio of LO

length: Valve L =  $0.069 \pm 0.012$  [range = 0.05-0.09,  $n = 45$ ], ratio of LO height:LO length =  $2.65 \pm 0.419$  [range = 2.00-3.25,  $n = 45$ ].

#### Description of Adult Male Characters

Carapace (Figs. 1A, B, 2A, C, D).—Oval with deep incisur and protruding keel; margins rounded, posterodorsal and laterodorsal margins similarly sloped. Keel large, joined by dorsal concave curve to posterior margin of valve below midheight of valve; incisur at about midheight of valve. D edge of incisur slightly overlapping V edge at inner end. Rostrum with few small bumps on anterior tip. Valve surface (Fig. 2A, C, D) with scale-like pattern visible on margins at 100 $\times$ , and on valve surfaces with SEM.

Muscle Scars.—About 14-18 arranged in irregular inverted "V" with 2-4 smaller scars inside "V".

Infold (Fig. 1C).—Infold posterior to rostral margin with row of 15-20 [ $n = 5$ ] double setae parallel to rostral margin (5-6 D to incisur, 1-5 double setae posterior to row, and 0-1 setae anterior to row; 2 very unequal double setae near posterodorsal edge of incisur and 1 min double seta posterior to D inner corner of incisur); sclerotized ridge (list) at angle D to incisur. Anteroventral infold with 3-4 short double setae near inner corner of incisur and 1 double seta near posterior edge of infold; row of 22-38 [ $n = 6$ ] double setae parallel to margin (2-4 V to incisur), without setae anterior to row and with 2-11 setae posterior to row. LT valve with 2-3 widely spaced setae on V margin and 0-2 on posteroventral infold. List becoming broader in vicinity of keel, forming a ridge. Ridge in LT valve straight with dorsal bend and ending dorsally in small knob, in RT valve slightly curved with slight bend near middle and posterior thin transparent fringe of tiny irregular teeth or spines and ending dorsally with bar.

Selvage.—Lamellar prolongation of selvage broad along rostrum, broad and striated along lower margin of incisur, narrower and with fainter striations along V margin, terminating on V margin of keel.

Valve Size (Figs. 1A, 2A).—Relatively small for F-Group: L = 1.56-1.70 mm, mean =  $1.62 \pm 0.03$  mm, Ht = 0.98-1.04 mm, mean =  $1.02 \pm 0.02$  mm; ratio of L:Ht = 1.56-1.65, mean =  $1.60 \pm 0.02$  mm ( $n = 45$ ).

Eyes.—Medial eye (Fig. 1D) small (0.13-0.15 mm [ $n = 4$ ]) with band of pigment. Lateral eye (Figs. 1A, D) larger (about 2 $\times$ ) than medial eye, about 17% of valve L (mean =  $17\% \pm 0.9\%$  [range = 16-19],  $n = 44$ ) with 16 ommatidia (slightly larger posteriorly); eye about 0.3 mm (0.26-0.30 mm,  $X = 0.28$  mm [ $n = 45$ ]). Eye pigment dark brown in reflected light, maroon-brown in transmitted light.

Bellonci Organ (Fig. 1D).—L about 0.08 mm, about half L of medial eye ( $n = 4$ ). Small, usually proximally cone-shaped, cylindrical distally (shape variable, often widening slightly before tapering, sometimes round, cylindrical, triangular, pear-shaped or oval and sometimes with distinct tip), without pigment, attached to V cup of medial eye.

Upper Lip (Figs. 1D, 3A, B, D).—Ventral anterior field (Figs. 1D, 3A, B) consisting of 3 rows of nozzles: a single

(slightly staggered) central row bordered on each side by a raised lateral row of pegs and a ridge. Central row with about 13 nozzles (anterior two together), pegs and ridges with about 24-26 nozzles (3-6/peg). Pair of long ventral tusks (Figs. 1D, 3A, B) lateral and posterior to anterior field, tusks tapering only near tip, tusks smooth with some proximal horizontal lines and rows of inconspicuous short lateral and longer distal, terminal hairs, about 5-6 posterior tiny steps (about 3-4 nonterminal nozzles and about 2 terminal nozzles). Ventral posterior part of upper lip hirsute (Figs. 1D, 3A, B). Paired more dorsal lateral field (Fig. 3A, D) anterior to mouth with about 2 nozzles. Small lobe (or bifid lobe) lateral to mouth; mouth with dense inward-directed medium-long spines. Upper lip sometimes with proximal pigment in preserved specimens.

Anterior of Body (Figs. 1D, 3A, C).—Single small rounded frontal knob plus 2-3 smaller triangular teeth ventral to knob.

Posterior of Body.—Smooth, about 29-31 narrow D muscle bands.

First Antenna (Fig. 2A).—First article bare. Second article with M spines forming rows and spines near and on D and V margins. Third article short with M spines forming rows. Setae of third and fourth articles with short spines. Third article with 1 D seta just proximal to middle and 1 longer V seta near middle. Fourth article with 1 terminal D seta shorter than that of third article and 1 distal V seta (0.5-0.6% of Valve L, shorter than that of third article). Sensory seta of fifth article with 10 long bare proximal and 2 distinctly more slender and shorter distal filaments and with bifurcate tip. Sixth article with short apparently bare M seta near D margin. Seventh article: a-seta longer than seta of sixth article; b-seta with stout proximal filament with bulbous base followed by large sucker and small distal process and pointed tip, 2 distal slender filaments each with proximal tiny bump, proximal filament bearing 4-6 small suckers and distal filament with 5 small suckers [ $n = 5$ ] (distal filament extending to about tip of seta); c-seta similar to b-seta but about twice as long, with slightly larger basal filament and sucker, with 2 more distal filaments each bearing proximal tiny bump and 3-5 small suckers, with 5 or 6 more distal bare filaments (first filament adjacent to distal sucker-bearing filament) [total small suckers on b- and c- setae = 12-21]. Eighth article: d- and e-setae longer than b-seta, bare, filamentous; long f- and g-setae with slender filaments (f- with 9, g-seta with 10) increasing in L distally, some with few spines. C-, f-, and g-setae tapering, becoming filamentous distally, longer (g-seta longest) than sensory seta; each of these 3 setae with bifurcate tips. Aberrant specimen: BZ05078.1-C with 1 limb with distal sucker filaments close together on c-seta.

Second Antenna (Fig. 2A).—Protopod with short bare seta with minute spines. Endopod 3-jointed: first article with 4 proximal setae (1 long and about twice L of 3 shorter setae) and 1 long distal spinous seta extending to near middle of third article; second article elongate with 1 short terminal seta usually extending to end of third article; third article about 1/2 to 2/3 L of second article, with long terminal

filament. Exopod: second article with seta with tip reaching to about sixth-seventh article, with 5-8 V tooth-like spines (mean =  $6.9 \pm 0.7$ ,  $n = 5$ ); articles 3-8 with setae with natatory hairs and with basal spines becoming longer distally (basal spines often with thin distal spinelet); Lat spine of ninth article about same size as spine of eighth article; ninth article with 4 setae (3 long with natatory hairs, 1 shorter with few short spines or bare).

Mandible (Figs. 2A, 4A-C, 5D).—Coxal endite (Fig. 4A) spinous, with ringed seta near base, endite tip with bare peg between 2 longer stouter spines (1 or both slightly ringed). Basis (Fig. 4A): 7 ringed setae on proximal 2/3 of V margin: 1 medium long spinous and 1 short bare (ca. 1/3 L of longer seta) M a-setae, 1 short bare Lat b-seta close to a-setae, 1 long spinous and 1 short bare c-setae and 2 d-setae (c-setae not close to d-setae; shortest a-, b- and c-setae all about same L); proximal d-seta medium long with short spines, distal d-seta very long and hirsute with short distal spines; distal (< 1/2) of D margin with 3 long setae with short spines (1 distal [Fig. 4B] and 2 longer, unequal, subterminal with slightly longer spines), M seta proximally unringed. Exopod (Fig. 4A): extending just beyond end of first endopodial article, with M wrinkled and/or hirsute D process extending to pointed tip and 2 V setae (longer proximal seta with short spines, distal seta shorter than proximal seta and with inconspicuous spines). Endopod: first endopodial article (Fig. 4A) with 4 ringed V setae (1 min bare a-seta, 1 medium short b-seta [with short spines], and 2 unequally long c- and d-setae [d-seta longer]; c-seta with short spines); Lat d-seta with some long hairs or spines near middle and distal short spines. Second endopodial article (Fig. 4A): D margin with about 17-20 setae: 1 a-, 1 b-, 1 c-, 2 d-setae (long, ringed with short spines, d-setae longest and almost extend to third article), 12 DM whisk setae with fine hairs, one short stout unringed M seta with short spines, 2-4 setae distal to d-setae [2-3 ringed with short spines and 0-1 whisk][see Fig. 4A]. V margin (Fig. 4A, C) with 2 short single setae proximal to finger (setae sometimes overlapping), and 1 about equally long finger seta (Figs. 4A, C, 5D) with base on Lat side of subterminal finger; finger (Figs. 4A, C, 5D) long stout sclerotized straight unringed with pointed tip (L a little shorter than that of terminal claws of third article). End article (Figs. 4A, 5D) with 3 rather long straight claws bearing few small proximal M teeth; V claws stouter with bent tips. D-Lat claw thinner, with slightly bent tip, about same L and not extending beyond V Lat claws; 4 ringed setae: 1 long VM c-seta (about 70-85% of VM claw L), 1 longer V Lat b-seta without bulbous base but stout and extending beyond claws, 1 very short VM a-seta, and 1 D Lat d-seta extending to beyond distal 1/4 L (80-86% L of D Lat claw). End of d-seta threadlike, unlike narrow tubular tip of a-, b-, and c-setae; b- and c-setae with proximal short spines.

Fourth Limb (Fig. 4D).—Endite setae (not shown): I = 11 long stout with long spines or hairs (most setae unringed, 1-3 distally ringed with bare pointed or bifid tip); II = 4-5 long, distally ringed with few proximal hairs and slender pectination or long spines, and 1 shorter with proximal hairs and spines; III = about 4 long, distally ringed, with long

spines. Coxa (not shown): hirsute lobe and stout hirsute D seta. Basis (not shown) with 2 long thin bare Lat setae (1 near base of exopod and longer than exopodial setae) and 1 distal M setae (1 may be on first endopodial article). Exopod (not shown) hirsute, with 1 long hirsute proximal seta and 2 long terminal setae (hirsute outer seta with distal short spines and slightly longer than inner seta [with short spines, but not hirsute]). Endopod first article rectangular. Sub-terminal cutting tooth big, squarish, with 2 blunt points, ventrally projected. 2 alpha-setae (alpha 1 longer and hirsute, alpha 2 with few short hairs), 3 ringed beta-setae, stouter and longer outer beta-3-seta shorter than alpha-seta and with row of about 30-35 long teeth (distal teeth abruptly shorter), beta 1- and 2-setae unringed with narrow tubular tips; first article with rows of M hairs; second article narrower than first endopodial article with 4 ringed a-setae (a-1, a-2, and a-4 setae with threadlike tip and a-3 with narrowed tube-like tip, a-3- and a-4-setae with few small teeth near middle); 3 stout pectinate b-setae, b-1 and b-2 ringed and finely pectinate (b-1 with about 13-17 and b-2 with 8-10 long teeth), b-3 shorter, unringed, claw-like, straight and tapering, with about 4-5 medium-sized teeth (usually only on anterior outer side), b2-L = 61 to 73% b1-seta; 3 ringed c-setae, (c2- and c3-setae long stout pectinate [c-2 with 9-11, c-3 with 11-12 teeth], c1-seta short slender ringed and with 0-3 teeth), L c1- = 40-50% L b2-seta; 3 long stout pectinate d-setae (d1- and d2-setae shorter unringed, claw-like with 5-7 and 6-9 teeth; d-3 ringed with 12-15 teeth), d1 L about 70-80% d-3 L. Abberation: BZ09078.1-A with beta-3 stunted on 1 limb.

Fifth Limb (not shown).—40-49 epopodial setae. Protopod with long, rather straight anterior distal tooth with expanded round tip and very small bump (sometimes also proximal bump) near middle. Endite setae: I = 6-7 stout, tapered, unequal, with long stout hairs or spines (all or most distally ringed, tips bare and pointed), seta 2 (adjacent to posterior-most seta) small and bare; II = 6 stout, unequal, most distally ringed with long proximal spines, some distally pectinate; III = 7 or 8 (seta # 1 [inner, posterior] stoutest, long, with proximal hairs, distally pectinate; adjacent 2-3 setae [# 2-3 and 4-5] usually unringed, pointed, rather claw-like [sometimes with distal teeth, # 2 seta very small, bare and triangular]; last [anterior] seta longest, with proximal hairs, distally ringed, with short spines; last 2 anterior setae usually similar). Exopod with 2 prominent sclerites; first article sclerite rather "L"-shaped, shorter, broader part of "L" underlying 6 teeth of article, longer part of "L" underlying anterior setal row; second article sclerite large, irregular, occupying outer half of article. First expodial article: Posterior row of 6 pectinate claw-like teeth and 1 proximal smooth triangular peg with tiny terminal teeth, with 1 large stout distally ringed peg-seta (with few [about 2-4] long proximal spiny long filaments and 1-2 short flat triangular teeth) proximal to peg (peg longer than wide, about  $130 \times 85$  [ $n = 2$ ]) peg-seta shorter than longest tooth, peg shorter than shortest tooth, shortest tooth with total of 5-6 small cusps (variable stout, distal cusp smallest, tooth tip stout and pointed); anterior row of 3 setae (1 short-medium long hirsute and often very faint, 2 very long with long proximal stout hairs or spines and distal rings and

pectination [stouter pectination on marginal seta]), and fourth anterior seta (on proximal margin of article over sclerite, may be on protopod) faint, short-medium long and hirsute. Second exopodial article with total of 13 setae: 4 stout unringed posterior a-claws with distal teeth, 7 long to medium-long ringed pectinate b-setae (posterior row of 3 b'-setae, anterior row of 4 longer b''-setae), 1 proximally hirsute posterior c-seta with distal rings and short spines, 1 hirsute anterior d-seta with distal rings and short spines. Inner lobe of third exopodial article with 3 ringed setae (shorter more proximal one with long proximal hairs and distal short spines, subterminal seta longest, distally ringed with short spines, terminal seta slightly ringed with few short spines); outer lobe hirsute with 1 terminal (slightly stouter) ringed seta with proximal hairs and distal short spines and 1 slightly subterminal ringed seta on inner side of lobe (inner seta with abruptly narrowed tip and bearing short spines). Fourth exopodial article hirsute with 4 ringed setae (with short spines, slightly longer spines on proximal seta). Fifth exopodial article hirsute, with 2 subequal ringed terminal setae with short spines; small spinous process present terminally on inner corner.

Sixth Limb (not shown).—End article basally separated by suture or groove from rest of limb, rather stubby or boxy, not very extended posteriorly, ventral margin curved, usually irregular and slightly angled near anterior end of gap between setae. 5 ringed epipodial setae. Endites separated from each other and rest of limb by grooves or sutures. Endites with M hairs. Endite setae: I = 3 (1 long terminal with long spines or stout hairs and unringed, 2 short unringed proximal, with long spines or hairs); II = 5 (2 long terminal with long mid spines or hairs and distal rings and short spines, 3 short proximal unringed with long hairs); III = 4 (2 terminal with long proximal or mid stout hairs or spines and distal rings and short spines, and 2 [1 terminal, 1 distal] unequally shorter, hirsute, ringed); IV = 3 ringed (2 terminal long with long proximal or mid stout hairs or spines and distal short spines, 1 distal, shorter with long hairs); 1 distal seta absent on 1 limb of 1 specimen. End article with long fine hairs on M surface, Lat surface with distal stouter long hairs, terminal (V) margin usually evenly convex (or curve slightly irregular within gap) with total of 10-11 V terminal setae: 1 shorter, thinner, spinous lateral seta usually without long proximal spines (some with few), 6 short to medium-long anterior setae with long proximal and medium-short distal spines (usually distally ringed), followed by long space (gap = about 35% V L of end article), between anterior setae and 3 posterior setae (shorter most anterior of the posterior setae with long midhairs and short distal spines and usually ringed, 2 most posterior setae unequally longer and hirsute, unringed).

Seventh Limb (not shown).—Limbs slightly expanded in distal setal area. Total of 7-12 setae [ $n=4$ ]. Comb side with 1-3 nonterminal (each with 1-4 bells) and 3-5 (usually 4) terminal setae (each with 3-4 bells, bells consist of encircling fringe); peg side with 1-3 nonterminal (each with 2-4 bells), and 3 terminal setae (each with 4-5 bells). Comb of 7 long tapered minutely fringed "teeth" with rounded tips (middle tooth shorter than those on either side of it) and 4-5 short blunt

teeth (2-3 on each side), short teeth grooved or brush-like. Single sclerotized peg (straight, thin, shorter than short comb teeth, with about 6 minute pointed terminal or subterminal teeth), base of peg slightly recessed from outer limb edge.

Copulatory Limb (eighth limb) (Figs. 4E-G, 5A-C).—The basal part of the first article with a prominent Y-sclerite with a strut so that the sclerite forms an irregularly rectangular loop (Fig. 4E) with a M distal inner extension (finger) terminating near the distal tip of the finger branch of the inner lobe (Fig. 4E, F); loop slightly broader distally and slightly elongated at outer distal corner. Inner lobe with 2 branches, finger branch and setal branch (Fig. 5B), separated by terminal cleft (Fig. 4E, G). Finger branch (Fig. 4F, G): tip with numerous minute triangular or knobby teeth (more prominent within cleft) and prominent large triangular tooth on cleft edge near end of finger sclerite. Setal branch (Figs. 4E, 5B): external surface with 6-9 ringed bare nonterminal setae with tapered bases; cleft region with prominent terminal rather straight and short claw (about same L but thinner than tooth, base of claw with rather simple fringes) (Fig. 4F, G). Outer lobe (second article, possibly an exopod): with thumb sclerite articulating with distal corner of strut of Y-sclerite of first article (see Fig. 4E), distally, sclerite associated with external long bare extended sclerotized thumb emerging at inner D base of hood (thumb not extending to base of hood) [see Figs. 4E, 5A]; 3 ringed bare thumb setae [ $n=5$ ] are grouped near and proximal to the thumb base; 2-3 proximal anterior ringed setae. Hood (distal extension of second article) [Figs. 4E, 5A, B]: usually folded over the distal inner lobe in preserved specimens (probably retracted position); tip of hood (Figs. 4E, 5C) bears subterminal minute scales, teeth or papillae, all of similar size (tip is a thin flap-like lobe, can be wrinkled or folded in slide mounts); apex of hood rounded, not peaked or only slightly peaked. Central lobe (third lobe) [Figs. 4E, 5B]: lies posterior and M to inner and outer lobes, rather central on limb; appears to be attached to basal part of first article just proximal to origin of finger sclerite extension; bears 2-3 ringed tapered terminal setae with short spines.

Furca (Figs. 1A, 2A, B).—Each lamella with 9 claws; claws 2 and 4 fused to lamella; claw 3 more slender than, but longer than claw 4; all claws with 2 rows of posterior teeth (1 M row, 1 Lat row) and larger claws with row of thin anterior teeth. Anterior lamella with few tiny spines; margin posterior to claws with several scale like groups of spines; area D and posterior to lamella with slightly indented rounded area with about 6 pads of short spines. Claw L ratios: first:second = about 1.1, second:third = about 1.5-1.6, third:fourth = 1.1-1.2, fourth:fifth = 1.5 ( $n=2-5$ ).

Parasites or Commensals.—Some specimens with ciliates attached to infold posterior to caudal list. Some with nicotoid copepods (probably *Sphaeronella* sp. undetermined) within valves, usually in posterodorsal area. One nicotoid copepod mounted on limb slide c, LACM CR 1988-406.3.

#### Description of Adult Female Characters

Carapace.—Shape of carapace more rounded and keel smaller than in males (Fig. 1B).

Infold.—Rostral row L valve with about 17-22 setae plus 0-2 anterior to row plus 5-9 posterior to row; anteroventral row L valve with about 32-39 setae plus 11-23 posterior to row [ $n = 4$ ]. Ambergris Cay female: Rostral row with about 17-19 setae plus 2 anterior to row; anteroventral row with 35-42 setae plus 13-16 posterior to row [ $n = 1$ ].

Size.—Carrie Bow Cay females: L = 2.01-2.05 mm, mean =  $2.02 \pm 0.02$  mm, Ht = 1.32-1.42 mm, mean =  $1.39 \pm 0.05$  mm, ratio of L:Ht = 1.42-1.52, X = 1.46 [ $n = 4$ ]. Ambergris Cay female: L = 1.90 mm, Ht = 1.29 mm, ratio of L:Ht = 1.47 [ $n = 1$ ].

Eyes.—Lateral eye: Absolute size about 20% smaller than in males.

First Antenna.—Seventh article lacks suckers.

Mandible.—Ambergris Cay female: Fewer D setae (8-9) on second article [ $n = 1$ ].

Genital Lobe (eighth limb).—Much smaller than in male and unjointed. Low irregularly tubular medial ridge terminating laterally in more prominent round knob; medial ridge with attached irregularly rounded spermatophore in BZ02066.1-C. Setose opening (Cohen and Morin, 1997) not observed [but specimen not examined with SEM].

#### DISCUSSION

*Vargula annecohenae* is the only species that displays in the grassbeds within its type locality. Two other species of F-Group *Vargula* also occur at Carrie Bow Cay, but can be distinguished from *V. annecohenae* by their morphology, bioluminescent displays and habitat. *Vargula annecohenae* displays only over grassbeds as a series of rapid flashes in an upward direction, while both *V. morini* (downward flashing display; Torres and Cohen, 2005) and *V. undescrpt* sp. (designated LSU in field notebooks, slow pulsed, vertical shortening display in an upward direction) display only over reef habitats. These two species are also distinguished from *V. annecohenae* by the number of setae on the infold. On the anteroventral infold, *V. morini* males have a row of 51-67 setae [ $n = 13$ ] and females a row of 65-78 [ $n = 7$ ], while LSU males have a row of 30-47 [ $n = 4$ ] and females a row of 35-39 [ $n = 1$ ].

Many male *V. annecohenae* have been captured during their displays and characterized. Specimens from Ambergris Cay were collected in baited traps, and during displays of males and are included as additional material because they differ in some respects from the type specimens. Males from Ambergris Cay, differ from Carrie Bow Cay males, particularly in the number of infold setae. On the anteroventral infold, Carrie Bow Cay males have a row of 22-38 setae plus 2-11 posterior to row [ $n = 6$ ], while Ambergris males have a row of 35-42 plus 13-16 posterior [ $n = 1$ ]. On the rostral infold, Carrie Bow Cay males have a row of 13-20 setae plus 0-1 anterior and 1-5 posterior to row [ $n = 5$ ], while Ambergris males have 17-22 plus 0 anterior [ $n = 1$ ]. Carrie Bow Cay males also differ from Ambergris males in the number of suckers on the last sucker filament of the b-seta of the first antenna. Carrie Bow Cay males had 5 suckers on this filament [ $n = 5$ ], while the

Ambergris males varied from 4-6 suckers [ $n = 3$ ]. It appears that Ambergris males and females may also have fewer D setae (8-9) on the second article of the mandible [ $n = 2$ ], however this difference is based on only a few observations. A slight difference was observed in the total number of setae on the seventh limb. Carrie Bow Cay males had a total of 7-12 setae [ $n = 4$ ], while Ambergris males had a total of 10-13 [ $n = 3$ ]. Due to the variation in some morphological characters these specimens are listed as additional material and tentatively assigned to this species.

The copepodite found within the valves of some *V. morini* appears to be a species of the genus *Sphaeronella* (Order Siphonostomatoidea, Nicothoidae), but the species identification is undetermined.

One other cypridinid, *Skogsbergia lernerii* Kornicker (1958) occurs with *V. annecohenae*, but *S. lernerii* lacks a luminescent display and differs from *Vargula* in numerous morphological characters (e.g. upper lip without tusk, furca with fourth claw shorter than fifth and only second claw without a suture, male first antenna with abundant long filaments on some terminal setae, endopod of second antenna with only 1 article, lateral eye with 25-30 ommatidia).

#### ACKNOWLEDGEMENTS

We thank Anne C. Cohen for measurement data, field collections, and assistance in the ostracode and copepod descriptions. We are grateful to Jody Martin and the Natural History Museum of Los Angeles County; K. Rutzler, Smithsonian CCRE field station, Carrie Bow Cay, Belize. We thank Dominic Valdez for field collections; Veronica Villa for entering field data into computer. Margaret Kowalczyk inked the figures. This work was supported by the National Science Foundation (BSR89-05931 and DEB-9412813), the Giles W. and Elise G. Mead Foundation (for SEM analysis), and a USPHS National Research Service Award GM-07104; is contribution number 666, Caribbean Coral Reef Ecosystems (CCRE), Smithsonian Institution. Travel was supported in part by the NSF Cea-CREST grant at California State University, Los Angeles (HRD-9805529).

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RECEIVED: 6 June 2006.

ACCEPTED: 16 January 2007.