Distribution of the Chuuk Islands Giant Millipede, *Acladocricus setigerus* (Spirobolida: Rhinocricidae), and Identification of Its Defensive Compounds[1]

Donald W. Buden,[2,4] *Athula Attygalle,*[3] *and Xiaogang Wu*[3]

Abstract: The spirobolidan millipede *Acladocricus setigerus* (Silvestri, 1897) grows to at least 155 mm long and is so far known only from Chuuk Islands, Micronesia. It occurs mainly in well-shaded habitats, usually on the forest floor and on tree trunks. It sprays defensive secretions from paired, lateral ozopores on trunk segments; the major compounds, identified here for the first time, are benzoquinones. The secretion stains human skin a reddish brown and causes a slight burning sensation, occasionally followed by slight blistering and exfoliation.

AMONG THE MORE than 600 islands composing the Federated States of Micronesia (FSM), only six of the larger islands of Chuuk (formerly Truk) Lagoon are known to harbor a millipede exceeding 100 mm in length. Taxonomic and phylogenetic relationships of this and other millipedes in the Pacific are incompletely studied and we follow Jeekel (2001) in treating the giant millipede on Chuuk as *Acladocricus setigerus* (Silvestri, 1897) pending a systematic review of the genus. Although *A. setigerus* was described over 100 yr ago, almost nothing is known of its biology. The scanty and widely scattered literature consists largely of morphological descriptions and briefly if at all annotated listings in faunal survey reports. This study provides new information on the distribution and habitat preferences of *A. setigerus* together with the first report on the composition of its defensive compounds and the clinical manifestations of human contact with them. The study is based largely on specimens, field observations, and anecdotal information from local residents obtained during visits to Weno, Tonoas, Fefan, Uman, and Tol islands, 20 June–1 July 2003.

Previous Reports

Silvestri (1897) described *Rhinocricus setigerus* as a new species of spirobolidan millipede from "Ins. Carolinae" (= Caroline Islands) based on a male measuring 150 mm long and 15 mm wide in the Dresden Museum collections. The exact provenance of the specimen is uncertain. The type was lost apparently during World War II and there is no record of it in Dresden Museum files (K. Schniebs, pers. comm.). If the Caroline Islands locality is correct, Chuuk is the most likely source inasmuch as all other specimens and documented sightings are from there, and comparably sized millipedes are unknown elsewhere in the FSM, which covers nearly all of the Caroline Islands, and where such a conspicuous organism is unlikely to have gone undetected. The Republic of Belau (Palau) occupies the extreme, westernmost Carolines, whence two other large rhinocricids are recorded: *Salpidobolus callosus* (Karsch, 1881) and *S. lissior* (Chamberlin, 1947). The possibility that the type of *A. setigerus* originated there, though slight, cannot be definitely eliminated. There is no evidence to suggest that the type of *A. setigerus* was col-

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[2] Division of Natural Sciences and Mathematics, College of Micronesia-FSM, P.O. Box 159, Kolonia, Pohnpei, Federated States of Micronesia 96941 (e-mail: don_buden@comfsm.fm).

[3] Department of Chemistry and Chemical Biology, Stevens Institute of Technology, Castle Point on Hudson, Hoboken, New Jersey 07030 (e-mail: aattygal@stevens-tech.edu).

[4] Corresponding author.

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lected anywhere other than in the Caroline Islands, but it is of at least passing interest to note that another millipede, *Tropitrachelus* (=*Anastreptus*) *unidentatus*, described by Silvestri from Dresden Museum material and labeled as from the Caroline Islands is endemic to East Africa (R. Hoffman, pers. comm.).

Brölemann (1913) erected the genus *Dinematocricus*, with *Acladocricus* as one of three subgenera, and which he (Brölemann 1914) subsequently raised to genus. Attems (1914) included *Acladocricus* as a subgenus within his own newly proposed genus *Polyconoceras* but without explanation. Hoffman (1974) pointed out this taxonomic irregularity, and later (Hoffman 1980) recognized *Acladocricus* as predominately an Indo-Australian genus with 11 species from the Celebes, Solomon Islands, and Philippines, and one (*A. setigerus* by inference) from the Caroline Islands. Kramer (1932) reported *Polyconoceras setigerus* as common in Truk during the German 1908–1910 Südsee-Expedition. In the most recent synopses of Indo-Australian spirobolidan taxa, Jeekel (2001) recognized *A. setigerus* from Truk in the Carolines, with congeners from the Celebes (9), Philippines (4), and Solomon Islands (2), and Marek et al. (2003) presented a similar list of *Acladocricus* species, but added two Australian species that Jeekel (2001) recorded under *Adelobolus* and transferred *A. hicksoni* (Pocock, 1894) of the Celebes to the genus *Salpidobolus*.

In the preliminary report on his entomological survey of Chuuk in 1949, Potts (1949) briefly mentioned encounters with a large species of millipede that he referred to as *Polyconoceras callosus* but is almost certainly *A. setigerus*; the species *Polyconoceras* (=*Salpidobolus*) *callosus* is known only from Palau (Jeekel 2001). A photograph (Gressitt 1954:83, fig. 38) taken on Mt. Winipot, Tol Island, in 1953 shows an aggregation of giant millipedes on a tree trunk, which are identified in the caption as "? *Polyconoceras*."

Vernacular Names

Kramer (1932:577 [426 in the original German text]) recorded the "finger-sized [fingergrossen] Myriopoda (sitol)" as being among the more "striking" [auffallen] animals encountered on Truk during the German 1908–1910 Südsee-Expedition; elsewhere in the same text, he (Kramer 1932:580 [428]) indicated that it is known locally as the "sitol or sidjol." Resident islanders interviewed during this study and asked to spell the Chuukese name of this animal referred to it as sichon (pronounced *see chon*, with the accent on the first syllable, ch as in church, and on as in the name John). They use this name for all millipedes, however, and seemingly make no nomenclatoril distinction between species. Goodenough and Sugita (1980) defined sichon as a "species of black worm about six inches long." Davis (1999) defined it as "millipede, including several types both small and large," and he included the name niyen as a synonym, but we did not hear that name used during our study. The name sichon is applied also to one or more fern species in the family Polypodiaceae (Goodenough and Sugita 1980, Merlin and Juvik 1996). We suggest the English vernacular name "Chuuk Islands Giant Millipede" for *A. setigerus*. It is among the largest of the Pacific Islands millipedes, although on a global perspective it is more mid-sized; some of the African spirostreptids are approximately twice as long as *A. setigerus*.

Study Area

Chuuk (151° 22′ to 150° 04′ E and 7° 07′ to 7° 41′ N) is one of four states composing the FSM. It is located near the center of the Caroline Islands chain in the west-central Pacific Ocean (Figure 1). The Carolines span approximately 3,200 km from Palau eastward to and including all of the FSM—Yap, Chuuk, Pohnpei, and Kosrae States. The approximately 290 islands of Chuuk State (127 km^2 total land area) include the 19 volcanic islands and 96 coralline islets of Chuuk Lagoon, together with 14 widely scattered atolls and low, single coral islets. The volcanic islands (Figure 2) are the emergent remains of a shield volcano that originated over a hot spot 14–8 million yr (myr) B.P. (Keating et al. 1984*a*) and about 1,500 km southeast of its

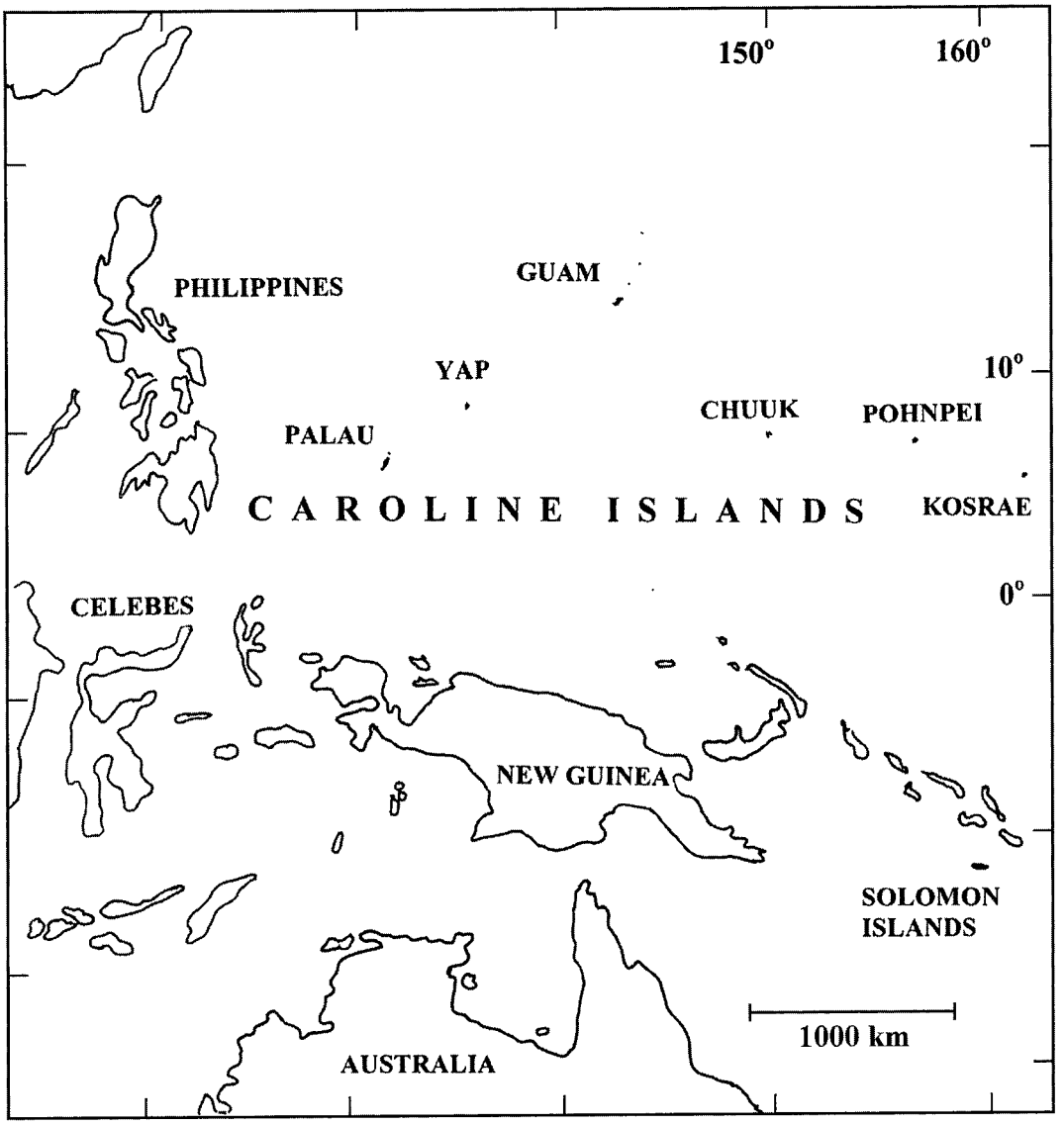

FIGURE 1. Location of the Caroline Islands.

current position. The reef and its associated islets enclose a lagoon 2,130 km^2 in area and "presumably trace the former extent of the volcano which may have had a height of 1,200 m above present sea level" (Keating et al. 1984*a*:350). Currently, the largest (and highest) islands in decreasing order of land area are Tol (34.2 km^2, 443 m high), Weno (18.9 km^2/373 m), Fefan (13.2 km^2/303 m), Tonoas (8.75 km^2/343 m), Udot (4.9 km^2/242 m), and Uman (4.7 km^2/273 m); the others are less than 2.0 km^2 and below 150 m (data from Bryan 1971).

The climate of Chuuk is warm and humid year-round. Average annual rainfall based on Weno weather station records for 1946–

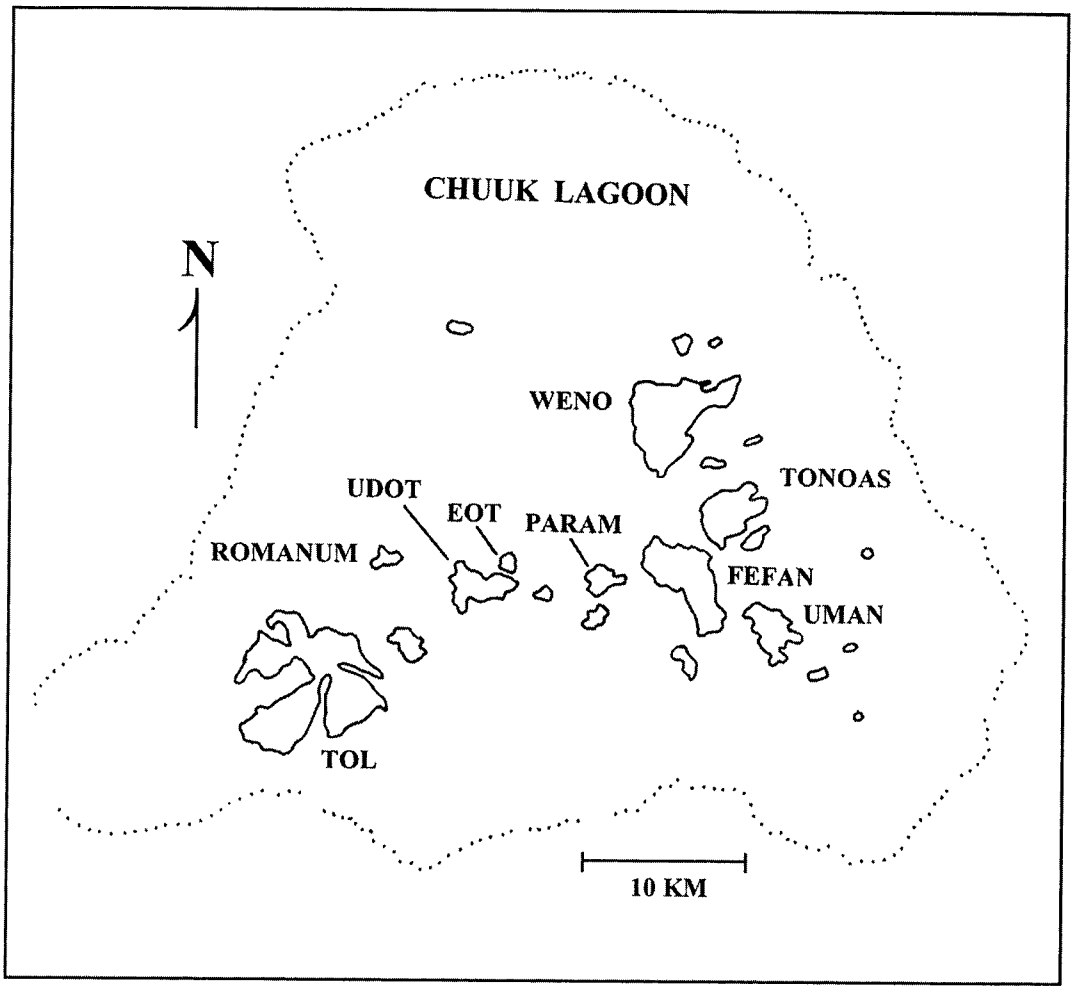

FIGURE 2. Location of Chuuk Lagoon Islands; dotted line indicates outer edge of the reef.

1990 is 3,632 mm, with the driest months (January–March) averaging 150–250 mm/month (Merlin and Juvik 1996). The average annual temperature is approximately 27°C, with a daily range of about 6°C (Merlin and Juvik 1996), and the humidity ranges from an average of 78% during the day to 87% at night (Department of Planning and Statistics 1996).

Chuuk is the most populous of the FSM states, with about half of the nation's population on less than one-fifth its land area (Merlin and Juvik 1996); 53,595 residents were counted during the 2000 census, including 8,930 on Tol, the largest island (treated as three islands [Tol, Polle, and Patta] separated by mangrove channels in some references), and 13,808 on Weno, the capital (Division of Statistics 2002). Centuries of human occupation have altered the vegetation greatly, which currently consists of weedy shrubs and herbs, grasslands, secondary woodland, agroforests, and other areas of cultivation. Remnants of primary forest in Chuuk are now confined to the less-accessible central peaks on the higher islands (Merlin

and Juvik 1996, Mueller-Dombois and Fosberg 1998).

MATERIALS AND METHODS

Logistical problems involving interisland transport from Weno limited the survey to five islands. With the exception of Weno, no more than 6 hr was spent on each island during each visit; Tonoas was visited twice, the others once each. Millipedes were collected by hand using forceps 23 cm long to coax them gently into cardboard boxes containing leaf litter and duff, though rarely without their ejecting defensive secretions; they were brought to Weno for processing later the same day. The collection was somewhat biased toward obtaining large specimens. Defensive compounds were obtained by placing a millipede in a glass jar and shaking the jar to stimulate release of the secretions, and by striking the millipede directly. Secretions collected on filter paper and in glass microcapillary tubes were sealed in glass ampules using a microtorch and shipped to laboratory facilities in Hoboken, New Jersey, where they were kept frozen until chemical analyses could be performed.

Analytical Procedures

For gas-chromatographic analyses, the tubes were opened and each sample was extracted with 50 µL of dichloromethane. A 1.0-µl aliquot of each sample was analyzed by GC-MS using a gas chromatograph (HP 5890 II) linked to a mass selective detector (HP 5970); a 25 m by 0.20 mm fused-silica column coated with 0.33 µm DB-5 was used. The oven temperature was kept at 40°C for 3 min and raised 6°C/min to 270°C.

OBSERVATIONS AND RESULTS

Coloration

Body color in *A. setigerus* is dark brown (nearly black in most specimens), occasionally paler (medium to light brown), and rarely with a grayish cast.

Meristics and Mensuration

Acladocricus setigerus is a large, robust millipede (Figure 3*A,B,C,E*): maximum length 155.0 mm, width 15.7 mm, weight 25.0 g; number of trunk segments 50–55, modally 52 (10 of 26 = 39%). No sexual dimorphism in size was evident in 24 males (Table 1) and three females—two from Tonoas (102 and 113 mm long) and one from Uman (148 mm). No hatchlings or very young were observed; the smallest individual encountered was 80 mm long. Aggregations of millipedes appeared to consist largely of individuals of similar size. The six males collected within an area of about 1.5 m^2 on the ground beneath a large abo tree (*Dysoxylon abo*) on a mountain slope in Fefan were uniformly large and nearly completely separated from all others in total length (Table 1). Ozopores through which defensive compounds are released are present bilaterally on nearly all trunk segments, beginning with the sixth. They are occasionally absent or very much reduced in size on the terminal segment and less frequently so among some of the midbody segments. Scobinae (paired, dorsal paramedian pits present on the trunk segments in some rhinocricids) are absent in *A. setigerus*.

Distribution

Acladocricus setigerus is known only from Weno [= Moen], Tonoas [= Dublon], Fefan [= Fefen], Uman, Udot, and Tol, the six largest islands in Chuuk Lagoon. We include Udot in the list of locality records based on personal communications from a resident of the island and from a former resident now living on Pohnpei, both of whom we consider reliable sources; all other locality records are from Potts (1949) and this study. Potts (1949:10) stated "the large julid milliped of the Truk area was quite common at the higher altitudes on Moen, Dublon, and Tol." During our study, *A. setigerus* was encountered on Tonoas, Fefan, Uman, and Tol Islands, but not on Weno despite more time spent in the field there than elsewhere; other islands were not visited. Residents of Weno variously indicated that it was common in the

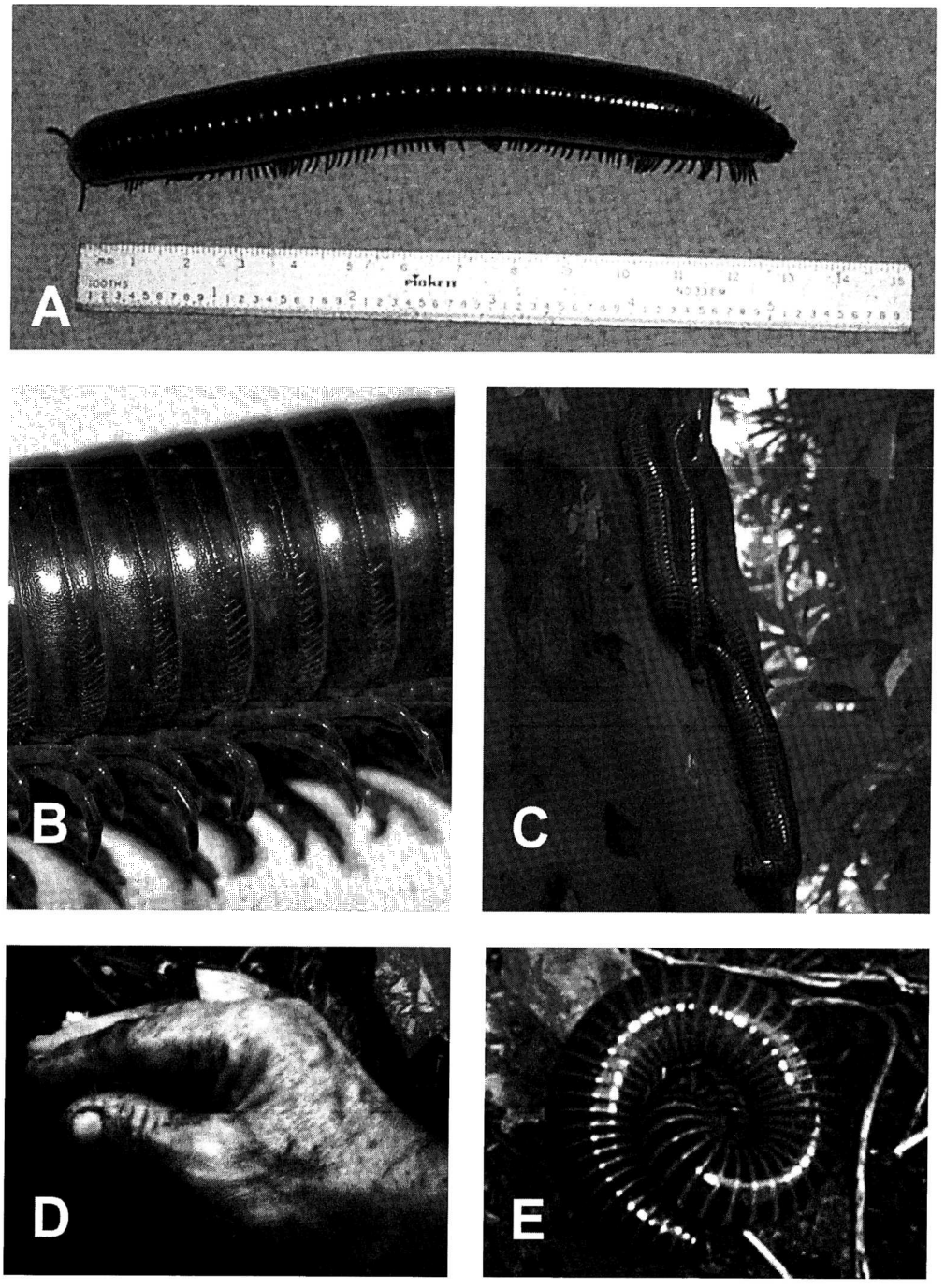

FIGURE 3. *Acladocricus setigerus* (Silvestri). *A,* whole animal; *B,* side view of midbody segments showing ozopores near top of view; *C,* part of an aggregation of six on trunk of coconut tree; *D,* fingers of collector stained with defensive compounds of *A. setigerus; E,* coiled, defensive posture.

TABLE 1

Measurements (Range, Mean, Sample Size in Parentheses) for Male *Acladocricus setigerus* Collected on Five Chuuk Lagoon Islands during June and July 2003

Character	Tonoas	Fefan	Uman	Tol
Body length (mm)	80.0–135.0 112.4 (14)	134.0–155.0 144.0 (6)	114.0–135.0 121.7 (3)	135.0 (1)
Body width (mm)	9.6–14.0 12.5 (14)	14.6–15.5 15.1 (6)	13.7–14.7 14.2 (3)	15.7 (1)
Weight[a] (g)	19.0–20.0[a] 19.7 (3)	23.5–25.0 24.6 (6)		22.0 (1)

[a] Measured on the three largest specimens; 126, 130, and 135 mm long.

mountains, that it was so in the past but not now, or that they were completely unfamiliar with it. One resident provided directions to a specific site in central Weno where she believed the sichon could be found, but a half-day search of that area and beyond to an elevation of about 274 m with two local assistants was unsuccessful. Harvey Segal, a long-term local naturalist and instructor in the Education Department at the College of Micronesia, recalled seeing giant millipedes in the vicinity of the Japanese gun emplacements above the Chuuk Hospital grounds when he first arrived in Micronesia in August 1964, but two visits during the recent survey revealed none. If *A. setigerus* is still present on Weno, it appears to be very scarce or extremely localized or both. On other islands visited during 2003, it was encountered widely but discontinuously from sea level to high on the forested slopes, being abundant in some areas but apparently absent in intervening ones of similar habitat. Some were exposed on tree trunks (mainly coconut, *Cocos nucifera*), but most were on the ground completely or partially covered by leaves, dead branches, clumps of grass, and procumbent vines. *Acladocricus setigerus* prefers shaded areas usually among the sprawling root bases of large trees, and it was found in the settlements as well as (and more frequently) in more remote and less-disturbed parts of the forest.

To what extent *A. setigerus* occurs on the smaller islands, if at all, is uncertain. Potts (1949) mentioned only the three large islands where he found it common, though he visited at least five other lagoon islands (Gressitt 1954). A student at the College of Micronesia reported (pers. comm.) that it did not occur on her home island, Eot, which is just off Udot, where it does occur, and we received an unconfirmed report from a member of the Chuuk Public Health Immunization Survey Team that it does not occur on Romanum, following his inquiry on our behalf during a brief visit to the island.

Identification of Defensive Secretions

The major defensive compounds of *A. setigerus* are toluquinone (2-methyl-1,4-benzoquinone) and 2 methoxy-3-methyl-1,4-benzoquinone.

Effects of Defensive Secretions on Humans

The clinical manifestations of human contact with the secretions of *A. setigerus* were first reported by Potts (1949:10), who wrote of his encounters with "*Polyconoceras callosus*" on Chuuk as follows [typographical errors retained as in original]:

"On one occasion, an average sized specimen (about 4–5 inches) was disturbed when I put my hand within an inch of it while scrambling up a moist slope. A considerable blob of the brown liquid emmited by the beast was sprayed onto the back of my hand while small drops of it were thrown up my

arm to a distance of at least 15 inches. There was an almost immediate slight burning sensation, particularly on the tenderer skin of the arm. The sensation presisted for some five or ten minutes. The caustic action, however appeared very minor although there was a persistent red-brown stain. At another time I inadvertently crushed a specimen under my light tennis shoe. No discomfort was noted, but the stain penetrating the canvas lasted for around two weeks despite repeated purposeful scrubbing with every shower."

During the 2003 survey, all millipedes were collected and handled by D.W.B. using metal forceps 23 cm long, bringing the hand to within about 15 cm of the specimens. Many sprayed their secretions when touched even gently. The spray was extremely fine or was colorless when released, because it was not observed until after it was in contact with a solid surface. No irritation from the secretion was felt on the thumb and forefinger, which were the most extensively stained areas (Figure 3*D*), but a slight burning sensation lasting for several minutes to about half an hour was felt on the back of the hand, which was only slightly spotted with secretion each time. None of the secretion apparently reached farther up the arm. The stain persisted on the skin for about a week, and there was no blistering or exfoliation. In addition to staining and irritating the skin, the secretions of *A. setigerus* have a disagreeable, acrid, pungent odor, somewhat reminiscent of an electrical wiring fire.

Resident islanders queried throughout the study reported only minor discomfort from contact with the secretion, the most frequent comment being that millipedes stained the feet red when stepped on. Three of them stated that children often played with the millipedes. One former teacher on Tol recalled that one of his students was sprayed in the eyes during a field trip to Mt. Winipot many years ago and though temporarily blinded suffered no long-lasting injury; she was able to descend the mountain without assistance later in the day. None of several Chuuk Hospital workers questioned during this study knew of any incidents of millipede burns being treated at the hospital.

DISCUSSION

Defensive Secretions

Millipedes secrete a variety of defensive compounds (Eisner et al. 1978, Attygalle et al. 1993, Deml and Huth 2000, Huth 2000). *Acladocricus setigerus* secretes quinones, as is typical of species in the orders Spirobolida, Spirostreptida, and Julida, and it can spray them at least 38 cm (Potts 1949). Maximum ejection distances for millipede secretions range to about 84 cm in *Rhinocricus latespargor* from Haiti (Loomis 1941:192) and "more than 60–70 cm" in *Polyconoceras* (= *Salpidobolus* ?) sp. in New Guinea (Jolivet 1970:51). Quinones are repellent to many arthropod and other potential millipede predators (Eisner et al. 1978). In a possible zoopharmacological application of these compounds, monkeys in gallery forest of Venezuela were observed rubbing the quinine-producing, spirostreptid millipede *Orthoporus dorsovittatus* on their bodies, with as many as four monkeys sharing a single millipede (Valderrama et al. 2000). Although the protective, repugnatorial effects have not been confirmed in that case, a positive correlation exists between anointment frequency and periods of high rainfall when mosquitoes and possibly other biting insects are more abundant (Valderrama et al. 2000). Weldon et al. (2003) reported similar behavior involving self-anointment with millipedes in wild and captive capuchin monkeys, and they experimentally demonstrated possible repellency of quinone compounds found in the millipedes to *Aedes aegypti* mosquitoes.

All millipedes that are known to spray their defensive compounds produce quinones (Eisner et al. 1978). These compounds stain reddish brown or purple and cause various degrees of irritation to skin and mucous membranes of eyes and nose in humans (Eisner et al. 1978, Schpall and Frieden 1991, Hopkin and Read 1992, Mason et al. 1994, Hudson and Parsons 1997, Huth 2000). McNamara (in Musgrave 1943) reported that his dog was permanently blinded in one eye following an encounter with a large millipede in New Guinea, but Hudson and Parsons (1997) found no documented evidence to support the claim by many New Guinea is-

landers that the secretions of giant millipedes sprayed into the eyes can cause permanent loss of sight in humans.

Biogeography

Millipedes have been largely understudied, and the Spirobolida of Oceania are among those that are poorly known (Jeekel 2001); uncertainty surrounds the taxonomy of many species currently assigned to the genus *Acladocricus* and allied Rhinocricidae (C. A. W. Jeekel, pers. comm.). Whether *A. setigerus* is indigenous and possibly endemic to Chuuk, or whether it was introduced by the earliest aboriginal colonists or their followers, or brought to the islands later by European and American explorers, traders, and missionaries during travels in the Pacific cannot be stated with certainty.

The taxonomic relationships and distribution of *A. setigerus* (as currently understood), along with the geological history of Chuuk and the occurrence of well-differentiated forms among taxa other than millipedes, support, or at least are compatible with, the view that *A. setigerus* is endemic to these islands. Chuuk islands are among the oldest in the Carolines (14–8 myr B.P. [Keating et al. 1984*a*,*b*]). They are the emergent peaks of a once-massive island that would have provided a large target for colonists and opportunities for establishment and differentiation. Although described well over 100 yr ago, *A. setigerus* remains known definitely only from Chuuk. Its absence elsewhere in the Carolines, at least in the FSM, is real because such a large and conspicuous animal that occurs in aggregations and exposed on tree trunks in daylight would not have gone unnoticed; there are no records of large millipedes on Yap, Pohnpei, and Kosrae. Chuuk hosts well-differentiated endemic species in a variety of taxa, some without any close representatives elsewhere in the FSM, and *A. setigerus* possibly falls into this category. Gressitt (1954:139) stated that the insect fauna of Truk [Chuuk] "is puzzling in its representation and affinities ... [being] exceedingly depauperate in some groups, whereas in others it has peculiar endemic forms, seemingly without close relationships." Lieftinck (1962:3) declared that *Teinobasis carolinensis*, a damselfly endemic to Chuuk, "is a highly interesting and aberrant zygopter, unlike anything known in this diversified genus ...," and Craig and Joy (2000) and Craig et al. (2001) reported that among the 40 species of black flies in the Pacific subgenus *Inseliellum* that they studied, molecular evidence indicated that *Simulium trukense*, endemic to Chuuk, is the most distantly related lineage and the only species of the subgenus in the Caroline Islands. Among terrestrial vertebrates, three of 12 resident breeding landbird species are endemic (Pratt et al. 1987), the most distinctive being the Chuuk Monarch, *Metabolus rugensis*, belonging to a monotypic genus and apparently most closely related to a species endemic to the Solomon Islands (Baker 1951).

If *A. setigerus* is not endemic to Chuuk it may still be indigenous to these islands, having arrived from an as yet unknown source, probably by rafting. Alternatively, it may have been introduced by the first aboriginal settlers. Humans appear to have dispersed into central Micronesia, including Chuuk, from western Micronesia and from Melanesia to the south about 2,000 yr ago (Intoh 1997, 1999). East-to-west movements within Micronesia occurred about the same time, as did dispersal northwestward from Polynesia to at least as far as Nukuoro and Kapingamarangi atolls in Pohnpei State (Intoh 1997). Inasmuch as "the cultures of Micronesia were formed by complex movements of human populations" and from different directions (Intoh 1997:25), our current knowledge of these movements does not by itself point to a most likely source of *A. setigerus* on Chuuk.

A more recent introduction by post-sixteenth-century European and American explorations is another possible explanation for the occurrence of *A. setigerus* on Chuuk, but those visits were relatively infrequent. Chuuk "remained relatively unknown to the outside world throughout most of the 19th century ... and enjoys the distinction of being the last major island group in Micronesia to have been opened to intensive contact with the colonial powers of East and West" (Hezel

1973:51). Furthermore, *A. setigerus* does not appear to be especially predisposed to human-assisted introduction. It has been known from Chuuk for about 100 yr, but it has not become established (or at least is not now present) on any of the other islands in the FSM, where seemingly suitable habitat and comparable environmental conditions are available and where interisland traffic has become increasingly more frequent.

In summary, *A. setigerus* has been recorded definitely only in Chuuk during the approximately 100 yr since it was first described and could justifiably be considered endemic to these islands; its absence elsewhere in the FSM almost certainly is real. But in view of the lack of comprehensive systematic studies of millipedes in the Pacific area and the possibility of it occurring elsewhere outside the FSM, we suggest that it be treated as a cryptogenic species (sensu Carlton 1996), possibly being indigenous and endemic to Chuuk but of unknown origin and of incompletely resolved phylogeny.

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