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Aquatic Plant Control Research Program

Australian Moths for Hydrilla Control

by Dale H. Habeck, University of Florida

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Prepared for Headquarters, U.S. Army Corps of Engineers

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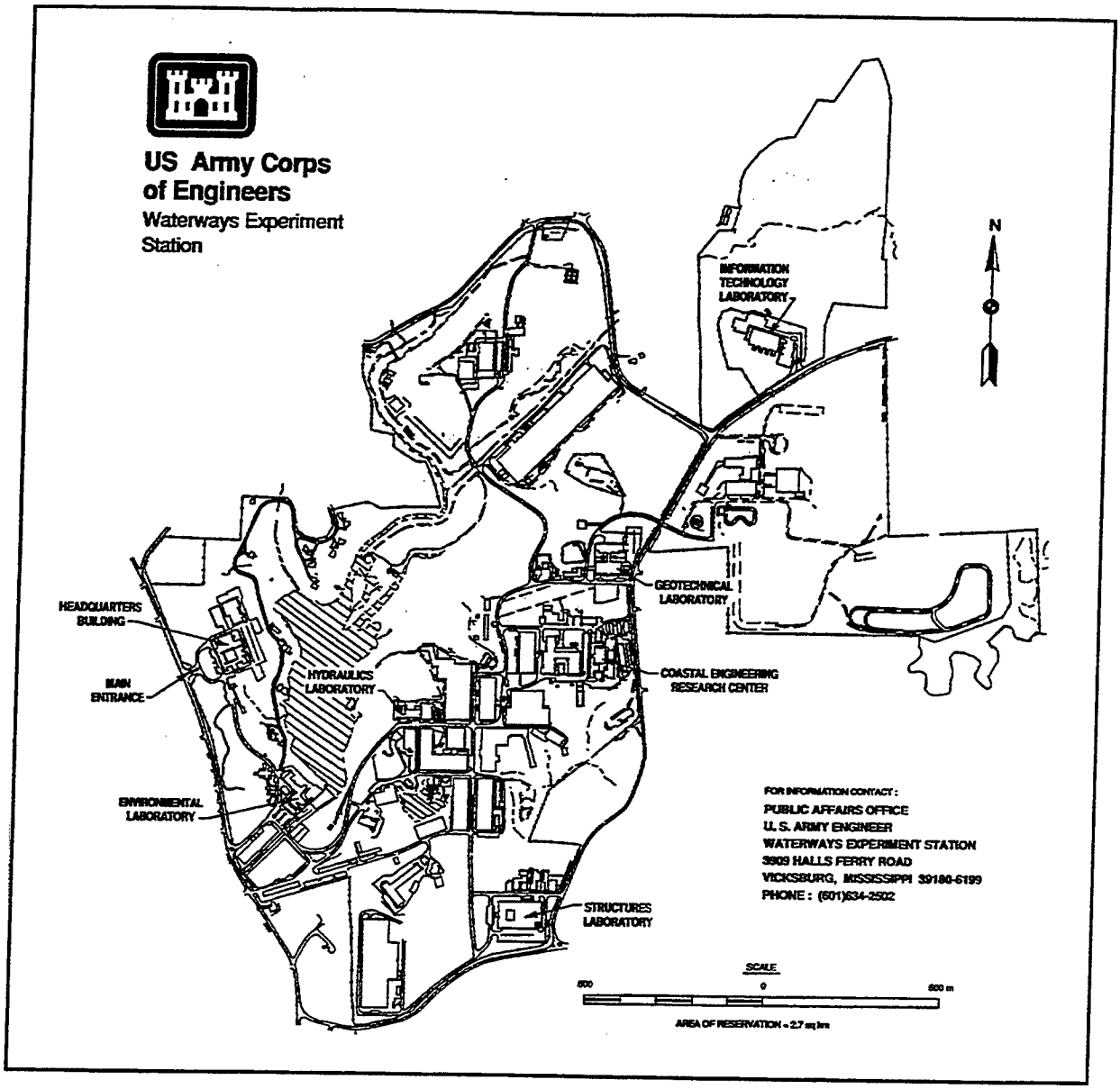

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Contents

Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 31799. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology (CAPRT), Dr. John W. Barko, Director.
Mr. Robert C. Gunkel, Jr., was Assistant Director, CAPRT. Technical Monitor during this study was Ms. Denise White, HQUSACE.

The Principal Investigator for this study and author of this report was Dr. Dale H. Habeck, Department of Entomology and Nematology, University of Florida, Gainesville, FL.

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The study was conducted under the direct supervision of Dr. Alfred F. Cofrancesco, Jr., Aquatic Ecology Branch (AEB), and Dr. Edwin A. Theriot, Chief, AEB, and under the general supervision of Dr. Conrad J. Kirby, Chief, Ecological Research Division, and Dr. John W. Keeley, Director, EL, WES.

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1 Introduction

Biological control of aquatic weeds began in Florida with the introduction of *Agasicles hygrophila* to control alligatorweed, *Alternantheria philoxeroides*, a native of South America. Subsequently, thrips and a stem borer were introduced. The success realized in controlling alligatorweed biologically led to the introduction of two weevils and a moth against waterhyacinth, *Eichhornia crassipes*, in the 1970s and a weevil and a moth against waterlettuce, *Pistia stratiotes*, in Florida. The biological control efforts on these three weeds and hydrilla are summarized by Cofrancesco (1993). Control of these latter two floating weeds is incomplete, and additional introductions are being considered.

A fourth aquatic weed, hydrilla (*Hydrilla verticillata*), is a submersed plant that clogs waterways and interferes with navigation (Schardt and Schmitz 1989). Four insects have been introduced from Asia and Australia for biological control of hydrilla: two weevils, *Bagous affinis* and *B. hydrillae*, and two ephydrid flies, *Hydrellia pakistanae* and *H. balciunasi*. The biological control campaign against hydrilla has been summarized by Grodowitz et al. (1993) and Cofrancesco (1993). While the effects of the four insects introduced against hydrilla are still being determined, one conclusion agreed upon by all is that the introduced biological control agents have not yet controlled hydrilla, and additional agents are being searched for particularly in Asia.

Balciunas and Center (1988) and Balciunas, Center, and Dray (1989) indicated that three Australian moth species that fed on hydrilla in flowing water only might be useful for controlling hydrilla in rivers and streams in Florida. The investigation reported here was initiated to obtain additional information on the usefulness of these three species, especially (*Aulacodes siennata* (Warren).

2 Literature Review

Nymphulinae are a subfamily of the Lepidoptera family Pyralidae according to most classifications. However, recently, Speidel (1984) used the subfamily Acentropinae for the aquatic moth subfamily and placed them in the family Crambidae. Apparently, most pyralid specialists are accepting the division of the Pyralidae into two families: Crambidae and Pyralidae. Under this system, the Nymphulinae (or Acentropinae) would be a subfamily of Crambidae. The purpose of this literature review is to indicate what is known about the aquatic caterpillars and moths of Australia and not to get involved in which system of higher classification is correct. Nymphulinae will be used here in the traditional sense.

The Nymphulinae are a group of moths whose larvae and pupae are aquatic with a few exceptions. Larvae and pupae have adapted to survive in the aquatic environment. Some live in stagnant unmoving water, while others occur only in flowing water or even torrents. Females of some species enter the water to oviposit using their long legs hair-fringed as oars to propel themselves through the water.

According to Common (1990), there are about 60 species of Nymphulinae in 23 genera in Australia. The largest genus is *Nymphula* with 14 species. A catalogue of the described Lepidoptera of Australia is being prepared. The Nymphulinae section is being prepared by E. D. Edwards and E. S. Nielsen of the Australian National Insect Collection in Canberra, M. Shaffer of the British Museum of Natural History in London, and perhaps others. Some species and genera have been transferred from the Nymphulinae to the Musotiminae, and many name changes will result from new synonymies and the shifting of species to other genera. A satisfactory classification of Australian Nymphulinae cannot be achieved until the immature stages, particularly larvae, are known. More information also is needed on larval host plants, biology, and seasonal and geographic distribution. Until the larval and pupal stages are known and revisionary studies are carried out on a worldwide basis, the placement of species into genera and higher categories must be considered tentative.

Tillyard (1926) reported on the biology of *Hydreuretis tullialis* (Walker), which makes portable cases of reed stems fastened together with silk. Common (1990) mentions *Nymphula nitens* (Butler), which has been reared from

Potamogeton crispus (Potamogeton aceae) and *Zostera* sp. (Zosteraceae). The latter plant grows in estuarine water with a rather high salt content. It is probable that *N. nitens* has other host plants as well. Virtually nothing else has been done on the biology, immature stages, or host plants of Australian Nymphulinae except for the investigations by Dr. J. K. Balciunas and his assistants at Townsville. Most of his research results remain unpublished, but preliminary studies are summarized in Balciunas and Center (1988) and Balciunas, Center, and Dray (1989). His research on insects attacking hydrilla in Australia focused on three species: *Aulacodes siennata* (Warren), *Nymphula eromenalis* (Snellen), and *Strepsinoma repititalis* (Warren). He reported that these three species appeared to be restricted to streams with permanent flows and that they had been collected almost exclusively from *Hydrilla verticillata*, *Blyxa octandra*, and *Vallisneria gracilis* (*spiralis*?) (all Hydrocharitaceae) (Balciunas and Center 1988). Balciunas (unpublished) reported *A. siennata* from *Myriophyllum trachycarpum*, *M. verrucosum* (Haloragaceae), *Ottelia alismoides* (Hydrocharitaceae), and *Nymphoides indica* (Menyanthaceae) in addition to the three plant species already mentioned. *Nymphula eromenalis* was collected only on the three plants except for single specimens on *Myriophyllum trachycarpum* and *Potamogeton tricarinatus* (Potamogetonaceae), while single specimens of *Strepsinoma repititalis* were collected on *Cabomba caroliniana* (Cabombaceae) *Myriophyllum trachycarpum, Potamogeton javanicus* (Potamogetonaceae), and *Villarsia* sp. (Menyanthaceae) (Balciunas, unpublished). Subsequent studies on *S. repititalis* were halted since it was more commonly collected on *Blyxa* and *Vallisneria* than on hydrilla (Balciunas, Center, and Dray 1989). Life history studies on *N. eromenalis* and *A. siennata* indicated that larval development was highly asynchronous, and as a result, it was very difficult to maintain cultures for further studies.

Some of the species occurring in Australia have been studied elsewhere. The larva of *Parapoynx diminutalis* Snellen, which is common on hydrilla in Australia (Balciunas unpublished), was described and illustrated by Yoshiyasu (1985). Its discovery in Florida (Del Fosse, Perkins, and Steward 1976) and spread (Balciunas and Habeck 1981) were followed by studies of its life history and host range (Buckingham and Bennett 1989). Larvae developed in the laboratory on 14 plant species in 13 genera, but in paired tests usually preferred hydrilla. Previous studies in Malaysia (Varghese and Singh 1976), India (Sankaran and Rao 1972), and Pakistan (Baloch and Sana-Ullah 1974) also indicated that *P. diminutalis* had a fairly wide host range.

Parapoynx stagnalis (Zeller) is a widespread rice pest. It (as *Nymphula depunctalis*) has been studied in the Phillipines (Sison 1938) and India (Viraktamath, Puttarudriah, and Channabasavanna 1974). Host plants in India include *Isachne dispar, Panicum repens, Leersia hexandra* (all Graminae) and. in the laboratory, *Sorghum vulgare, Zea mays, Eleusine coracana, Saccharum officinale, Cynodon dactylon*, and *Cyperus rotundatus* (Viraktamath, Puttarudriah, and Channabasavanna 1974). In the Phillipines, it consumed *Panicum repens* and seven other grass species (Sison 1938). Both papers include considerable information on the biology of *P. stagnalis*. The larva

and pupa have been described and illustrated by Yoshiyasu (1985). *Parapoynx fluctuosalis* (Zeller) also feeds on rice (Tsuda 1936) in Japan and feeds on water lilies (Nymphaceae) and three grass species, *Panicum, Paspalum,* and *Eragrostis*, in Hawaii (Williams 1944; Zimmerman 1958).

Parapoynx crisonalis (Walker) feeds on *Limnanthemum indicum* (Nymphaeaceae), *Trapa natans* (Trapaceae), Jussiaea repens (Onagraceae), *Euryale ferox* (Nymphaeaceae) (Takahashi 1930), and *Nymphaea* (Nymphaceae) (Yoshiyasu 1983b). The larva and pupa have been described and illustrated by Yoshiyasu (1985).

Elophila difflualis (Snellen) has alos been known as *Nymphula enixalis*. Its hosts include *Vallisneria* (Hydrocharitaceae), *Synnema* (Acanthaceae), *Echinodorus* (Alismataceae), *Marsilea* (Marsileaceae), and *Potamogeton* (Potamogetonaceae) (Agassiz 1978). *Elophila responsalis* feeds on *Pistia responsalis* (Yoshiyasu 1983b). In Indonesia, *E. responsalis* was considered the most important natural enemy of *Salvinia cucullata* (Mangoendihardjo 1977).

Biological information or host plants or immature stages are apparently known (based on publication) for only about 12 species, representing less than 25 percent of the Australian fauna of Nymphulinae. This information is very incomplete even for these 12 species. Considering that additional new species await description, the real figure is probably less than 15 percent.

The availability of illustrations for identification of adults of Australian Nymphulinae is indicated in Table 1.

Four species of aquatic caterpillars have been reported feeding on hydrilla *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae) in Australia (Balciunas, Center, and Dray 1989). One of these, *Parapoynx diminutalis* Snellen, is adventive in Florida where it was first reported by Del Fosse, Perkins, and Steward (1976). This species occurs in lakes and ponds or in backwaters along rivers. The other three species, *Aulacodes siennata* (Warren), *Nymphula eromenalis* (Snellen), and *Strepsinoma repititalis* (Warren), apparently are restricted to permanent streams.

Table 1
Illustrations of Adult Characteristics Useful for Identification of Australian Nymphulinae

Species	Wing Patterns			Genitalia	
	M	U	F	M	F
Aulacodes siennata (Warren) Balciunas and Center 1988	X				
Elophila difflualis (Snellen) Agassiz 1978 Speidel 1984 Yoshiyasu 1985	X X X	 X X	X X X	X X X	X X X
Elophila responsalis (Walker) Yoshiyasu 1983b			X	X	X
Hydreuretis tullialis (Walker) Common 1990		X			
Margarosticha australis (Feld and Rogenh.) Common		X			
Nymphula eromenalis (Snellen) Balciunas and Center 1988	X				
Nymphula nitens (Butler) Common 1990		X			
Paracataclysta fuscalis (Hampson) Yoshiyasu 1983a			X	X	X
Parapoynx crisonalis (Walker) Yoshiyasu 1983b Speidel 1984 Yoshiyasu 1985		X	 X X	 X X	 X X
Parapoynx diminutalis (Snellen) Agassiz 1978 Speidel 1984 Yoshiyasu 1985	X X X		X X	X X X	X X X
Parapoynx fluctuosalis (Zeller) Sison 1938 Williams 1944 Zimmerman 1958 Viraktamath et al. 1974 Agassiz 1981 Speidel 1984 Yoshiyasu 1985	X X X X X X		X X X X X	 X X X	 X X X
Parapoynx polydectalis (Walker) Agassiz 1981	X		X		
Parapoynx stagnalis (Zeller) Agassiz 1981 Speidel 1984 Yoshiyasu 1985	X X		 X X	 X X	 X X
Parapoynx villidalis (Walker) Yoshiyasu 1987	X			X	X
Strepsinoma croesusalis (Walker) Yoshiyasu 1987			X	X	X
Strepsinoma repititalis (Warren) Balciunas and Center 1988	X				

Note: M = male; F = female; U = unspecified.

3 Methods and Materials

Investigations on the hydrilla feeding Nymphulinae were conducted in Australia for nearly 4 months during winter (June-September) in Queensland, Australia. Winter is the dry season in northern Australia and streams and the weeds in them are accessible since water levels are low. Floods during the rainy season frequently scour the streams of most aquatic plants.

The Queensland Department of Primary Industries in Mereeba provided laboratory and greenhouse space for the work. Mareeba is about 60 km west of Cairns in northern Queensland. Previous surveys by Dr. J. K. Balciunas indicated that the area from Cairns north to Daintree was the best place to collect these insects. Mareeba is located at 145.04° longitude and 15.34° latitude. It is basically an agricultural area producing crops by an extensive irrigation network originating from Tinaroo Dam.

In evaluating potential biological control agents, great emphasis is placed on determining host specificity. This is usually done in quarantine by conducting choice and/or no-choice tests where the insect is confined with only one plant species or several species plus the target weed. The concern is two-fold—one, will the insect feed on the test plant? Two, can the insect reproduce on the plant? These studies tend to err on the negative side since some species of insects may feed on plants in no-choice studies that they are never found on in nature. Studies on *Parapoynx diminutalis* indicate that this species feeds on many more plant species in the laboratory than in the field (Buckingham and Bennett 1989). Similarly, *Parapoynx stratiotatum* (Linnaeus) fed on many plants in the laboratory that it was not found on in the field (Habeck 1982). Similar examples could be cited with insects feeding on terrestrial weeds.

Efforts in Australia were concentrated on collecting aquatic weeds of many species and bringing them back to the laboratory where each plant was carefully checked for insect larvae. These larvae were usually killed by placing them in boiling water and then preserved in 70-percent alcohol. Some larvae were placed in 1-oz cups with water and the host plant for rearing.

Hydrilla, while not rare, was sporadic in occurrence and not always easy to locate. Many miles were traveled on highways looking for streams that might harbor hydrilla populations. Most of the bridges spanned dry

streambeds. Other areas that had water did not have flowing water; hydrilla was not present; or hydrilla was present but not at the surface and therefore relatively inaccessible to insects. Other areas, especially estuarines, were unsafe to sample because of the presence of crocodiles.

Plant samples were placed in plastic bags in a cooler for return to the laboratory. Some samples were placed in Berlese funnels. Berlese funnels were slower in getting the specimens out but more efficient, particularly in separating the small larvae. Unknown plants were identified by Dr. John Clarkson or Dr. John Nelyar of the Department of Primary Industries in Mareeba.

Larvae were examined under a dissecting microscope and separated into the various types. Detailed descriptions and drawings of the full grown larvae feeding on hydrilla were prepared. A key was devised to separate the four species commonly found on hydrilla. Representatives of the larvae of each species will be deposited in the Australian National Collection in Canberra, the Florida State Collection of Arthropods in Gainesville, the Smithsonian Institute in Washington, DC, and the collection of Y. Yoshiyasu at Kyoto Prefectural University of Agriculture in Kyoto, Japan.

4 Results

All four species of aquatic moths are relatively brightly colored and distinctly marked. The adults of *Aulacodes siennata* and *Parapoynx diminutalis* are sexually dimorphic and fairly easy to separate. The larvae are also easily separated. *Parapoynx diminutalis* (Figures 1-5) is separated from the other three species by the presence of branched gills and the conspicuous brown peritremes around the setae on the head and most setae on the dorsal and lateral aspects of the prothorax and mesothorax.

Nymphula eromenalis is also easily separated by the presence of gills on the prothorax and ventrally on the mesothorax and metathorax and abdominal segments 1-2 and sometimes on abdominal segments 3-6. In addition, the lateral gill groups on abdominal segments A8, A9, and A10 form a fanlike posterior when viewed dorsally or ventrally. This is similar to the fanlike gills found on *Eoparargyractis* species in North America. Another distinguishing character of *N. eromenalis* is the very large condyle on the mandible.

The larvae of *Aulacodes siennata* and *Strepsinoma repititalis* are superficially similar. They can be separated by the number of gill groups on abdominal segments 3 to 6. *Strepsinoma repititalis* has three, while *A. siennata* has four. The head is prognathous in *S. repititalis* and hypognathous in *A. siennata*.

The larvae of *S. diminutalis* is creamy-white, while the others are dingy grayish to brown.

Parapoynx diminutalis (Snellen), (Figures 1-5)

Distinguishing characteristics: gills branched; all setae and pores on head and prothorax and most on mesothorax and metathorax with a conspicuous dark brown peritreme. Maximum length: 14 mm; in a portable case.

Color: Head, prothoracic shield, crochets and sclerotized ring around prolegs pale yellowish-brown. Thoracic legs and anal shield light yellowish-brown. Body creamy-white. All head, prothoracic, and most mesothoracic and metathoracic setae and pores with conspicuous dark brown peritremes.

Gills: Branched gills present on T2-3 and A1-9. Dorsal gills: two on T1-2 and A1-6, one on A-7. None on A8-9. Lateral gills: two on T-2 and A1-7; one on T2 and A8. Subventral gills: one on T2 and A1-6. Most gills from one-half to three-fourths width of body. Most gills with four branches.

Head: (Figure 2). Maximum width 1.1 mm hypognathous. Adfrontals extending nearly to vertical triangle Clypeo-frons extending 0.87 of way to vertex. Seta P2 above frons; line through P1 setae would pass slightly anterior to AF2 setae but posterior to AF puncture. AF2 setae below apex of frons. F1 setae above line through F punctures. AF1 setae nearer to F1 seta than to P1 seta. A2 seta posterior of and near A1 seta. A2 seta very short, about 0.2 as long as A1 seta and 0.1 of A3 seta, which is very near L1 seta. S2 seta 2x as long as S1 seta and 4x as long as S3 seta. Labral notch extending about 0.33 of way to base. Labrum with six unmodified setae. Mandible yellowish-brown with reddish brown teeth. Mandible with five teeth plus two on the outer ridge (Figure 4). Condyle small. Six stemmata represented by a dark area except stemma 6, which is very inconspicuous; stemmata 3, 4, and 5 very close. Lens usually apparent on stemmata 1-5, with 3 and 4 larger than others.

Thorax: T1 with XD2 seta slightly closer to XD1 seta than to SD1 seta (Figure 3). Distance between XD1 and XD2 setae slightly more than between XD1 and D1 setae, which is directly posterior of XD1 seta. D2 seta on posterior roll of prothoracic shield. SD2 seta posterior-dorsal of SD1 seta. Lateral setae very fine, short, and without an obvious pinaculsum. SV setae about equal in length, also without an obvious pinaculum. On T2 and T3, setae D1, D2, SD1, and SV1 are easily located. The anterior dorsal gill arises ventro-posterior of D2 seta. Seta SD2 very minute. Lateral setae very fine, with L2 slightly more conspicuous. L1 seta dorsal to and nearer L2 seta than to L3 seta, which is more dorsal and posterior. Coxae touching on all three segments.

Abdomen: Spiracles present on A2-4. Prolegs on A3-6 and 10 with uniserial, biordinal crochets in a circle. A10 circle incomplete posteriorly. Sclerotized ring around crochets. All setae inconspicuous. 2L setae on A9. SV setae: one on A1, A8-9, two on A2, seven and three on A3-6, those on A3-6 anterior to the crochets. Anal plate: SD1 only robust seta, twice as long as D2 seta (Figure 5). SD2 seta more ventral and anterior. SD2 seta about equidistant between SD2 and D1 setae.

Aulacodes siennata (Warren), (Figures 6-11)

Distinguishing characteristics: Head hypognathous. Adfrontals extending 0.85 to vertical triangle. Clypeofrons extending 0.7 to vertical triangle. Prothoracic shield with an indistinct transverse furrow near posterior margin. XD1 and XD2 setae 0.33x as far apart as XD2 and SD1 setae. D1 and D2 setae posterior-dorsad of XD1 seta. Gill groups: three on T2-3, five on

A1-2, four on A3-8, and two on A9. Maximum length: 25 mm. Usually in a silken tube shelter covered with plant parts; sometimes free.

Color: Head light brown with dark markings (Figure 7). Body light brown but appearing darker due to dense covering of stellate asperities. Prothoracic shield, leg segments brown. Crochets and sclerotized ring around crochets dark brown to black.

Gills: Unbrached filamentous in groups: three on T2-3, five on A1-2, four on A3-8, and two on A9. Maximum length of gills: about 0.5-0.6 body width.

Head (Figure 7): Maximum width 2 mm, hypognathous. Line through P1 setae would pass about midway between AF1 and AF2 setae. Line through P2 setae would pass above AF2 setae and below apex of frons. Line through F1 setae would pass through or slightly below F punctures. A1 seta almost directly anterior of A2 seta; distance between A1 and A2 setae greater than distance between A3 and L1 setae. S2 seta long, more than 2x longer than S1 seta and less than 2x as long as SO3 seta. Stemmata 3 and 4 adjacent, stemma 6 barely discernible. Labrum notched, seta M3 modified into scalelike scraping structure (Figure 9). Mandible (Figure 10) with three ventral pointed teeth and two obtuse dorsal teeth; all teeth with ental ridges, but with second, third, and fifth (starting dorsally) especially strong.

Thorax: Conspicuous shield on T1 with an indistinct transverse furrow near posterior margin (Figure 8). XD1 and XD2 setae about 0.33x as far apart as XD2 and SD1 setae. D1 and D2 setae posterior-dorsad of XDI seta. SD2 seta posterior and slightly dorsad of SD1 seta. Two L setae and two SV setae conspicuous. D2 setae on T2-3, short and inconspicuous. L1 and L2 setae close together, very fine. SD1 and SV setae in gill groups. Coxae touching on T1; T3 coxae separated most but by less than 0.25 width of coxa.

Abdomen: Spiracles on A2-4. D1 setae small, D2, SD1, L1, and SV setae in gill groups. SV setae: one on A1, 7-9, two on A2, and three on A3-6. L3 seta in front of SV gill group. 2L setae on A9. V1 on A3-6 near circular ring, and slightly posterior of a line going through the middle of prolegs.

Prolegs on A3-6 with uniserial, triordinal crochets in a circle. Sclerotized ring around crochets. A10 crochets triordinal in a transverse row. Anal shield undifferentiated. SD1 and D2 setae approximately equal in length and robustness. DI and SD2 setae finer and equal in length.

Strepsinoma repititalis (Warren), (Figures 12-17)

Distinguishing characteristics: Prognathous head, adfrontals extending to vertex. Prothoracic shield with setae D1 and D2 dorso-posterior of XD1 seta

and SD2 seta almost dorsad of SD1 seta. With three gill groups on T2-3 and A1-8 and 2 on A9. Maximum length: 20 mm. In an elongate shelter made of two leaves or one leaf usually covered with algae filaments.

Color: Head yellowish-brown with a lighter genal area extending to stemmata. Body light brown. Prothoracic shield distinct, slightly darker. Anal shield undifferentiated. Crochets, leg segments, claws, and sclerotized ring around crochets dark brown.

Gills: Unbranched filamentous gills in groups. T2-3 and A1-8 with three gill groups. A9 with two gill groups. Gill groups located at SD, L1+2 and SV setal positions on T2-3 and at D2, L1+2 and L3 setal positions on A1-8. Longest gills about two-thirds of body width.

Head: (Figure 13) Maximum width: 1.95 mm, prognathous. Adfrontals extending to vertical triangle. Clypeofrons extending about 0.85 distance to vertical triangle. P1 and P2 setae at about level of AF1 and AF2 setae, respectively. AF2 setae below frons apex and adjacent to AF puncture. F1 setae at or slightly above level of F punctures. A1 seta anterior of and as far from A2 seta as A3 seta is from L1 seta. Area between P1 seta and A1 seta, laterally almost to A3 seta and posteriorly slightly behind a line from L1 seta to P1 seta, shagreened. Distance between S3 and S2 setae about 4x distance between S1 and S2 setae. S2 seta nearly 2x as long as S3 seta and more than 2x length of S1 seta. Stemmata 3 and 4 touching, 6 inconspicuous. Labrum with a shallow notch, seta M3 modified into a scalelike scraping structure (Figure 15). Mandible with four teeth each with an ental ridge (Figure 16).

Thorax: T1 with XD2 seta about equidistant between XD1 and SD1 setae (Figure 14). D1 and D2 setae posterior-dorsad of XD1 seta and further from XD1 seta than XD1 if from XD2 seta. SD2 seta almost dorsad of SD1 seta. L1 setae about 2x longer than L2 seta. SVI and Sv2 setae about equal length. Setae D2, SD1, and SV1 on T2 and T3 conspicuous but other setae minute and difficult to see. L3 seta may be lacking. Coxae of T1 touching except anteriorly. T2 coxae separated by about width of coxal base and T3 coxae slightly further apart.

Abdomen: Spiracles present on A2-4. Prolegs on A3-6, with uniserial, irregularly triordinal crochets anteriorly, but generally biordinal posteriorly. Sclerotized ring around crochets. Crochets on A10 irregularly triordinal. D1 setae minute on A1-9, 2L setae on A9. Setae L1 and L2 minute, close together, the more dorsal one hair-like and about 2x as long as the ventral one, which has a conspicuous peritreme. L3 seta in front of gill group. SV setae: one on A1, 7-9, two on A2, and three on A3-6. Anal plate with SD1 and D2 setae about same length and equally robust (Figure 17). D1 seta and SD1 seta much finer and about 0.33x length of SD1 and D2 setae. SD2 seta slightly posterior of D1 seta.

Nymphula eromenalis (Snellen), (Figures 18-23)

Distinguishing characteristics: Gills on T1. Midventral gills on T2-3, A1-2, and occasionally single or double filaments midventrally on A3-6. Gill filaments forming fanlike appearance on A8-10 (especially when viewed dorsally) (Figure 23). Anal plate with eight long subequal setae. Very large mandibular condyle (Figure 22). Maximum length: 16 mm. In a shelter attached to plants.

Color: Head pale yellowish-brown with prominent dark markings extending anteriorly from vertex (Figure 19). A light brown genal stripe extending to stemmatal area. Prothoracic shield yellowish-brown with a few darker spots. Leg segments, crochets, and circular ring around crochets brown.

Gills: Numerous, unbranched filamentous gills in groups. Two T1 gill groups: the larger group posterior to the lateral setae and the smaller group ventral-posterior to the SV setae. T2 with six gill groups on each side plus a midventral group behind coxae and near posterior margin. Other gill groups include two small dorsal groups, anterior one around D1 + D2 setae, a subdorsal group around SD setae, two lateral groups, the largest anterior and around 2L setae, the lower gill group surrounding a single SV seta. T3 with four gill groups on each side and two midventral groups of which the posterior one is as on T2; the anterior group is between the coxae and slightly anterior of a line drawn through the middle of the coxae. Other gill groups as on T2 except dorsal posterior group and lower lateral group are absent. A1-2 with dorsal, subdorsal, 2L and SV gill groups (may be absent or reduced to one or two filaments) and a midventral gill group (may be absent on A1). A second dorsal gill group (one to four filaments) often present on A1 and A4, but usually absent on A2-3. A5-6 with two dorsal gill groups associated with D1 and D2 setae, respectively, a subdorsal gill group surrounding SD setae, one lateral group on A3-5 but A6 with an additional smaller posterior gill group. A subventral gill group dorso-posterior of the prolegs. Single or double gill filaments may occur midventrally behind the prolegs. A7 similar to A6 but with the SD group extending posteriorly and without midventral gills. A8 with posterior dorsal gill group. SD gill group elongate extending anterior to posterior over most of the segment. L gill groups smaller, V and SV gill group absent. A9 with posterior dorsal gill group. SD group large and on a lobelike projection across segment. A10 with lateral gills on posterior portion. Gills longest on A10, as long as body width.

Head: (Figure 19) Maximum width: 1.45 mm, hypognathous. Adfrontals extending about 0.75 of way to vertical triangle. Clypeofrons extending 0.6 to vertical triangle. Seta P2 at level of seta AF2. Line through P1 setae would pass midway between AF1 setae and AF punctures. AF2 setae midway between apices of frons and adfrontals. F1 setae above line through F punctures. A2 lateral of and close to A1 setae. A2 setae very short, less than 0.2 length of A1 and A3 setae. A3 setae near L1 seta. S2 seta nearly 2x as long as S3 seta which is about 2x as long as S1 seta. SS3 seta as long as S2

seta. Labral notch extending about 0.3 to base. Labrum with six setae, M3 modified into scalelike, scraping structure (Figure 21). Mandibles yellowish-brown, dark at condyle with six teeth along margin (Figure 22). First, third, and fourth teeth with ridges adorally. Condyle very large. Stemmata 3 and 5 larger than others, 3 and 4 appressed. Most of posterior margin of head dorsal from genal notch bordered in dark brown or black.

Thorax: Distance between XDI and XD2 setae slightly more than 0.5 the distance between XD2 and SD1 setae. D1 and D2 setae dorso-posterior to XD1 and XD2 setae, respectively, and with D2 seta much nearer to posterior margin of T1 shield than to anterior margin. SD2 seta dorso-posterior to SD1 seta. L setae separate from T1 shield, L1 seta much longer and slightly posterior and dorsal of L2 seta. SV setae (2) subequal in length. T1 coxae touching, T2 coxae about one-half as far apart as T3 coxae.

Abdomen: SV setae: one on A1, 7-9, two on A2, and three on A3-6. D2 setae absent on A1-6, present and larger on A7-9 than D1 seta. A2-4 with prominent spiracles. A3-6 with prolegs with biordinal brown crochets in a circle. Sclerotized ring around crochets sometimes incomplete posteriorly. SV setae on A7 about 2x as far apart as SV setae on A8 and A9. A9 with 2L setae. Anal plate undifferentiated, bilobed, each lobe with four long subequal (stoutness and length) setae (Figure 23).

Biology

Moths of the aquatic caterpillars were frequently observed on the underside of leaves sometimes considerable distances from water. Blacklights are commonly used to attract moths to sheets where the desired moths can be collected individually in small plastic cups. The numbers of aquatic moths attracted to blacklight set up near water (10-60 ft away from the Barron River) were very small. More *Aulacodes siennata* were collected at a carport light one-half + miles from the Barron River. The best place for collecting aquatic moths was a caravan park, (about 40-50 ft above the river) and perhaps one-fourth mile away. Some moths were attracted to incandescent lights on the caravans, but they were most attracted to a spotlight on the restroom building. As many as 40 *Aulacodes siennata* moths were collected there in one night in late August. Collecting was also good for some other aquatic moths and nonaquatic moths.

Aulacodes siennata moths (1 male + 1 female) were placed in 50-dram snap cap vials lined inside with moist toilet tissue. Eggs were usually laid the first of second night. The number of eggs varied from 68-715 with an average of 402/female.

Newly hatched larvae of *A. siennata* were very phototropic. They congregated at the side of the dish nearest to a window or other light source. Even when supplied with an abundance of hydrilla, many caterpillars never fed, indicating a tendency to disperse before feeding.

Development of larvae was very uneven. Some grew rapidly and molted to the second or third larval instar (stage), while other remained at first instars. This asynchronous development, first reported by Balcuinas and Center (1988), and Balcuinas, Center, and Dray (1989), makes it very difficult to establish a laboratory colony unless facilities and personnel are available to rear very large numbers of larvae.

Another interesting characteristic is the ability of *A. siennata* larvae to survive for long periods of time in small 1-oz rearing cups. Since the larvae are only found in flowing water, they would be expected to have difficulty surviving in small confined areas where oxygen might be limited. The water in the cups was changed usually every other day, but sometimes only every 3 days. Nevertheless, larvae survived for almost a month under these conditions.

Aulacodes siennata larvae were found on a variety of plants (Table 2). *Vallisneria, spiralis, Blyxa octandra, Hydrilla verticillata*, and *Ottelia alismoides* (all Hydrocharitaceae) were among the plant species on which *A. siennata* was collected. The first three species were fairly common, but *Ottelia* was not. *Nymphula eromenalis* and *Strepsinoma repititalis* also were common on the first three plants, but *Parapoynx diminutalis* was found only on hydrilla. Some *P. diminutalis* larvae and pupae were found on *Nymphoides indica* (Menyanthaceae), but this was only where the hydrilla and *Nymphoides* were growing together. The larvae were probably seeking pupation sites since the pupal cases were usually constructed with hydrilla leaves and leaf fragments. *Aulacodes siennata* also was found on *Polygonum* (Polygonaceae) sp., *Salvinia molesta* (Salviniaceae), *Aponogeton bullosus* (Aponogetonaceae), and *Callitriche* sp. (Callitricheaceae) in the water among the live roots of grasses and trees growing on the stream margin and on an unidentified species of Apiaceae. The latter plant also harbored larvae of *Nymphula eromenalis* and *Strepsinoma repititalis*. On one occasion, an *A. siennata* moth emerged from a cocoon collected from a submerged rock with no plants nearby.

Of the four Australian aquatic moths associated with hydrilla, *A. siennata* has the least restrictive host range (Table 2). It was collected from nine species plus tree roots, and Balciunas (unpublished) found it on three additional species. *Nymphula eromenalis* is the most host specific of the three species. It was found on five plant species in this study and on four by Balciunas (unpublished). *Strepsinoma repititalis* was found on six plant species by Balciunas (unpublished) and five in this study. *Strepsinoma repititalis* is more common on *Vallisneria* and *Blyxa* than on hydrilla, which resulted in the earlier decision to halt work on this species as a potential biological control agent.

About 8,000 eggs of *A. siennata* and 1,000 eggs of *N. eromenalis* were sent to quarantine in Gainesville. From these eggs, about 100 adults of *A. siennata* and 30 of *N. eromenalis* were obtained (Bennett 1993). This low percentage of success is due in part to lack of information on rearing

Table 2
Plant Species on Which Hydrilla-Feeding Aquatic Caterpillars Were Found in the Field

Family Genus and Species	*Parapoynx diminutalis*	*Aulacodes siennata*	*Nymphula eromenalis*	*Strepsinoma repititalis*
Hydrocharitaceae				
Blyxa octandra		X	X	X
Hydrilla verticillata	X	X	X	X
Vallisneria spiralis		X	X	X
Ottelia alismoides		X		
Nymphaceae				
Nymphoides indica	X	(X)		
Najadaceae				
Najas tenuifolia			X	
Haloragaceae				
Myriophyllum verrucosm		(X)		
M. trachycarpus		(X)	(X)	(X)
Cabombaceae				
Cabomba caroliniana				(X)
Potamogetonaceae				
Potomogeton tricarinatus			(X)	
P. javonicus				(X)
Salviniaceae				
Salvinia molesta		X		
Polygonaceae				
Polygonum sp.		X		
Apiaceae				
Unidentified sp.		X		
Callitrichaceae				
Callitriche sp.		X		
Aponogetonaceae				
Aponogeton bullosus		X		

Note: (X) = Balciunas (Unpublished record).

techniques. It is also a reflection of the asynchronous development of the larvae and the emergence of adults over a long period of time making it difficult to obtain mating (Balcuinas, Center, and Dray 1989). Any attempt to colonize these moths in quarantine will require a large commitment of space, personnel, and time. Running water is probably not a necessity despite the fact that these species are only known to occur in flowing water in Australia.

5 Conclusions

The fairly wide host range of *A. siennata* would ordinarily preclude this species from consideration as a biological control agent against hydrilla. The host range is similar in many ways to that of *Bagous hydrillae*, which has been released in Florida. Therefore, the possibility of introducing *Aulacodes siennata* or *Nymphula eromenalis* should not be dismissed lightly. The host range of *N. eromenalis* is the more restrictive of the two and would be the best choice if a decision is made to import either of these species. If exploration in Asia to find additional natural enemies is unsuccessful, these two moths should be considered for importation.

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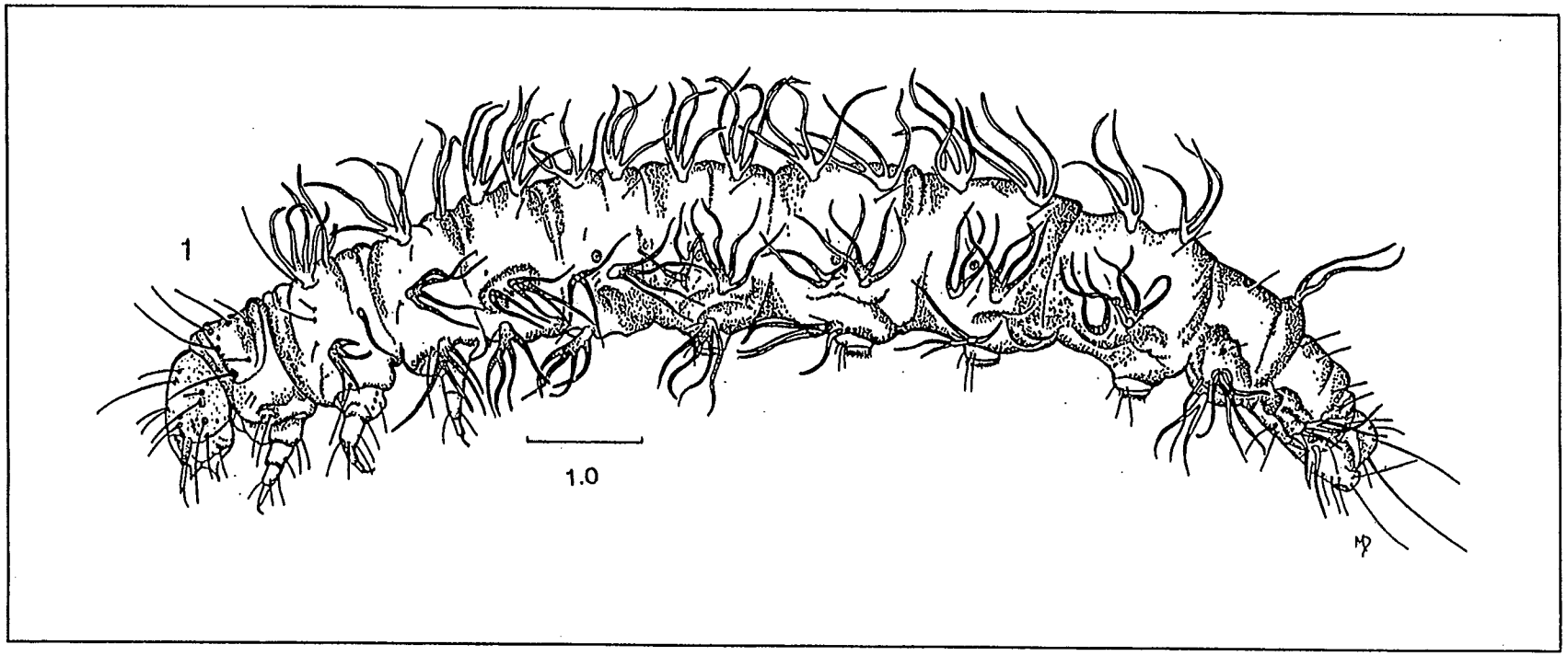

Figure 1. *Parapoynx diminutalis*: mature larva, lateral view

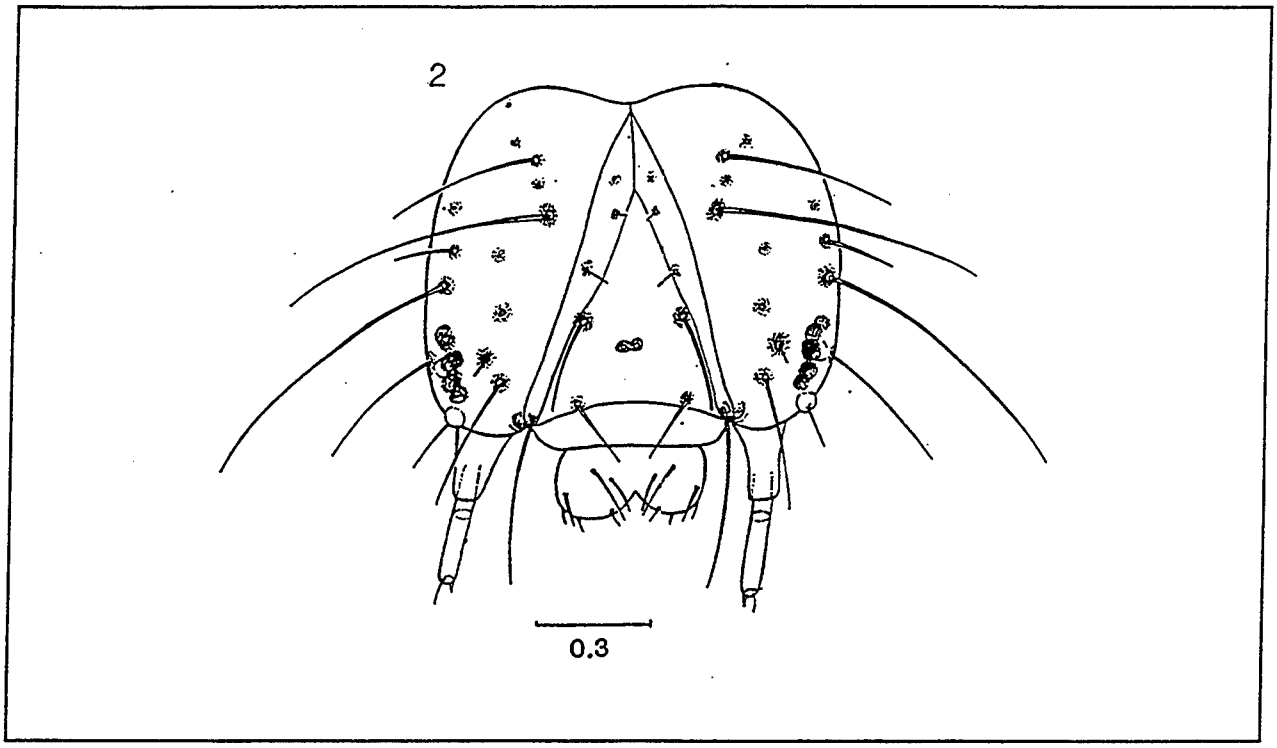

Figure 2. *Parapoynx diminutalis*: head

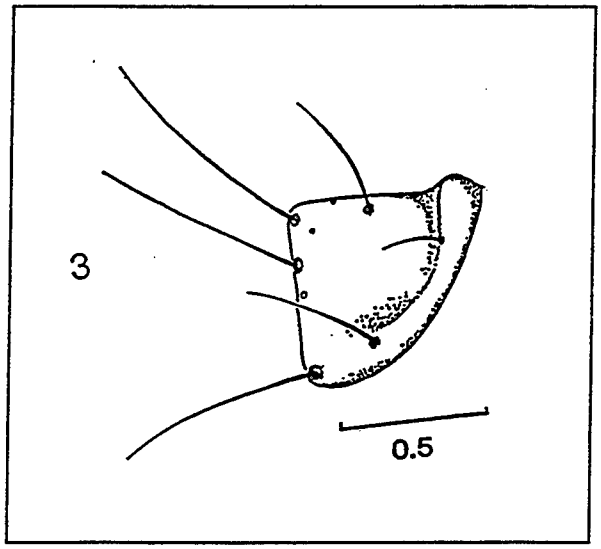

Figure 3. *Parapoynx diminutalis*: prothoracic shield

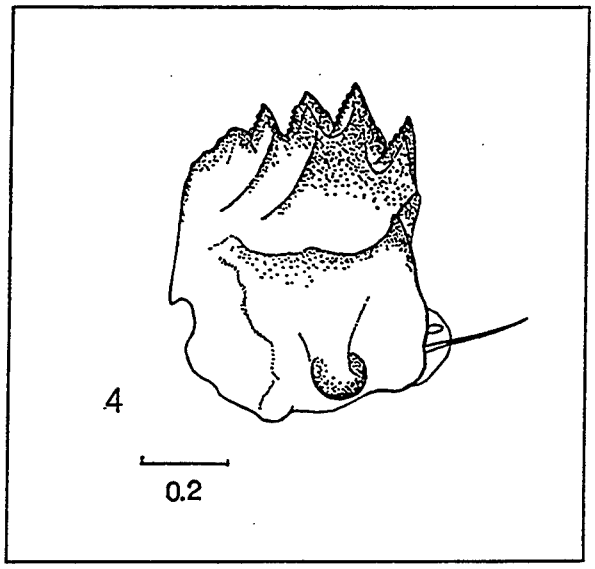

Figure 4. *Parapoynx diminutalis*: mandible

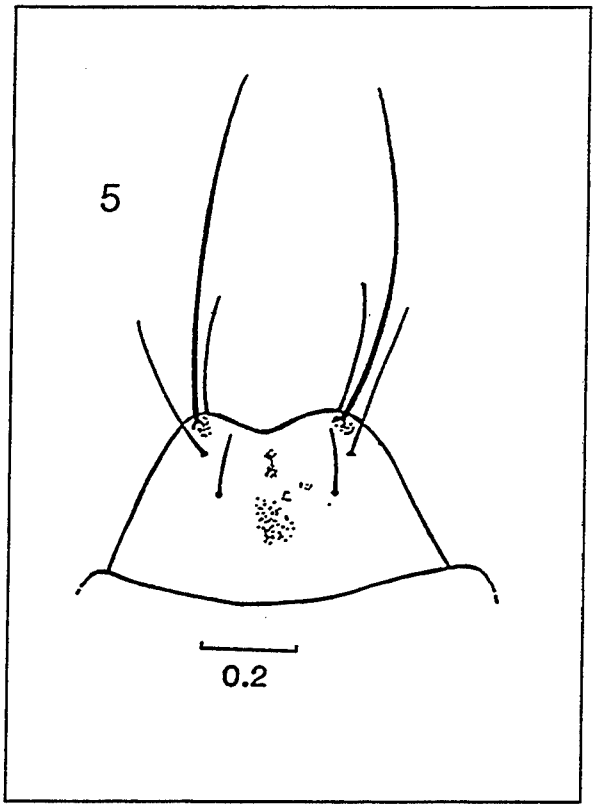

Figure 5. *Parapoynx diminutalis*: anal plate

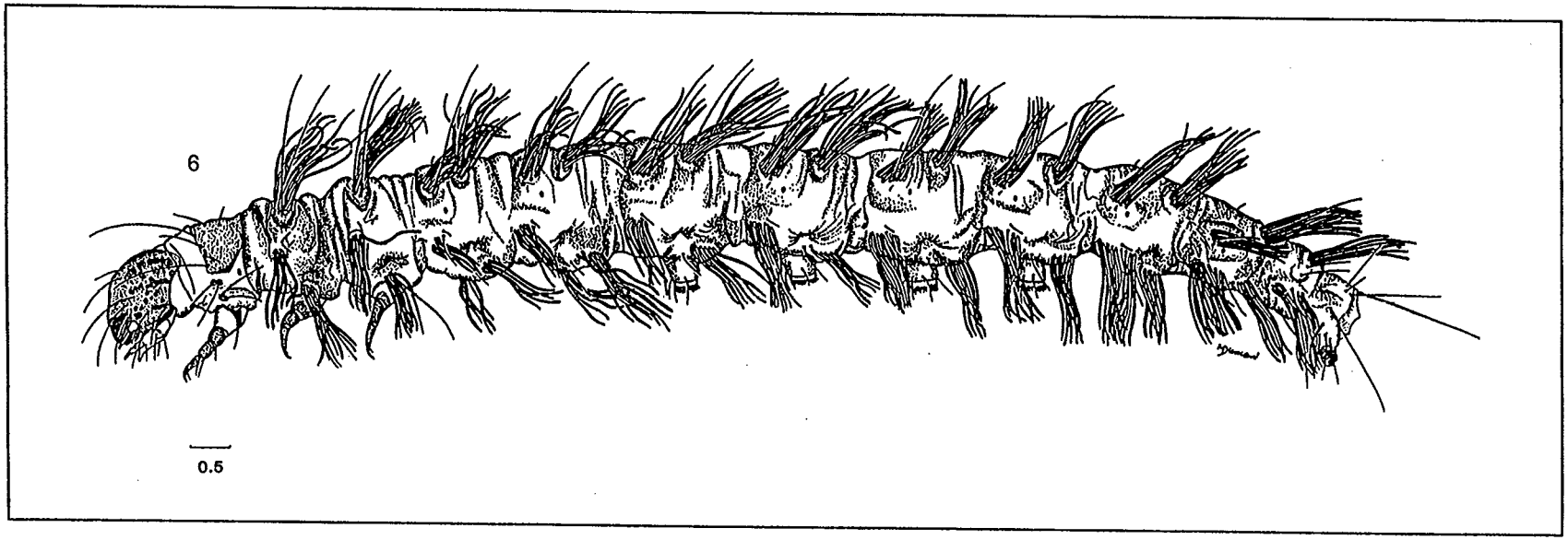

Figure 6. *Aulacodes siennata*: mature larva, lateral view

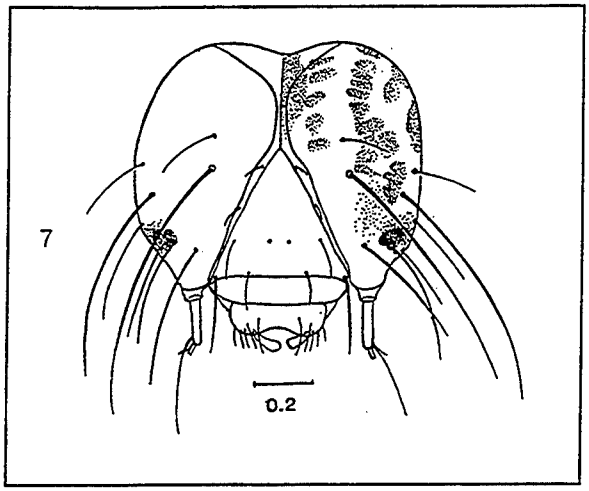

Figure 7. *Aulacodes siennata*: head

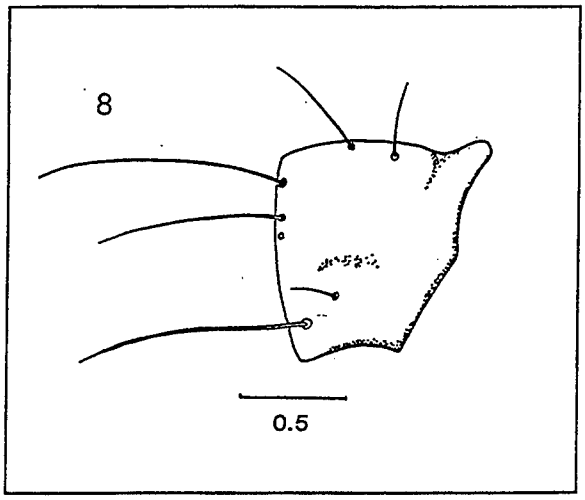

Figure 8. *Aulacodes siennata*: prothoracic shield

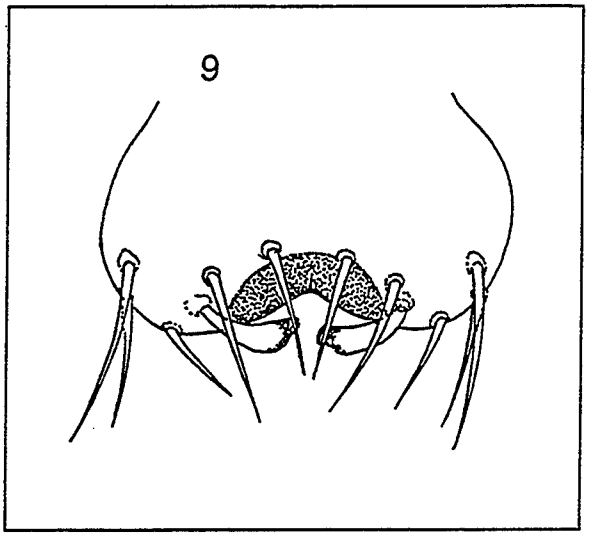

Figure 9. *Aulacodes siennata*: labrum

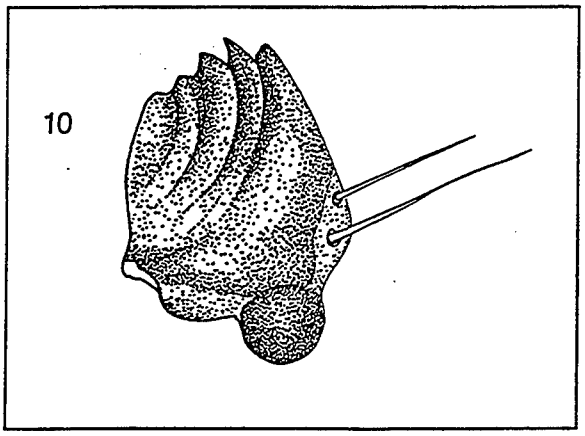

Figure 10. *Aulacodes siennata*: mandible

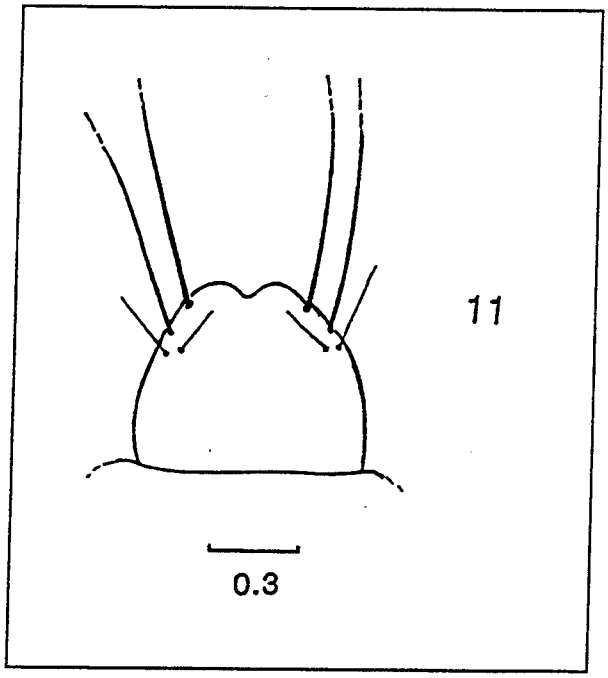

Figure 11. *Aulacodes siennata*: anal plate

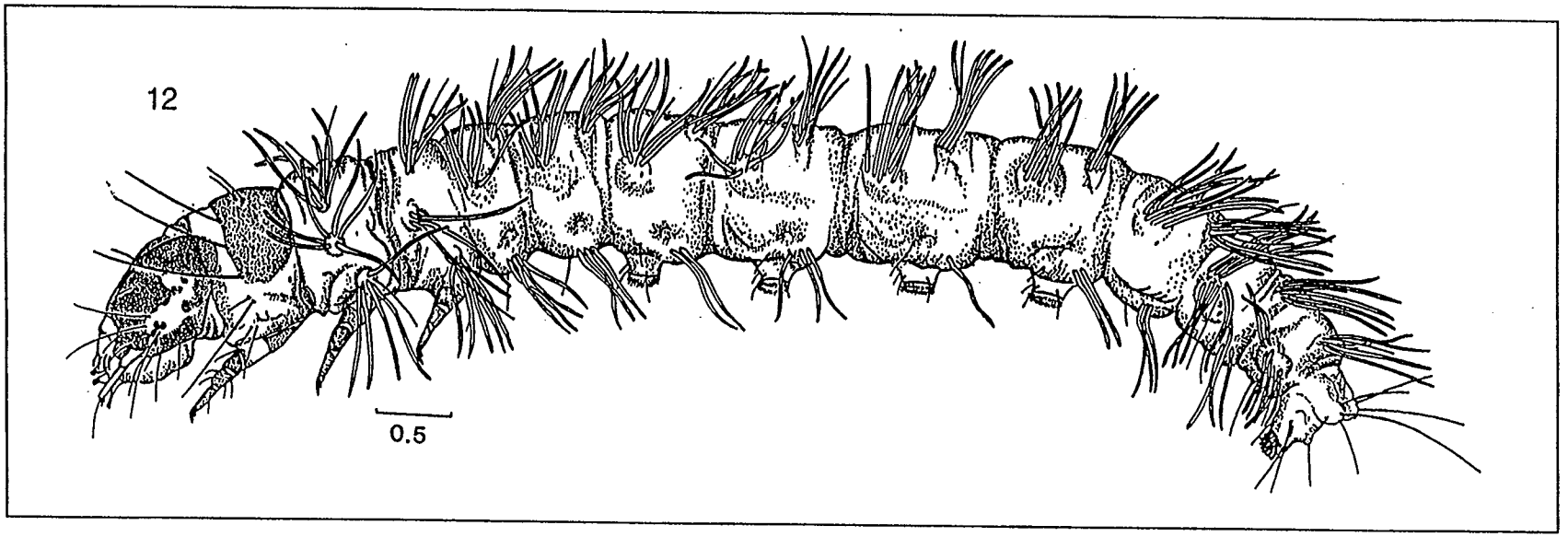

Figure 12. *Strepsinoma repititalis*: mature larva, lateral view

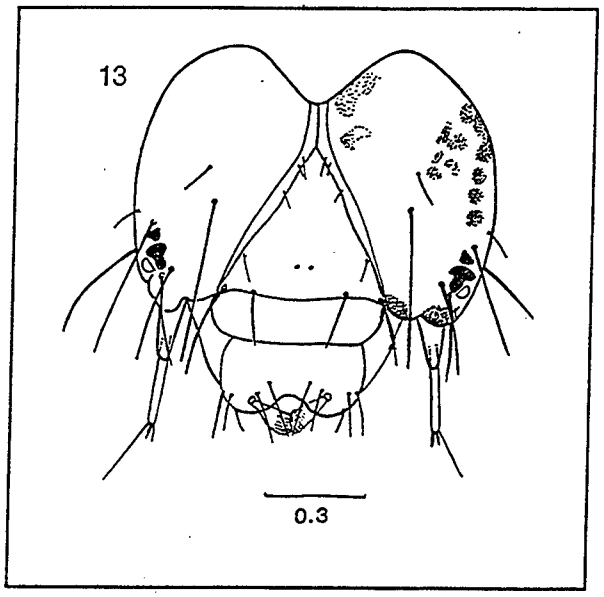

Figure 13. *Strepsinoma repititalis*: head

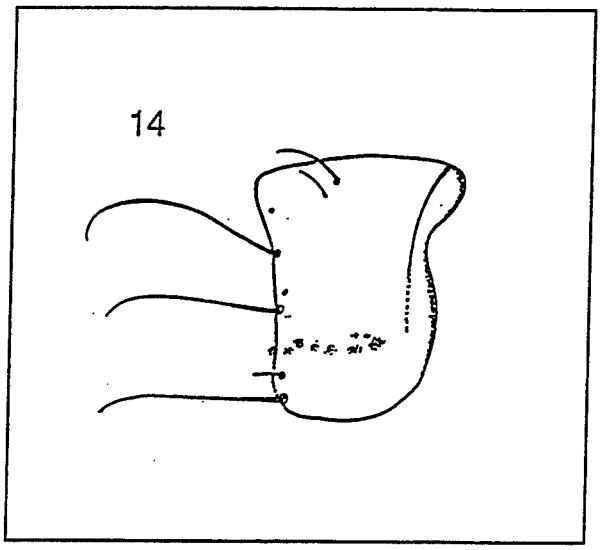

Figure 14. *Strepsinoma repititalis*: prothoracis shield

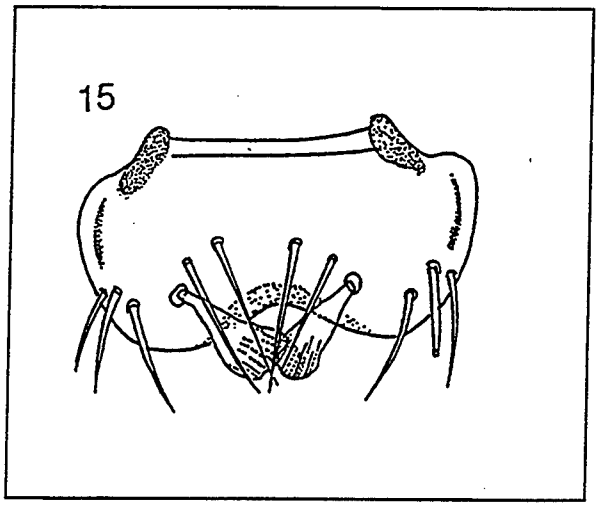

Figure 15. *Strepsinoma repititalis*: labrum

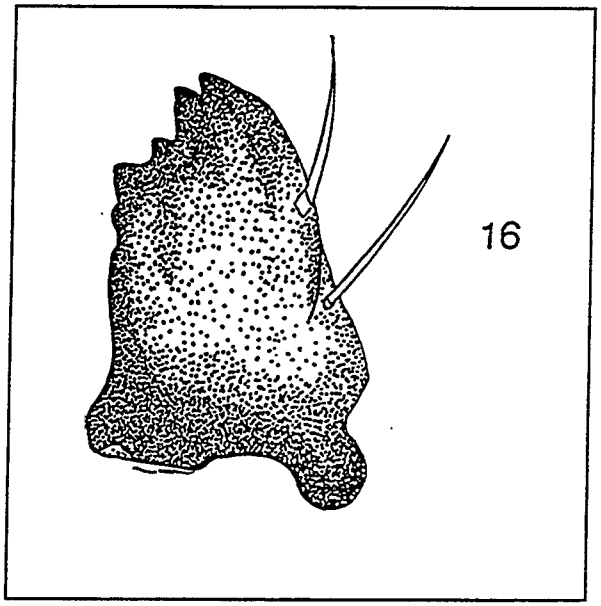

Figure 16. *Strepsinoma repititalis*: mandible

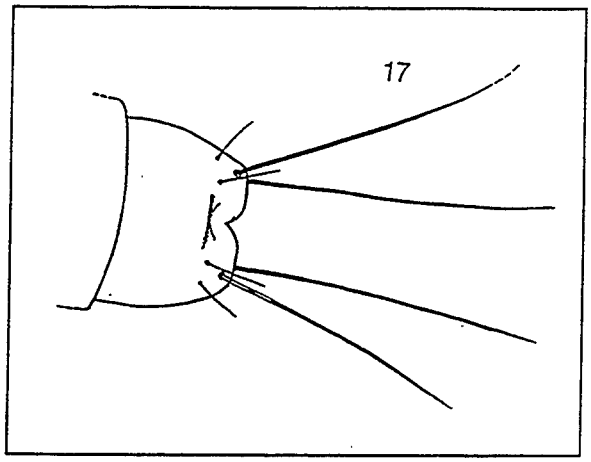

Figure 17. *Strepsinoma repititalis*: anal plate

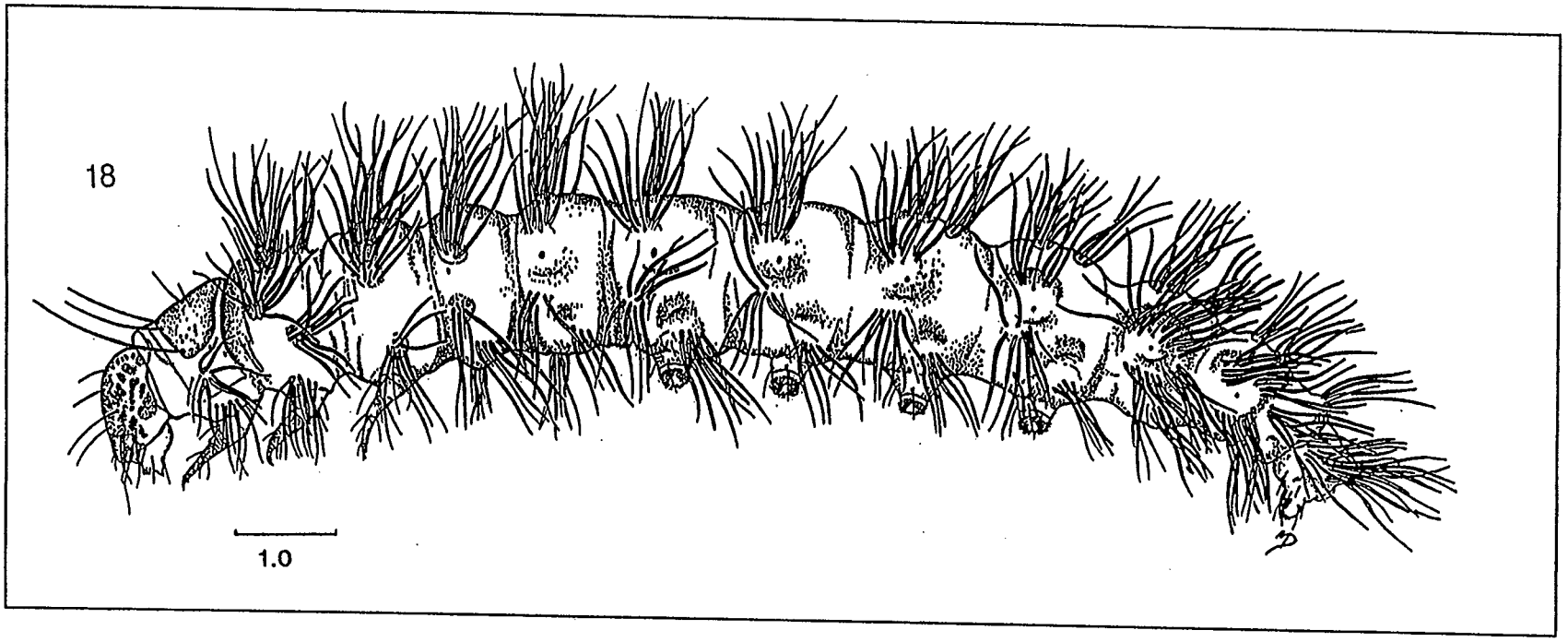

Figure 18. *Nymphula eromenalis*: mature larva, lateral view

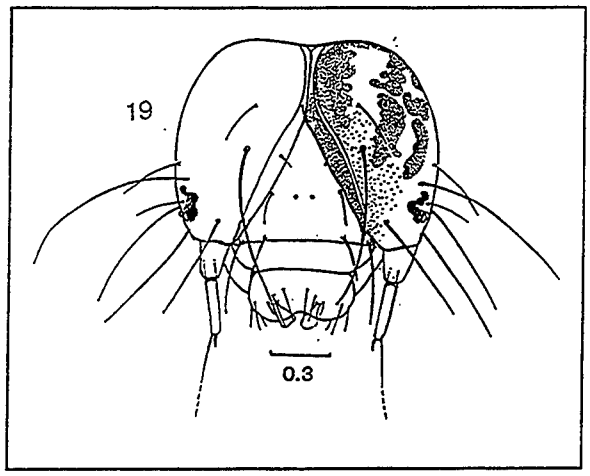

Figure 19. *Nymphula eromenalis*: head

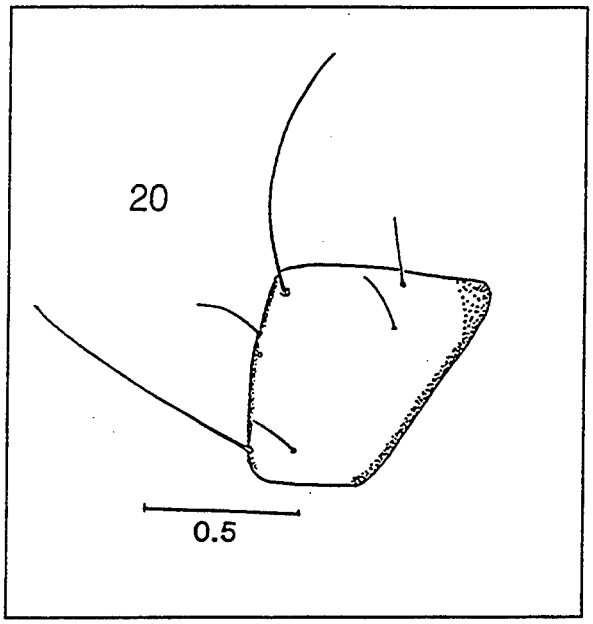

Figure 20. *Nymphula eromenalis*: prothoracic shield

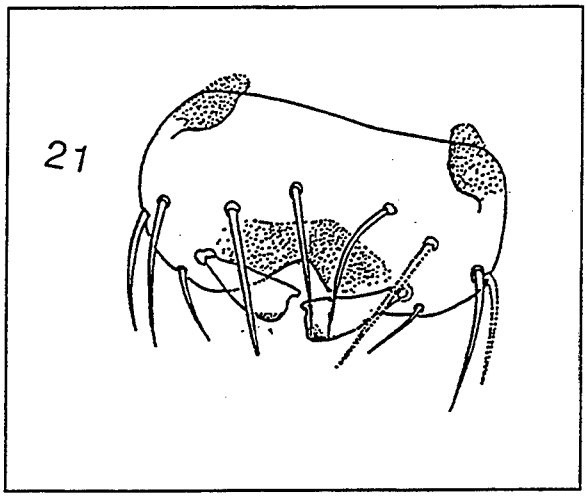

Figure 21. *Nymphula eromenalis*: labrum

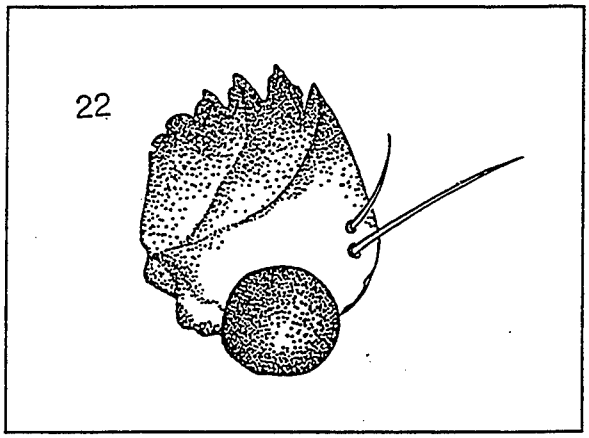

Figure 22. *Nymphula eromenalis*: mandible

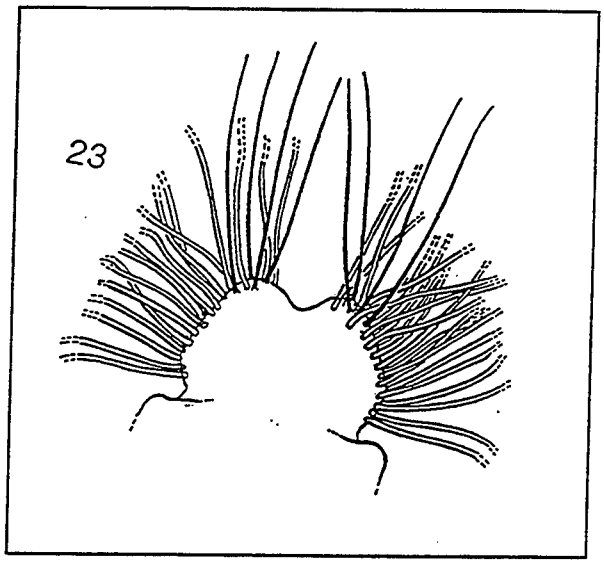

Figure 23. *Nymphula eromenalis*: anal plate

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Biological studies and initial host-range tests of four species of aquatic caterpillars that feed on *Hydrilla verticillata* were conducted in Australia. One of these species, *Parapoynx diminutalis*, has accidentally been introduced into the United States and occurs in lakes and ponds or in backwaters along rivers. The other three species, *Aulacodes siennata, Nymphula eromenalis,* and *Strepsinoma repititalis*, apparently are restricted to permanent streams and have never been found in the United States.

Studies documented a fairly wide host range for *A. siennata*, which ordinarily would preclude this species from consideration as a biocontrol agent; however, in many ways, it is similar to the biocontrol agent *Bagous hydrillae*, which is currently being used as a biocontrol agent of Hydrilla. *Nymphula eromenalis* also has a fairly wide host range, but it is the more restrictive of the two species. If additional exploration does not provide other more specific agents, these two moths should be considered for further testing as potential biocontrol agents of Hydrilla.

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