

ANTENNAL CUTICULAR SENSILLA IN SOME MAYFLIES (EPHEMEROPTERA)

ELDA GAINO¹ AND MANUELA REBORA²

¹Istituto di Zoologia dell'Università di Perugia, Via Elce di Sotto, 06123 Perugia, Italy

²Istituto di Zoologia dell'Università di Genova, Via Balbi 5, 16126 Genova, Italy

A survey at ultrastructural level on the antennal sensilla of several mayfly species is presented. The species here considered belong to Leptophlebiidae (*Choroterpes picteti*, *Habroleptoides confusa*, *Habrophlebia eldae*), Heptageniidae (*Ecdyonurus venosus*, *E. helveticus*, *Electrogena grandiae*, *Epeorus sylvicola*, *Rhithrogena loyolaea*), Baetidae (*Cloeon dipterum*), Caenidae (*Caenis luctuosa*), Siphonuridae (*Siphonurus lacustris*). Sensilla are categorized on the basis of their fine external morphology. Their diversification and relative position is illustrated in nymphs and adults. Nymphs show a vast variety of sensilla, mainly located on pedicel and flagellum. Adult antennae are strongly reduced and their morphology changes even from subimago to imago; sensilla are few and less diversified. The functional and taxonomic relevance of mayfly sensilla is discussed in consideration of the role performed by the sensory systems in insects.

INTRODUCTION

Numerous studies have been carried out on insect sensilla with particular attention to antennae (KEIL & STEINBRECHT, 1984; ALTNER & LOFTUS, 1985; MCLIVER, 1985; ZACHARUK, 1985; SOLINAS *et al.*, 1987; FAUCHEUX, 1990; KAPOOR, 1991; ROSS, 1992; OLSON & ANDOW, 1993; BOURGOIN & DEISS, 1994; CATALÀ & SCHOFIELD, 1994; PRAKASH *et al.*, 1995).

As far as Ephemeroptera are concerned, sensilla and related structures have been studied in the past (EASTHAM, 1936) and repeatedly taken into some consideration for taxonomic purposes (MÜLLER-LIEBENAU, 1969; PETERS & EDMUNDS, 1970; AGNEW, 1980; SARTORI & THOMAS, 1991; SOLDÁN & LANDA, 1991). Nevertheless, investigation on their fine architecture is limited to the description of mechanoreceptors in the pedicel of a few species (SCHMIDT, 1974). A recent scanning electron microscopy study concerns the antennal sensilla in the ephemerellid *Vietnamella dabieshanensis* (SU & CAI, 1994). We have considered the main kind of mayfly antennal sensilla on the basis of their fine external morphology. Our interest has been focused mostly on aquatic stages, since, in comparison with adults, nymphs show a greater variety of their receptors.

MATERIALS AND METHODS

Representatives of Leptophlebiidae (*Choroterpes picteti*, *Habroleptoides confusa*, *Habrophlebia eldae*), Hepta-

geniidae (*Ecdyonurus venosus*, *E. helveticus*, *Electrogena grandiae*, *Epeorus sylvicola*, *Rhithrogena loyolaea*), Baetidae (*Cloeon dipterum*), Caenidae (*Caenis luctuosa*), Siphonuridae (*Siphonurus lacustris*) were considered in this study. Antennae were essentially examined under interference phase contrast and scanning electron microscopes (SEM). Selected material was dissected from anesthetized specimens collected in the Scrivia river (Casella, Liguria), Verde stream (Isoverde, Liguria), Berlino stream (Rossiglione, Liguria), Erro stream (Arzello, Piemonte). Samples were fixed in KARNOVSKY'S medium (1965) for 1 hour and rinsed in cacodylate buffer.

For SEM analysis antennae were critical point dried using a CO₂ Pabisch CPD 750 apparatus, mounted on stubs with silver conducting paint and coated with gold palladium in a Balzers Union evaporator. Specimens were observed with a Philips EM 515 scanning electron microscope.

A preliminary investigation with transmission electron microscope (TEM) was carried out on the antennae of *Ch. picteti*, after having postfixed them for 1 hour in osmium tetroxide, rinsed in cacodylate buffer, dehydrated in graded ethanol series and finally embedded in Epon-Araldite mixture resin. Thin sections, obtained with a Reichert ultratome, were collected on formvar-coated copper grids, stained with uranyl acetate and lead citrate, and observed with a Philips EM 400 electron microscope. The basic descriptive terminology used by ZACHARUK (1985) is followed in the present paper.

RESULTS

This study illustrates sensilla diversification in shape and arrangement on the antennae, also in consideration that a drastic modification of the antennae occurs at the emergence from water.

Leptophlebiidae

The flagellum of nymphs of *Choroterpes picteti*, *Habroleptoides confusa*, *Habrophlebia*

eldae shows sensilla trichodea (Figs 1-4). They emerge isolated and in groups of three elements as well; in both cases they jut out from a discrete socket (Figs 1-3). In spite of the species belonging to different genera, a uniform pattern in morphology and distribution of antennal sensilla is evident.

Longitudinal sections of the sensilla of *Ch. picteti* examined under TEM reveal the association of a tubular body (Fig. 4) with the dendrites extending along the lumen of the shaft (inset of Fig. 4).

Along the distal border of the pedicel of the nymph of this species, campaniform sensilla are present (Fig. 5). At SEM level (Fig. 5) they appear as simple depression of the cuticle (Fig. 6).

In the subimaginal stage of *Habrophlebia eldae*, scape and pedicel are uniformly covered by microtrichia (Fig. 7). The unsegmented flagellum is decorated with densely packed ribs (Fig. 8).

Heptageniidae

In the nymphs of *Rhithrogena loyolaea* and *Epeorus sylvicola* flat-tipped sensilla occur (Figs 9-12). They are located on the distal portion of the flagellar segments together with sensilla basiconica (Figs 11, 12). Most of the flat-tipped sensilla protrude beyond the border of the segment but they only occasionally touch the surface of the next segment. Their apical portion has an arrowhead shape and bears a pore (Fig. 10). In *Epeorus sylvicola* a groove extends from the base to the top of each sensillum (Fig. 12).

The nymphs of *Ecdyonurus helveticus* have different kinds of sensilla present along the distal portion of each flagellar segment (Figs 13-15). Together with sensilla basiconica, other coeloconic-like sensilla are present (Figs 14, 15). Both are completely included in their socket but show a different morphology: one type is round-shaped (Fig. 14) and the other is slightly elongated with a pore located in its upper region (Fig. 15).

The subimago of *Electrogena grandiae* has its pedicel uniformly covered by microtrichia, while the flagellum shows a ribbed decoration (Fig. 16). Sensilla coeloconica are interspersed among ribs (Fig. 17) and emerge isolated or in

pairs. Sometimes a pore at their apex is evident (inset of Fig. 17). At the imaginal stage, microtrichia, which cover the scape and pedicel of the subimago, disappear and are replaced by scales (Fig. 18). The initial part of the flagellum is covered by fan-like cuticular projections that gently enlarge giving rise to irregular folds towards the distal portion of the flagellum. Sensilla coeloconica are scattered among folds along the ventral side of the flagellum (Fig. 19).

Baetidae

The nymphs of *Cloeon dipterum* have sensilla trichodea on the flagellum (Fig. 20). In the imago, scape and pedicel are covered by scales; the flagellum has a folded appearance and shows sensilla coeloconica among folds (Fig. 21).

Siphonuridae

The nymphs of *Siphonurus lacustris* have sensilla placodea included in a wide socket and mainly located along the lateral surfaces of the flagellum (Fig. 22). In these nymphs sensilla chaetica with a slight groove in the middle occur. They are located along the distal border of the pedicel (Fig. 23).

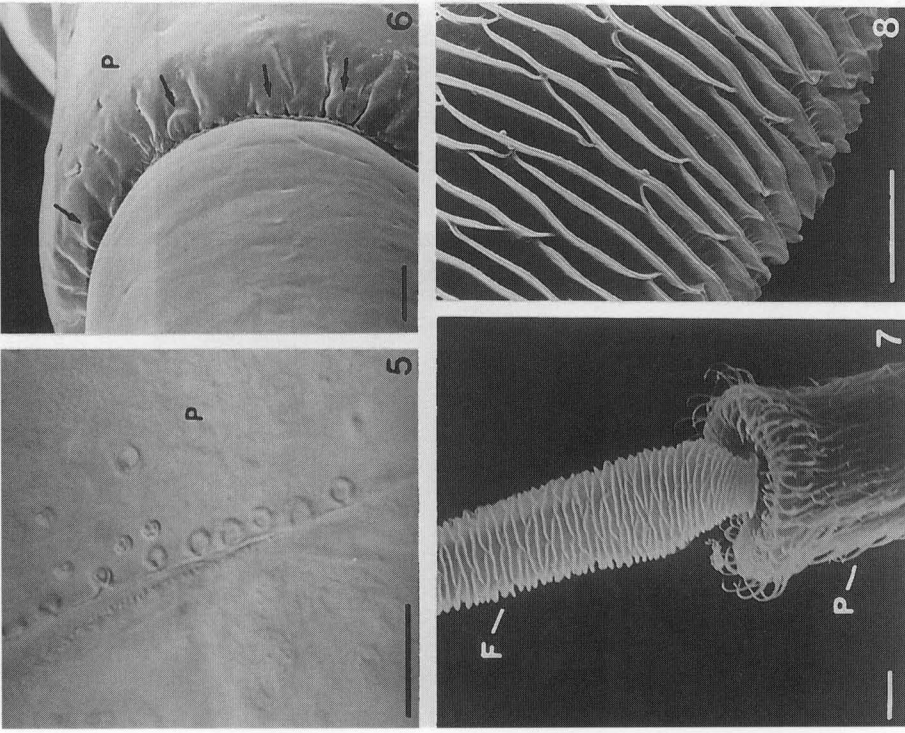
Ephemerellidae

Sensilla trichodea emerge in groups in the antennae of the nymphs of *Torleya major* (Fig. 24). The subimago exhibits the cuticular ribs (Fig. 25).

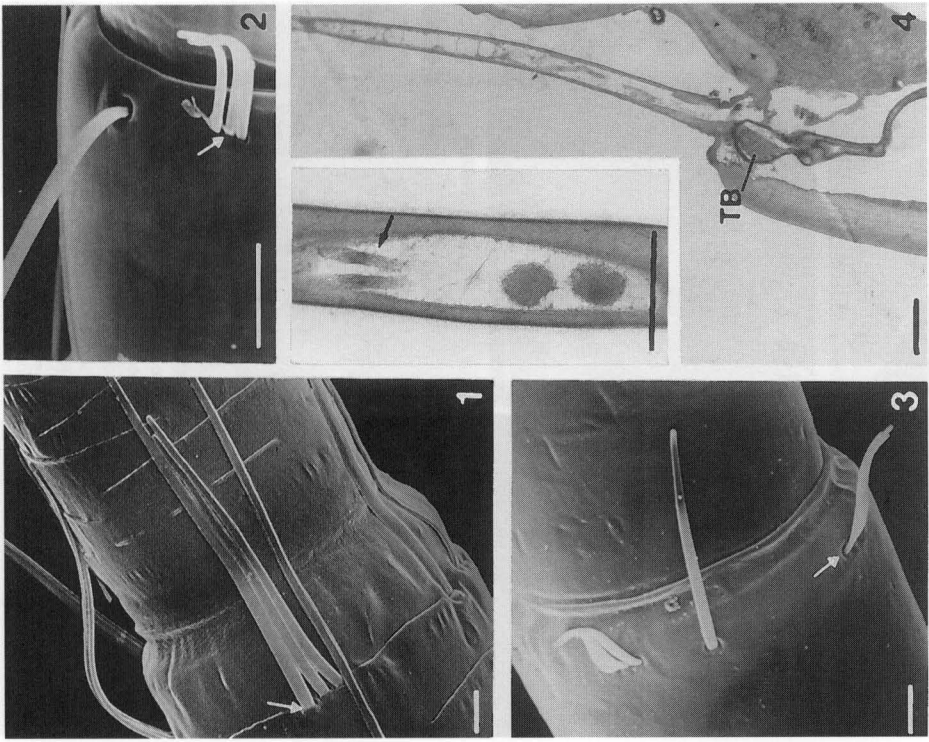
In the imago of *Ephemerella ignita*, the pedicel is covered by scales compressing towards the flagellum (Fig. 26). Sensilla trichodea are present among the scales (Fig. 27).

Caenidae

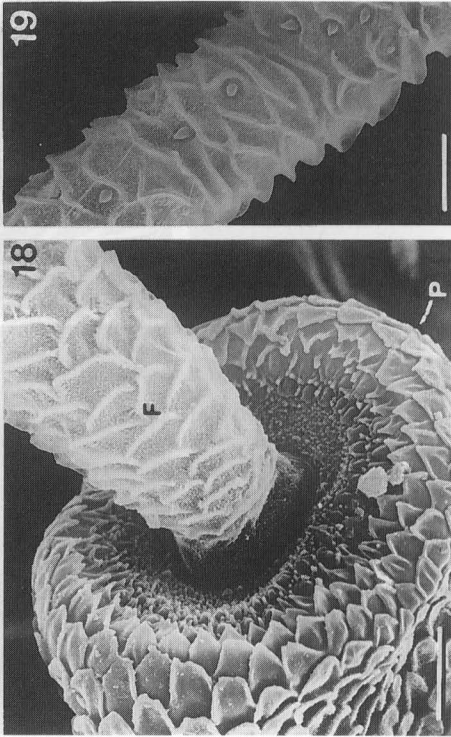
In the imago of *Caenis luctuosa*, scape and pedicel apparently lack sensilla. The pedicel has a wrinkled surface (Fig. 28) and shows a smooth cuticular ring in its apical region (Fig. 29). The flagellum shows a honeycomb-like cuticle (Fig. 29). Pits with emerging coeloconic sensilla are present along the ventral side of the flagellum (Fig. 30). The terminal region of the antenna has a tapered and pleated cuticle (Fig. 31).



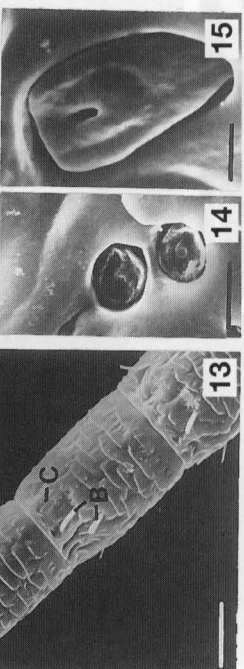
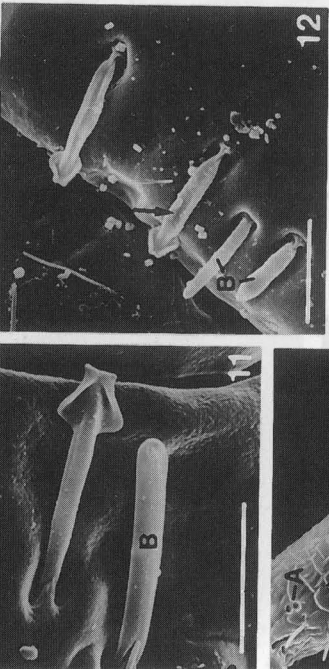
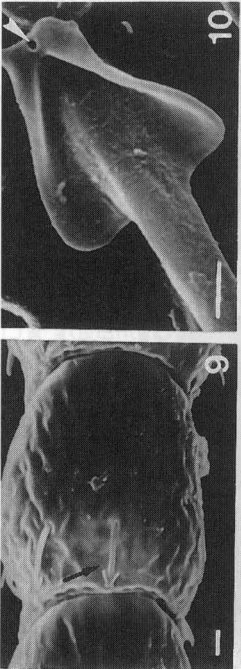
Figs 5-8. Sensilla of the nymph of *Choroterpes picteti* (5, 6) and of the subimago of *Habrophlebia eldae* (7, 8). 5: sensilla campaniformia on the distal part of the pedicel (P), under interference phase contrast microscope. Bar = 10 μ m; 6: pedicel (P) showing the ring of sensilla campaniformia (arrows), Bar = 10 μ m; 7: pedicel (P) with microtrichia and flagellum (F) with ribs, Bar = 10 μ m; 8: ribs of the flagellum. Bar = 5 μ m.



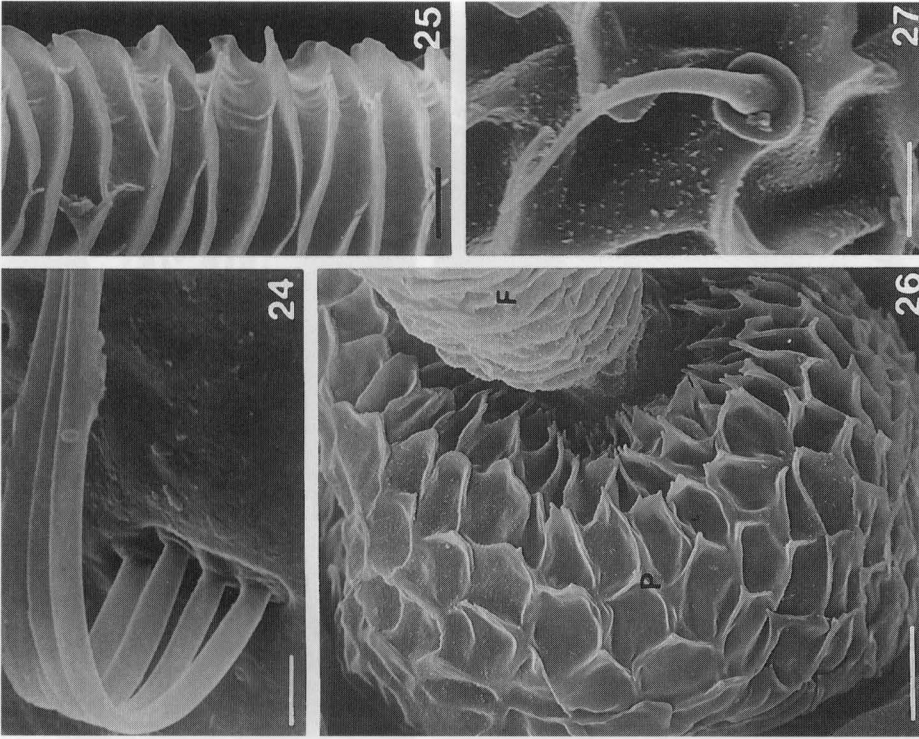
Figs 1-4. Sensilla trichodea emerging from their sockets (arrows) on the flagellum of the nymphs of *Habrophlebia eldae* (1). Bar = 1 μ m; *Habroleptoiles confusa* (2). Bar = 10 μ m; *Choroterpes picteti* (3). Bar = 2 μ m; 4, longitudinal section of a sensillum trichodeum in *C. picteti* showing the tubular body (TB). Note the two dendrites (arrow) in the inset. Bars = 1 μ m.



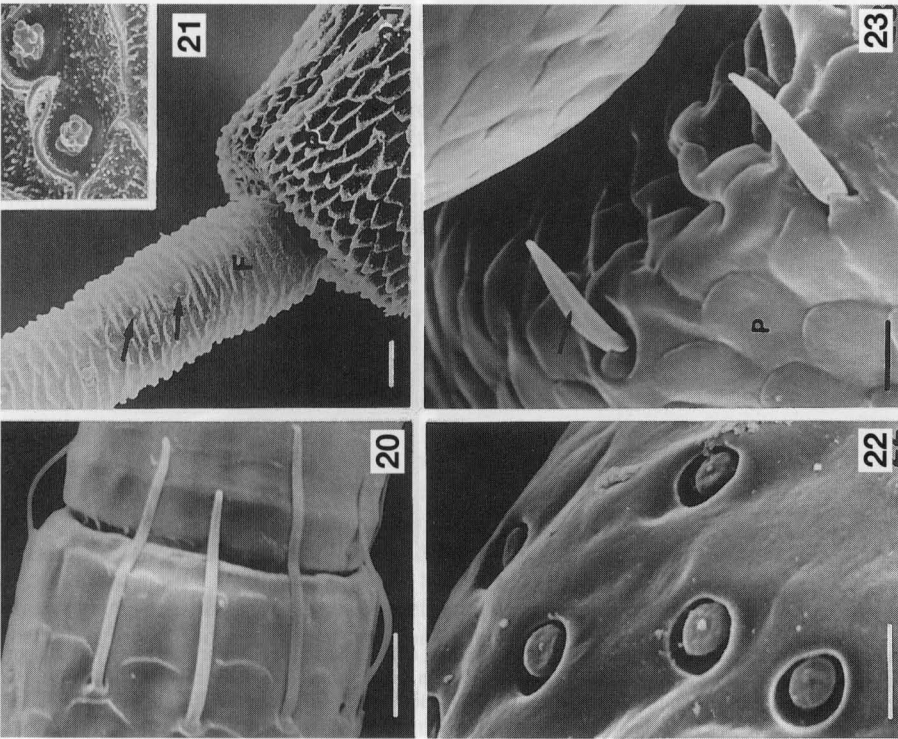
Figs 16-19. Antenna of the subimago (16, 17) and of the imago (18, 19) of *Electrogenia grandia*: 16: pedicel (P) covered by microtrichia and flagellum (F) uniformly ribbed. Bar = 10 μ m; 17: sensilla coeloconica (arrows) on the ventral side of the flagellum. Bar = 5 μ m. Magnification of one of them in the inset. Note the apical pore (arrowhead). Bar = 1.5 μ m; 18: pedicel (P) with scales and flagellum (F) ribbed. Bar = 10 μ m; 19: sensilla coeloconica among folds of the flagellum. Bar = 10 μ m.



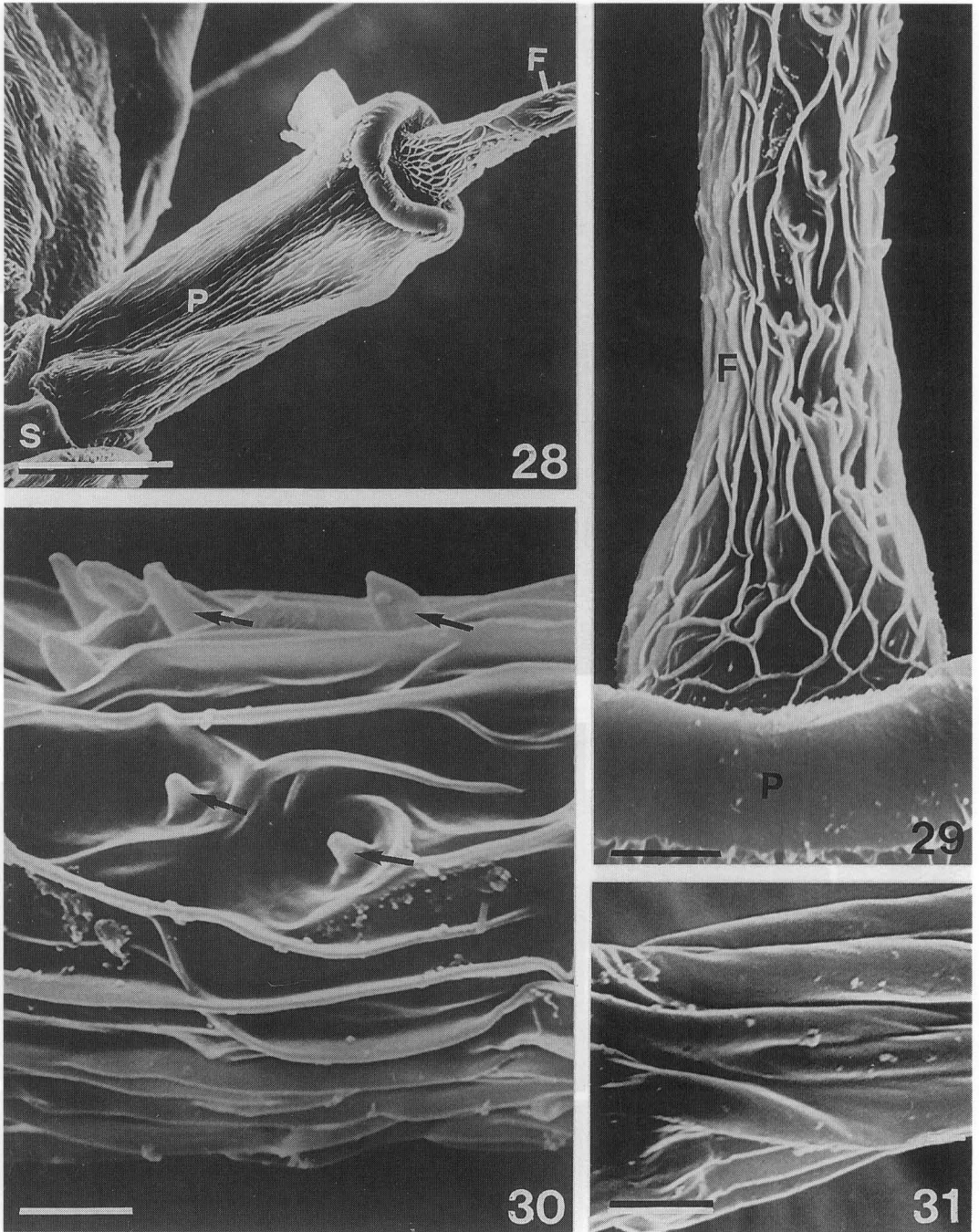
Figs 9-15. Antennal sensilla on the flagellar segments of the nymph of *Rhiithrogena loyola* (9-11), *Epeorus sylvicola* (12), *Echyonurus helveticus* (13-15). 9: flat-tipped sensillum (arrow). Bar = 10 μ m; 10: apical pore (arrowhead) of a flat-tipped sensillum. Bar = 1 μ m; 11: a flat-tipped sensillum with a sensillum basiconicum (B). Bar = 10 μ m; 12: flat-tipped sensillum with a groove in their middle (arrow) and sensilla basiconica (B). Bar = 10 μ m; 13: two kinds of coeloconic-like sensilla (A, C) on the distal portion of each antennal segment associated with sensilla basiconica (B). Bar = 20 μ m; 14: enlarged view of porous sensilla (A in Fig. 13). Bar = 2.5 μ m; 15: enlarged view of porous sensilla (C in Fig. 13). Bar = 1 μ m.



Figs 24-27. Antenna of the nymph (24) and of the subimago of *Torleya major* (25) and of the imago of *Ephemerella ignita* (26, 27). 24: sensilla trichodea on the flagellum. Bar = 2.5 μm; 25: ribs on the flagellum. Bar = 5 μm; 26: pedicel (P) with scales compressing towards the flagellum (F). Bar = 10 μm; 27: a sensillum trichodeum on the pedicel. Bar = 2.5 μm.



Figs 20-23. Antenna of the nymph (20) and of the imago (21) of *Cloeon dipterum* and of the nymph of *Siphonurus lacustris* (22, 23). 20: sensilla trichodea on the flagellum. Bar = 10 μm; 21: pedicel (P) with scales and flagellum (F) with folds. Bar = 10 μm. Sensilla coelocnica (arrows) are magnified in the inset; 22: sensilla placodea on the flagellum. Bar = 5 μm; 23: sensilla chaetica on the distal portion of the pedicel (P). Note the slight groove (arrow) in their middle. Bar = 5 μm.



Figs 28-31. Antenna of the imago of *Caenis luctuosa*. 28: scape (S), pedicel (P) and flagellum (F). Bar = 50 µm; 29: distal portion of the pedicel (P) along its smooth cuticular ring and flagellum (F) with a honeycomb-like organization of the cuticle. Bar = 10 µm; 30: sensilla coeloconica (arrows) on the ventral side of the flagellum. Bar = 2,5 µm; 31: distal portion of the flagellum. Bar = 2,5 µm.

DISCUSSION

Larval stages and adults of mayflies live in different habitats and they require specialized sensillar devices adapted to work in both aquatic and air condition. Under SEM, mayfly sensilla show a wide range of diversification but, at present, it is difficult to establish a clear relationship between the morphology and the specific function they perform. Indeed, it is well known that sensory systems can be tested only by means of TEM investigation coupled with electrophysiological analysis (ZACHARUK, 1985).

In the present study, mayfly sensilla have been tentatively classified on the basis of their external morphology and included into the general categorization proposed for insects (SCHNEIDER, 1964; ZACHARUK, 1985). Since a mechano-chemosensitive function has been assessed only for the sensilla trichodea of *Choroterpes picteti*, the probable functions of the other sensilla can be suggested from analogy with receptors of known function described in other insect species. The morphological traits are consistent with the occurrence of sensilla trichodea (Leptophlebiidae, Heptageniidae, Baetidae, Ephemerellidae), campaniformia (Leptophlebiidae), coeloconica (Baetidae, Caenidae), basiconica (Heptageniidae), placodea and chaetica (Siphonuridae). Sensilla campaniformia are mechanoreceptors and they probably sense the movements of the flagellum over the pedicel (KAPOOR, 1991). Sensilla coeloconica and basiconica perform different functions and their internal organization is crucial for assessing a specific task. Sensilla placodea are reported to be chemosensory (ZACHARUK, 1985). The occurrence of an apical pore in the peculiar flat-tipped sensilla found in *Rhithrogena loyolaea* and *Epeorus sylvicola* might be consistent with a gustatory function (GAINO & REBORA, 1996).

Compared with adults, mayfly nymphs show more numerous types of sensilla. This feature is in agreement with previous investigations carried out by KAPOOR (1985) on the stonefly *Paragnetina media*. In this species the absence of nymphal sensilla in the adults reflects a specialization of the sensory system for different environmental requests.

Mayfly nymphs are strictly aquatic and require diversified sensilla in order to acquire informa-

tion about environmental conditions. During the short and unfeeding adult phases, hygrosensitivity is of paramount importance to avoid dehydration. It seems acceptable to assume that the aporous sensilla coeloconica of the flagellum could be hygrosensory. This in view of the external morphological characteristics exhibited by this kind of receptors (ALTNER & LOFTUS, 1985).

As far as mating is concerned, sight seems to allow males to reach females (BRINCK, 1956); the presence of pheromones is hypothesized only in species with small eyes that mate at night (MCCAFFERTY & BLOODGOOD, 1989). We found no evidence of sexual dimorphism in antennal receptors, which are notoriously involved in intersexual communication (HARBACH & LARSEN, 1977; CUPERUS, 1985; FAUCHEUX, 1991; NEWMAN *et al.*, 1993; MELLOR & ANDERSON, 1995; JOURDAN *et al.*, 1995). This feature agrees with the predictions of the lack of reception of sex attractant in mayflies whose distinct and finite timing of emergence (BRITAIN, 1982) could favor mating and swarming.

Comparative studies on antennal sensilla have evidenced the taxonomic applications of such receptors (ROSS, 1992; WCISLO, 1995), sometimes utilized to resolve difficult questions (CATALÁ & SCHOFIELD, 1994). The occurrence of two very similar kinds of flat-tipped sensilla in *Rhithrogena* and *Epeorus* stresses the relationship between these genera considered to be adelphotaxa (TOMKA & ELPERS, 1991).

In conclusion, SEM analysis of the antennal sensilla highlighted the morphological variety of these sensory systems in mayflies. This diversification, other than reflecting the taxonomic position of the species, represents a starting point for further investigations in such a field. This in order to ascertain the relationship between these insects and their environment together with the possible intra- and inter-specific communication.

ACKNOWLEDGMENTS

Many thanks to Drs. J. and P. Flanagan for their criticism during the preparation of the manuscript. We also thank G. Vigo and Dr. G. Magnino for their help in the laying out the plates, and F. Di Lauro for his technical assistance.

Research financially supported by Italian Ministry of University and Research in Science and Technology (M.U.R.S.T. 40% and 60% funds).

REFERENCES

- AGNEW, J.D. 1980. Ultrastructural studies on Oligoneuridae - taxonomic applications. *In*: FLANNAGAN, J.F. & MARSHALL, K.E. (Eds) *Advances in Ephemeropteran Biology*. pp. 353-366, Plenum Press, New York and London.
- ALTNER, H. & LOFTUS, R. 1985. Ultrastructure and function of insect thermo- and hygroreceptors. *Ann. Rev. Entomol.* 30: 273-295.
- BOURGOIN, T. & DEISS, V. 1994. Sensory plate organs of the antenna in the Meenoplidae-Kinnaridae group (Hemiptera: Fulgoromorpha). *Int. J. Insect Morphol. & Embryol.* 23(2): 159-168.
- BRINCK, P. 1956. Reproductive system and mating in Ephemeroptera. *Opusc. Ent.* 22(1): 1-37.
- BRITAIN, J.E. 1982. Biology of mayflies. *Ann. Rev. Entomol.* 27: 119-147.
- CATALÁ, S. & SCHOFIELD, C. 1994. Antennal sensilla of *Rhodnius*. *J. Morphol.* 219: 193-203.
- CUPERUS, P.L. 1985. Ultrastructure of antennal sense organs of small ermine moths, *Yponomeuta* spp. (Lepidoptera: Yponomeutidae). *Int. J. Insect Morphol. & Embryol.* 14(3): 179-191.
- EASTHAM, L.E.S. 1936. The sensillae and related structures on the gills of nymphs of the genus *Caenis* (Ephemeroptera). *Trans. R. Ent. Soc. London.* 85: 401-414.
- FAUCHEUX, M.J. 1990. Antennal sensilla in adult *Agathiphaga vitiensis* DUMBL. and *A. queenslandensis* DUMBL. (Lepidoptera: Agathiphagidae). *Int. J. Insect Morphol. & Embryol.* 19(5/6): 257-268.
- FAUCHEUX, M.J. 1991. Morphology and distribution of sensilla on the cephalic appendages, tarsi and ovipositor of the european sunflower moth, *Homoeosoma nebulella* DEN. & SCHIFF. (Lepidoptera: Pyralidae). *Int. J. Insect Morphol. & Embryol.* 20(6): 291-307.
- GAINO, E. & REBORA, M. 1996. Fine structure of flat-tipped antennal sensilla in three species of mayflies (Ephemeroptera). *Invert. Biol.* 115(2): 145-149.
- HARBACH, R.E. & LARSEN, J.R. 1977. Fine structure of antennal sensilla of the adult mealworm beetle, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae). *Int. J. Insect Morphol. & Embryol.* 6(1): 41-60.
- JOURDAN, H., BARBIER, R., BERNARD, J. & FERRAN, A. 1995. Antennal sensilla and sexual dimorphism of the adult ladybird beetle *Semiadalia undecimnotata* SCHN. (Coleoptera: Coccinellidae). *Int. J. Insect Morphol. & Embryol.* 24(3): 307-322.
- KAPOOR, N.N. 1985. External morphology and distribution of the antennal sensilla of the stonefly, *Paragnetina media* (WALKER) (Plecoptera: Perlidae). *Int. J. Insect Morphol. & Embryol.* 14(5): 273-280.
- KAPOOR, N.N. 1991. Antennal campaniform and coeloconic sensilla of the stonefly nymph, *Paragnetina media* (WALKER) (Plecoptera: Perlidae). *In*: ALBA-TERCEDOR, J. & SANCHEZ-ORTEGA, A. (Eds) *Overview and strategies of Ephemeroptera and Plecoptera*. pp. 39-46, Sandhill Crane Press, Florida.
- KARNOVSKY, M.S. 1965. A formaldehyde-glutaraldehyde fixative of high osmolality for use in electron microscopy. *J. Cell Biol.* 27: 137-138.
- KEIL, T.A. & STEINBRECHT, R.A. 1984. Mechanosensitive and olfactory sensilla of insects. *In*: KING, R.C. & AKAI, H. (Eds) *Insect Ultrastructure (Vol. II)*. pp. 477-516, Plenum Press, New York and London.
- MCCAFFERTY, W.P. & BLOODGOOD, D.W. 1989. The female and male coupling apparatus in *Tortopus* mayflies. *Aquat. Insects.* 2(3): 141-146.
- MCIVER, S. 1985. Mechanoreception. *In*: KERKUT, G.A. & GILBERT, G.L. (Eds) *Comprehensive insect physiology, biochemistry and pharmacology*, vol. VII. Nervous system: Sensory. pp. 71-131, Pergamon Press, New York.
- MELLOR, H.E. & ANDERSON, M. 1995. Antennal sensilla of whiteflies: *Trialeurodes vaporariorum* (WESTWOOD), the glasshouse whitefly, *Aleyrodes proletella* (LINNAEUS), the cabbage whitefly, and *Bemisia tabaci* (GENNADIUS), the tobacco whitefly (Homoptera: Aleyrodidae). Part 1. external morphology. *Int. J. Insect Morphol. & Embryol.* 24(2): 133-143.
- MÜLLER-LIEBENAU, I. 1969. Revision der europäischen Arten der Gattung *Baetis* LEACH, 1815 (Insecta, Ephemeroptera). *Gewäss. Abwäss.* 48/49: 1-214.
- NEWMAN, S.M., McDONALD, I.C. & TRIEBOLD B. 1993. Antennal sexual dimorphism in *Diabrotica virgifera virgifera* (LE CONTE) (Coleoptera: Chrysomelidae): male specific structures, ultrastructure of a unique sensillum, and sites of esterase activity. *Int. J. Insect Morphol. & Embryol.* 22(5): 535-547.
- OLSON, D.M. & ANDOW, D.A. 1993. Antennal sensilla of female *Trichogramma nubilale* (ERTLE & DAVIS) (Hymenoptera: Trichogrammatidae) and comparisons with other parasitic Hymenoptera. *Int. J. Insect Morphol. & Embryol.* 22(5): 507-520.
- PETERS, W.L. & EDMUNDS, G.J. 1970. Revision of the generic classification of the Eastern Hemisphere Leptophlebiidae (Ephemeroptera). *Pac. Insects* 12(1): 157-240.
- PRAKASH, S., MENDKI, M.J., RAO, K.M., SINGH, K. & SINGH, R.N. 1994. Sensilla on the maxillary and labial palps of the cockroach *Supella longipalpa* FABRICIUS (Dictyoptera: Blattellidae). *Int. J. Insect Morphol. & Embryol.* 24(1): 13-34.
- ROSS, K. 1992. Comparative study of the antennal sensilla of five species of root maggots: *Delia radicum* L., *D. floralis* F., *D. antiqua* MG., *D. platura* MG. (Diptera: Anthomyiidae) and *Psila rosae* F. (Diptera: Psilidae). *Int. J. Insect Morphol. & Embryol.* 21(2): 175-197.
- SARTORI, M. & THOMAS, A.G.B. 1991. Contribution to the systematics of *Baetis muticus* (L.) and allied species from south western palearctic region (Ephemeroptera: Baetidae). *In*: ALBA-TERCEDOR, J. & SANCHEZ-ORTEGA, A. (Eds) *Overview and strategies of Ephemeroptera and Plecoptera*. pp. 223-233, Sandhill Crane Press, Florida.
- SCHMIDT, K. 1974. Die Mechanorezeptoren im Pedicellus der Eintagsfliegen (Insecta: Ephemeroptera). *Z. Morph. Tiere.* 78: 193-220.
- SCHNEIDER, D. 1964. Insect antennae. *Ann. Rev. Entomol.* 9: 103-122.
- SOLDÁN, T. & LANDA, V. 1991. Two new species of Caenidae (Ephemeroptera) from Sri Lanka. *In*: ALBA-

- TERCEDOR, J. & SANCHEZ-ORTEGA, A. (Eds) Overview and strategies of Ephemeroptera and Plecoptera. pp. 235-243, Sandhill Crane Press, Florida.
- SOLINAS, M., NUZZACI, G. & ISIDORO, N. 1987. Antennal sensory structures and their ecological behavioural meaning in Cecidomyiidae (Diptera) larvae. *Entomologica (Bari)*. 22: 165-184.
- SU, C.-R. & CAI, Z.-L. 1994. Scanning electron microscopy of antennal sensilla of the *Vietamella dabiesshanensis* (Ephemeroptera: Ephemerellidae). *Acta Entomol. Sin.* 37: 382-384.
- TOMKA, I. & ELPERS, C. 1991. Problems in the phylogeny of the Ephemeroptera. *In*: ALBA-TERCEDOR, J. & SANCHEZ-ORTEGA, A. (Eds) Overview and strategies of Ephemeroptera and Plecoptera. pp. 115-134, Sandhill Crane Press, Florida.
- WCISLO, W.T. 1995. Sensilla numbers and antennal morphology of parasitic and non-parasitic bees (Hymenoptera: Apoidea). *Int. J. Insect Morphol. & Embryol.* 24(1): 63-81.
- ZACHARUK, R.Y. 1985. Antennae and sensilla. *In*: KERKUT, G.A. & GILBERT, G.L. (Eds) Comprehensive insect physiology, biochemistry and pharmacology, vol. VII. Nervous system: Sensory. pp. 1-69, Pergamon Press, New York.