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An Atlas of Collembola Species in the Sapporo Experimental Forest of Hokkaido University in Northern Japan

SUETSUGU Naoki[1], SATOH Fuyuki[2] and KOIKE Takayoshi[1]*

[1] Silviculture & Forest Ecological Studies, Hokkaido University, Sapporo 060-8589, Japan
[2] Hokkaido University Forests, Sapporo 060-0809, Japan

Abstract

Collembola (Hexapoda: Collembola) is one of the most common soil animals in forests. Collembolans play an essential role in soil ecosystems, but their community structure and ecological role in forests are not fully understood because of difficulties with their classification. We have consequently developed an atlas of Collembolans in certain forest stands within the Sapporo Experimental Forest. The community structure of Collembolans varied greatly in each forest stand. The Isotomidae family was predominant in a mature larch stand and in young broad-leaved mixed stands, but in a spruce plantation the dominant family was Onychiuridae. The most abundant genera in the Isotomidae family also varied with the type of forest stand: *Folsomia* was found in larch and spruce stands, and *Desoria* and *Pteronychella* in young broad-leaved mixed stands. We observed 13 species of Collembola in our study sites.

Key words: soil meso-funa, atlas, Collembola, larch, spruce

Introduction

The taxonomy of soil faunae is still incomplete, and this limitation may hinder progress in studies of soil ecosystems (Kaneko and Ito 2004). Collembola (Hexapoda: Collembola) usually dominate in the forests soil of Hokkaido, northern Japan; these forests are situated partly in cool-temperate and partly in sub-frigid zones (Tatewaki 1958). Collembolans are soil micro- arthropods with body size ranging from 0.2 mm to 5 mm. Their population density in forest soil is estimated to be 10,000 m^{-2} and on occasion up to 100,000 m^{-2} (Kaneko 2007). They play an essential role in the decomposition of organic matter, including the regulation of nutrient cycling through the feeding of microorganisms (Kaneda and Kaneko 2008).

At present, 14 families, 106 genera and 376 species of Collembola are known in Japan (Workshop on Collembola, 2000), but species are still being found and others disappear each year (e.g. Nakamori *et al*. 2009, Tanaka 2010). Unfortunately, we do not possess comprehensive classification information. Even though Hokkaido is one of the most advanced regions for Collembola study in Japan (Uchida and Tamura 1967, 1968, Uchida and Suma 1973, Suma 1993), the notes available relate only to a limited area and a few collembolan spices of Hokkaido. More information on Collembola throughout Hokkaido is needed.

As a contribution to the classification and taxonomy of collembolans in Hokkaido, we studied the collembolan community and compiled an atlas of Collembola in different stand types in forests within the Sapporo Experimental Forest of Hokkaido University.

Materials and Methods

Site description

The study site is located in the experimental nursery which is part of the Sapporo Experimental Forest of Hokkaido University in northern Japan (43°04′N; 141°20′E, 150m a.s.l.).

There are three types of forest stand: spruce (*Picea glehnii*) plantation (460 m^2, about 30 years old), larch (*Larix kaempferi*) plantation (126 m^2, about 50 years old), and young, 6-year-old broad-leaved mixed stands (18.8 m^2, tree species: ash, birches, basswood, elm, kalopanax, maple and oak) (Eguchi *et al*. 2008) (Table 1). In the broad-leaved mixed stands there were two CO_2 treatments: one is control (ambient CO_2) and the other has elevated CO_2 (500 ppm) via a FACE (Free Air CO_2 Enrichment) system (Eguchi *et al*. 2008). The organic layer was about 1-5 cm deep in each stand.

Soil sampling and Collembola extraction

We sampled soil cores (100 cc, 5 cm depth and cross-sectional area 20 cm^2), including the organic layer, from each stand, in July 2009 (spruce and larch stands) and August and September (mixed stands) 2009. The samples collected were brought immediately to the laboratory, and soil animals in the samples were extracted using Tullgren funnels (40 W, mesh size 1.5 mm) for 72h.

After this extraction, all collembolans were collected under a stereo-microscope (SZX9, OLYMPUS, Japan) and a slide was prepared. The collembolans were classified using an optical microscope (OLYMPUS, Japan). Classification was made according to the criteria of Aoki (1999) at gene level, and species were checked by referring to the Workshop on Collembola (2000).

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* Corresponding author: tkoike@for.agr.hokudai.ac.jp

Results

Table 2 shows the density of individuals of collembolan by family. Of the 14 families of collembolan recorded in Japan, we found 9 families of collembolan. The greatest density of collembolans was in the larch stand, followed by the spruce stand; it was least in the young broad-leaved tree stands, especially in the elevated CO_2 plot.

The most abundant family in the larch stand was Isotomidae (84%), and in spruce was Onychiuridae (67%). Although Isotomidae were also dominant in the young broad-leaved tree stands, the dominant genera were different. *Folsomia* was dominant in the larch and spruce stand, but was not found in the young broad-leaved tree stands. We found two species belonging to the genus *Folsomia*: *F. regularis* Hammer, 1953 and *F. diplophthalma* (Axelson, 1902). The genus *Desoria* and the genus *Pteronychella* were dominant in the young broad-leaved tree stands. The young broad-leaved mixed stands have higher percentage of families which jump actively, such as Tomoceridae, Entomobryidae, and Sminthuridae, than at the other sites.

Photographs have been published of 13 species that were common at our study site: *Schaeffer emucronata decemoculata* Stach, 1939, *Tullbergia yosii* Rusek, 1967, *Onychiurus* (*Protaphorura*) *longisensillatus nutak* Yosii, 1972, *Friesea japonica* Yosii, 1954, *Folsomia diplophthalma* (Axelson, 1902), *Folsomia regularis* Hammer, 1953, *Folsomides parvulus* Stach, 1922, *Isotomiella minor* (Schäffer, 1896), *Pteronychella spatiosa* Uchida et Tamura, 1968, *Desoria dichaeta* (Yosii, 1969), *Tomocerus* (*Tomocerus*) *ocreatus* Denis, 1948, *Sinella* (*Coecobrya*) *dubiosa* Yosii, 1956, *Lepidocyrtus cyaneus* Tullberg, 1871. Some species that we collected look different from these notes. Here, we defined such species by similar species noted in the Workshop on Collembola (2000).

Table 1. Site description

Stand	Age	Density	Species
Picea forest	30	4300 / ha	*Picea glehnii*
Larix forest	50	1200 / ha	*Larix leptolepis*
Young cool-temperate forest (Ambient CO_2)	6		*Betula platyphylla, Quercus crispula Fraxinus mandshurica, Ulmus davidiana*
Young cool-temperate forest (Elevated CO_2)	6		*Kalopanax pictus, Fagus crenata Tilia japonica, Acer mono*

Table 2. Mean number (Upper) and ratio (Below) of collembolan family per units (/m2; n=10-30)

Family	Stand Picea forest	Larix forest	Young cool-temperate forest Ambient CO_2	Young cool-temperate forest Elevated CO_2	Representation spicies
Onychiuridae	6250 (67)	4800 (14.5)	1400 (11.5)	800 (14)	*Tullbergia yosii* *Onychiurus (Protaphorura) longisensillatus nutak* *Onychiurus (Allonychiurus) conjungens*
Pseudachorutidae Hypogastrura	400 (4.5)	150 (0.5)	250 (2)	450 (8)	*Friesea (Friesea) japonica* *Schaefferia emucronata decemoculata*
Neanuridae	50 (0.5)	0 (0)	0 (0)	50 (1)	*Vitronura rosea*
Isotomidae	1400 (15)	27200 (84)	9400 (77.5)	2300 (40.5)	*Folsomia diplophthalma* *Folsomia regularis* *Isotomiella minor* *Desoria dichaeta*
Tomoceridae	0 (0)	0 (0)	550 (4.5)	450 (8)	*Tomocerus (Tomocerus) ocreatus*
Entomobryidae	400 (4.5)	150 (0.5)	300 (2.5)	900 (16)	*Sinella dubiosa* *Entomobrya sp* *Lepidocyrtus cyaneus*
Neelidae	700 (7.5)	150 (0.5)	150 (1)	200 (3.5)	*Megalothorax minimus*
Sminthuridinae	100 (1)	0 (0)	150 (1)	500 (9)	*Sminthurinus sp* *Ptenothrix sp*
Total	6250 (67)	4800 (14.5)	1400 (11.5)	800 (14)	

Discussion

The densities of collembolans in the larch stand were all approximately 40,000 m^{-2}, similar to that reported in Hokkaido, northern Japan by Tamura (1967) and Kitazawa *et al*. (1985). However, the collembolan density in the spruce stand was only about 10,000 m^{-2}. Moreover, the dominant family differed from that in other forests. The low density and differing proportions we found in the spruce stand may be attributed to the effects of forest management, such as frequent pruning and significant disturbances with litter use (Suetsugu *et al*. 2010).

The densities of collembolans in the young broad-leaved stands were also lower, at 5,000–10,000 m^{-2}. This may be due to poor development of the organic layer, i.e. the FH layer, in which collembolans live (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected by the development of the soil organic layer, because these species usually live on or close to the soil surface, including the litter layer (Petersen 2002). As a result, surface families are abundant in the young broad-leaved stands.

Previous studies in Hokkaido suggest that the most dominant genus is *Folsomia*, belonging to the family of Isotomidae which lives in forests (Tamura 1967, Suma and Ohnishi 2009). Since the morphology of *Folsomia* is adapted for living in deeper soil layers, its habits are matched to forests with a well-developed organic layer (Greenslade 1999). In fact, the genus *Folsomia* was not found extracted in the young broad-leaved stands, presumably because of the poor development of the organic layer (Suetsugu *et al*. 2010). In the present extraction we found two species belonging to the genus *Folsomia*. We did not, however, find *F. octoculata* Handschin, 1925 which is the dominant species in many regions of Honshu and some parts of Hokkaido (Takeda 1987, Suma and Ohnishi 2009). *F. regulars* and *F. diplophthalma* may prefer a cool environment, such as high latitude regions (Potapov and Babenko 2000).

Moreover, the species *Onychiurus* (*Protaphorura*) *longisensillatus* Yosii, 1956, belonging to the Family of Onychiuridae, has a "*nutak*" subspecies character recorded by Yosii (1972) at Mt. Poroshiri (2,052 m alt.) Hokkaido. The collembolan community in this study site therefore corresponds to the community in cool-temperate forests.

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Atlas

Schaeffer emucronata decemoculata Stach, 1939 (Photos 1-4)

Found in spruce and larch stands. Body color is grey (Photo. 1). This species is characterized by a low number of eyes, 5+5 (normally Hypogastruridae are 8+8), and some long setae (Photo. 2, Photo. 3). The Post Antennal Organ (PAO) consists of four lobes (Photo. 4).

Tullbergia yosii Rusek, 1967 (Photo. 5 - 7)

Found in every stand. Body color is completely white (Photo. 5). *T. yosii* is the only species recorded in Japan of the genus *Tullbergia*. The sensory organ of Ant. III has two sensory clubs bent towards each other (Photo. 6). According to Rusek (1967), the position of chaeta p1 at Abd. VI of *T. yosii* is more backward than p2. However, the chaeta p1 is located more forward than p2 in our sample, and this characteristic is similar the individual recorded as *T. krausbaueri* by Uchida and Tamura (1968) (Photo. 7). Pseudocelli at the base of the antenna is of form 1+1 (Photo. 8).

Onychiurus (*Protaphorura*) *longisensillatus nutak* Yosii, 1972 (Photos 9-12)

Found in every stand, especially in the spruce stand. Body color is completely white (Photo. 9). *O* (*P*). *longisensillatus nutak* is a subspecies of *O* (*P*). *longisensillatus* which is characterized by two slender sensory rods at Ant. III and three pseudocelli behind the head (Photo. 10, 11). This subspecies was first recorded by Yosii in 1972 at Mt. Poroshiri, and has since been found in many locations in Hokkaido (Suma 2009, etc). These two subspecies differ in the number of pseudocelli at the base of antenna, 4 in "*nutak*", and 3 in "*longisensillatus*" (Photo. 12).

Friesea japonica Yosii, 1954 (Photos 13-15)

Found in every stand. Body color is dark-gray (Photo. 13). This species is a member of the family Pseudachorutidae which has no mandibular plate on the mandible (Photo. 14). This species is characterized by three anal spines (Photo. 15) and is recorded in many places in Hokkaido (Yosii 1972).

Folsomia diplophthalma (Axelson, 1902) (Photos 16-19)

Found in the larch stand. Body color is white and has many dark-blue spots (Photo. 16). In general, the abdomen of Collembola is divided into 6 segments. However, the abdomen of *Folsomia*, specifically Abd. IV-VI, are fusing, so that the abdomen is divided into 4 segments (Photo. 17). There are 12 *Folsomia* species in Japan, which can be classified by sensilla position on the terga and some traditional characteristics (Potapov and Babenko 2000). The number of chaetae on the anterior side of the manubrium in our sample is 1+1, and the eyes comprise 1+1 ommatidia (Photos. 18, 19). Potapov and Babenko (2000) assert, however, that the number of chaetae on the anterior side of the manubrium in *F. diplophthalma* is 4+4.

Folsomia regularis Hammer, 1953 (Photos 20-23)

Found in the spruce and larch stands. Body color is white (Photo. 20). *F. regularis* also has 1+1 ommatidia (Photo. 21). The difference from previous species is in the number and position of the chaetae on the anterior side of the manubrium (Photo. 22). These chaetae may range from 3+3 to 5+5. Potapov and Babenko (2000) described this species. In their opinion, *F. ozeana* Yosii 1954, which is synonymized by Yosii (1969), is different from *F. regularis* because of the number of latero-distal chaetae on the ventral tube and macrochaeta on Th.III. Our samples have 3+3 latero-distal chaetae on the ventral tube, and this character is the same as *F. ozeana* (Photo. 23). It would be valuable to consider some *Folsomia* species in Japan.

Folsomides parvulus Stach, 1922 (Photos 24-26)

Found in the young cool-temperate forest stands (ambient CO_2). Body color is completely white (Photo. 24). This species has *Folsomia*-alike PAO, but the abdomen is divided into 6 segments (Photos. 24, 25). There are two species in Japan recorded as genus *Folsomides*, which are easy to classify by the number of eyes (2+2 in *F. parvulus*, Photo. 25). The furca is small and the manubrium and dens are fused (Photo. 26).

Isotomiella minor (Schäffer, 1896) (Photos 27-30)

Found in every young cool-temperate forest stand. Body color is completely white, and there are some macrochaeta (Photo. 27). This genus does not have both PAO and eyes (Photo. 28). The genus *Isotomiella* in Japan has long been considered to comprise a single species. Tanaka and Niijima, (2009) however, divided *I. minor* specimens recorded in Japan into three species. According to their classification, our sample resembles *I. tamurai* Tanaka et Niijima, 2009, based on the number of chaetae, 4+4 anterior-distal, on the manubrium (Photo. 29, 30).

Pteronychella spatiosa Uchida et Tamura, 1968 (Photos. 31-34)

Found in every stand. Body color is purple or sometimes dark-blue (Photo. 31). The PAO shape is elliptical, and the eyes consist of 8+8 ommatidia (Photo. 32). This species is characterized by very short pseudonychia (Photo. 33). The number of tenaculum setae is 5, but the positions of these 5 setae differ between our samples (1, 2+2) and those identified by Uchida and Tamura (1968) (1,1+1,1+1) (Photo. 34).

Desoria dichaeta (Yosii, 1969) (Photos 35-37)

Found in every stand. Body color is gray (Photo. 35). Eyes consist of 4+4 ommatidia (Photo. 36). There are many chaetae on the anterior side of the manubrium, and 2+2 on the tenaculum (Photo. 37, 38).

Tomocerus (*Tomocerus*) *ocreatus* Denis, 1948 (Photos 39-42)

Found in every young cool-temperate forest stand. Body color is brown and body size is large, about 3.5 mm (Photo. 39). The family Tomoceridae is characterized by long antennae and strong spines on dens (Photo. 40, 41). The dental spines of this species are positioned 4/3-4, 2, and specify what is covered with many spiny setae (Photo. 41, 42).

Sinella (*Coecobrya*) *dubiosa* Yosii, 1956 (Photos 43-45)

Found in every young cool-temperate forest stand. Body color is completely white, and specimens do not have any eyes or PAO (Photo. 43). The claws have clear unguiculus, which reaches to the middle of the claw (Photo. 44) As is characteristic of the subgenus *Coecobrya*, the mucro consists of one dens and one spine (Photo. 45).

Lepidocyrtus cyaneus Tullberg, 1871 (Photos 46-48)

Found in every young cool-temperate forest stand. Body color is purple and sometimes dark-blue (Photo. 46). Th. II is clearly risen and covered by many scales (Photo. 47). There are three species recorded in Japan in the genus *Lepidocyrtus* in Japan; the other two species have a white body. The eyes consist of 8+8 ommatidia (Photo. 48).

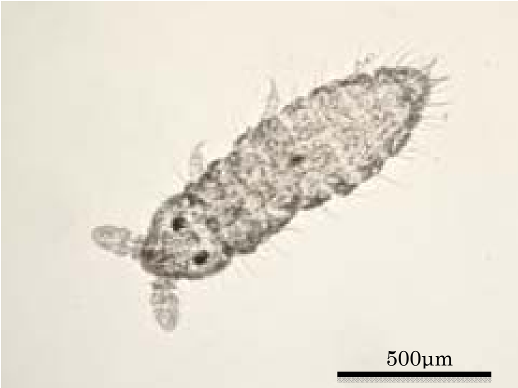

Photo 1. *Schaefferia emucronata decemoculata* Stach, 1939

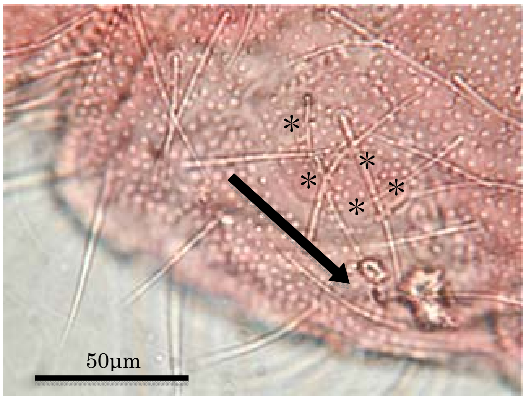

Photo 2. *S. emucronata decemoculata* Eyes. By KOH treatment

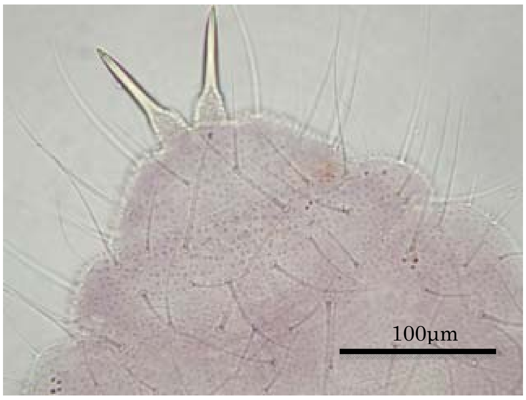

Photo 3. *S. emucronata decemoculata* Dorsal chaetotaxy of Abd. IV - VI. By KOH treatment

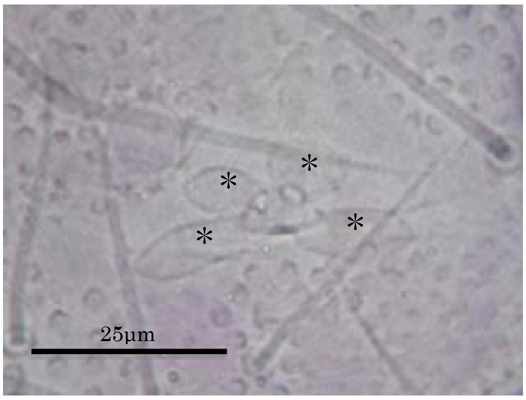

Photo 4. *S. emucronata decemoculata* The shape of PAO. By KOH treatment

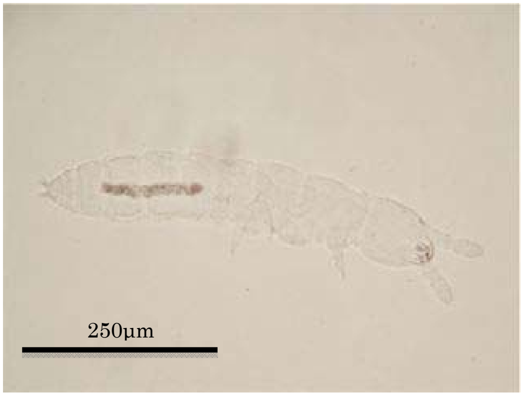

Photo 5. *Tullbergia yosii* Rusek, 1967

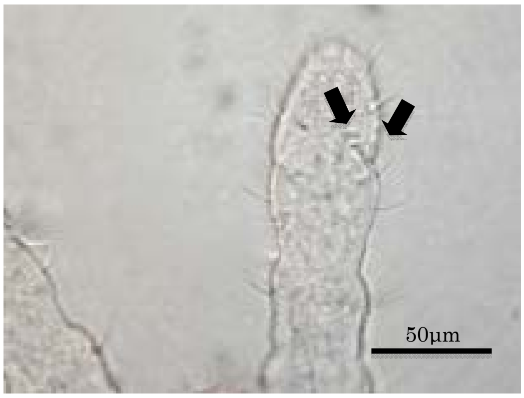

Photo 6. *T. yosii* The sensory organ of Ant. III.

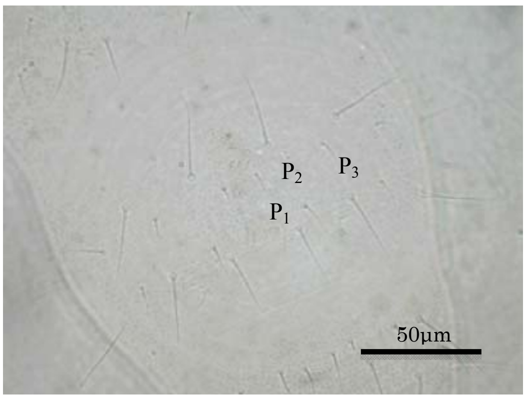

Photo 7. *T. yosii* Dorsal chaetotaxy of Abd. IV.

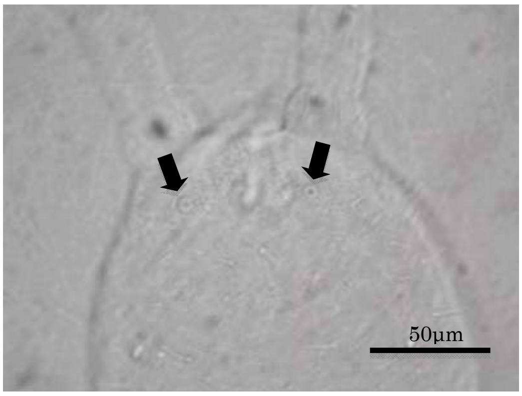

Photo 8. *T. yosii* Pseudocelli at the base of the antenna.

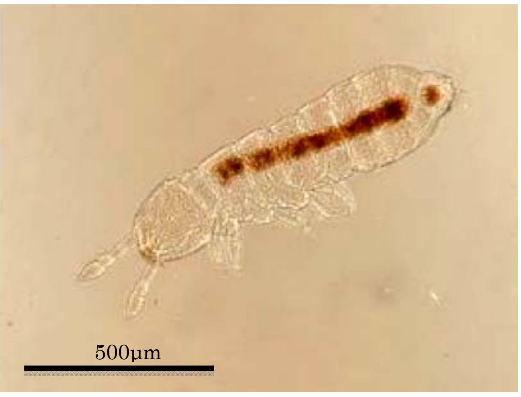

Photo 9. *Onychiurus (Protaphorura) longisensillatus nutak* Yosii, 1972

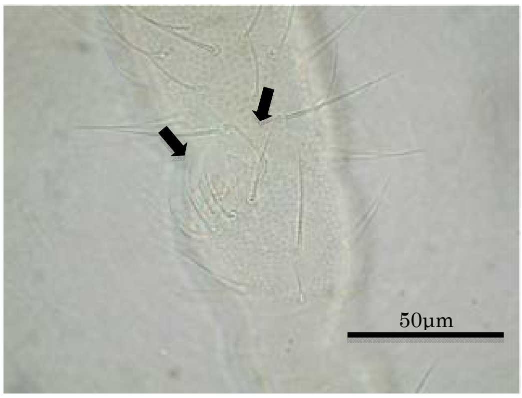

Photo 10. *O. (P.) longisensillatus nutak*
Ant. III organ and slender sensory rods.

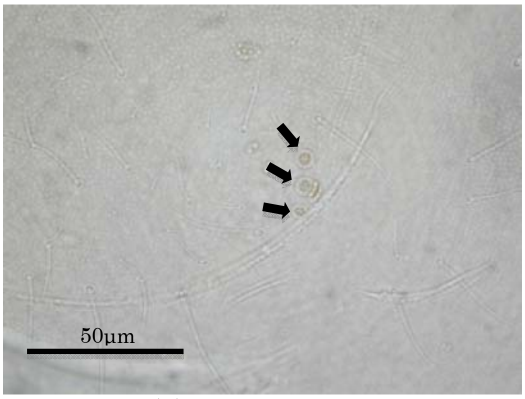

Photo 11. *O. (P.) longisensillatus nutak*
Pseudocelli at the backward of head.

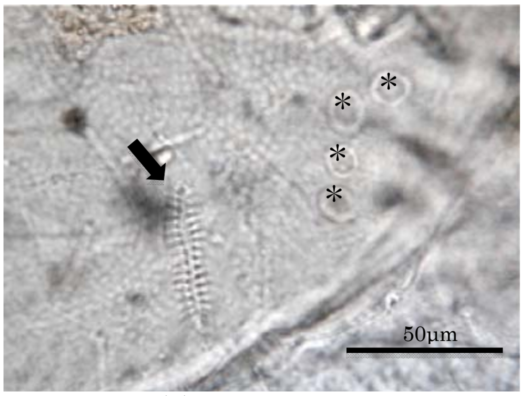

Photo 12. *O. (P.) longisensillatus nutak*
Pseudocelli (Mark) and PAO (Arrow) at antenna organ.

Photo 13. *Friesea (Friesea) japonica* Yosii, 1954

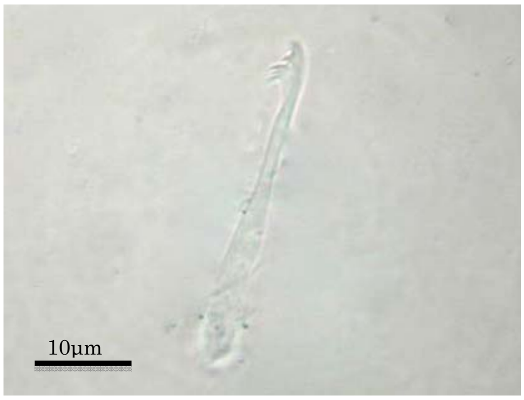

Photo 14. *F. (F.) japonica*
The shape of Mandible.

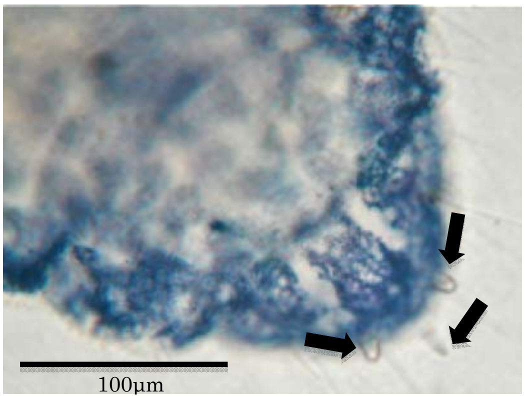

Photo 15. *F. (F.) japonica*
Anal spins on Abd. VI.

Photo 16. *Folsomia diplophthalma* (Axelson, 1902)

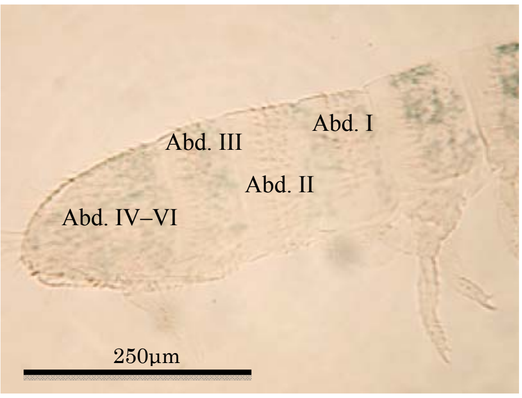

Photo 17. *F. diplophthalma*
Abdomen segments.

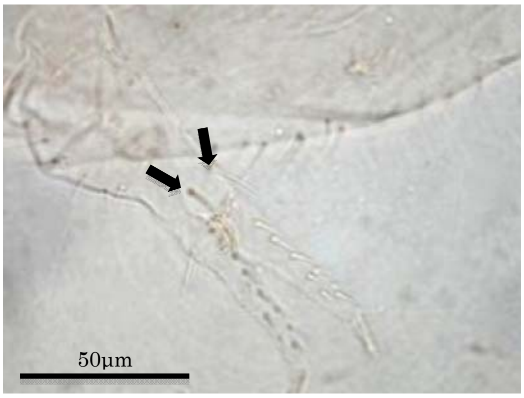

Photo 18. *F. diplophthalma*
Chaetae on anterior side of manubrium.

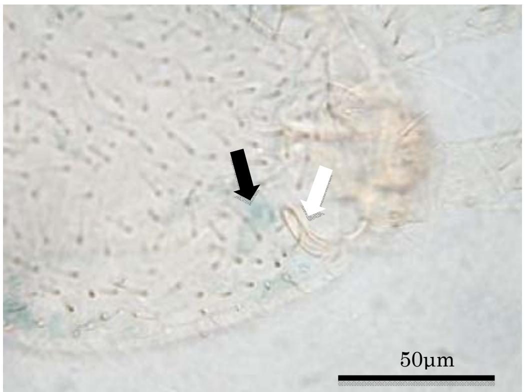

Photo 19. *F. diplophthalma*
PAO (white) and eye (black).

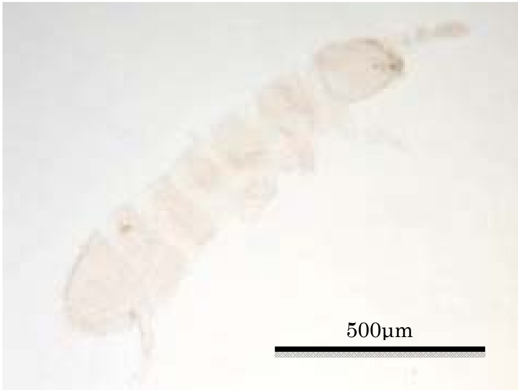

Photo 20. *Folsomia regularis* Hammer, 1953

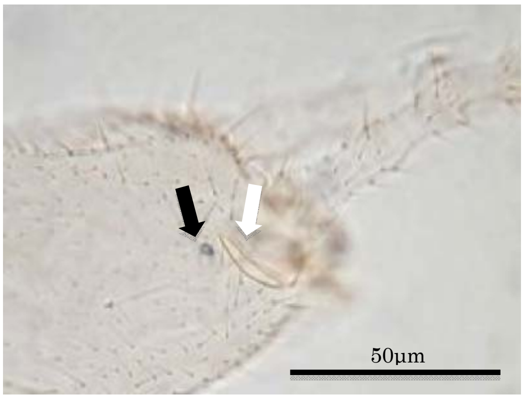

Photo 21. *F. regularis*
PAO (white) and eye (black).

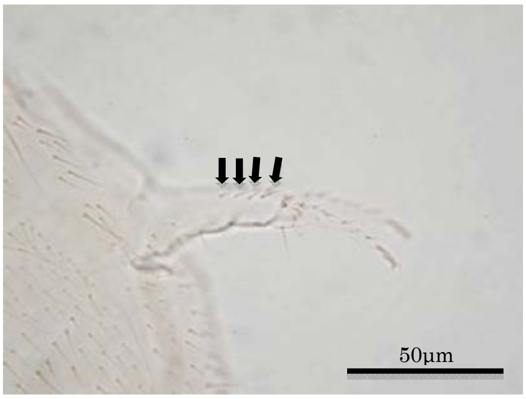

Photo 22. *F. regularis*
The chaetae on the anterior side of manubrium.

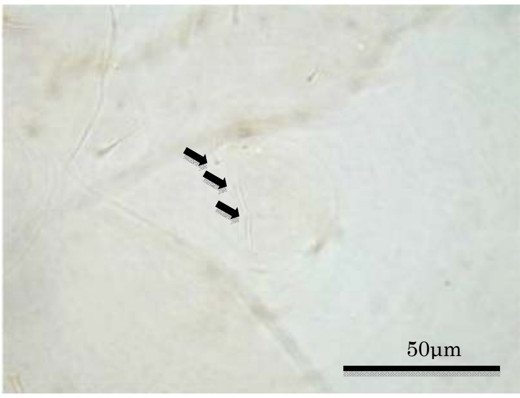

Photo 23. *F. regularis*
The latero-distal chaetae on the ventral tube.

Photo 24. *Folsomides parvulus* Stach, 1922

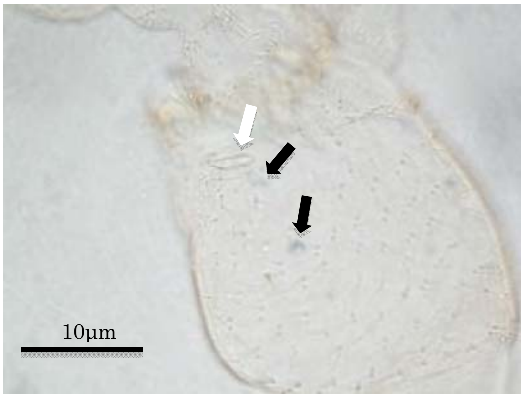

Photo 25. *F. parvulus*
PAO (white) and eye (black).

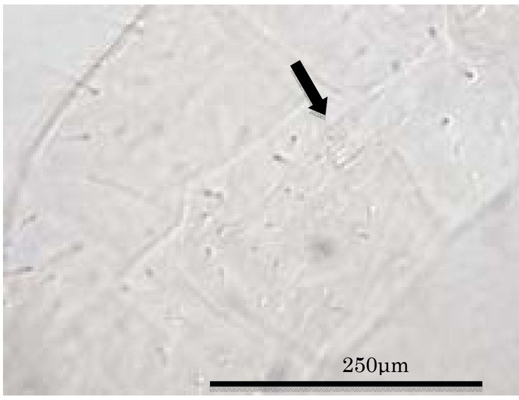

Photo 26. *F. parvulus*
Furca.

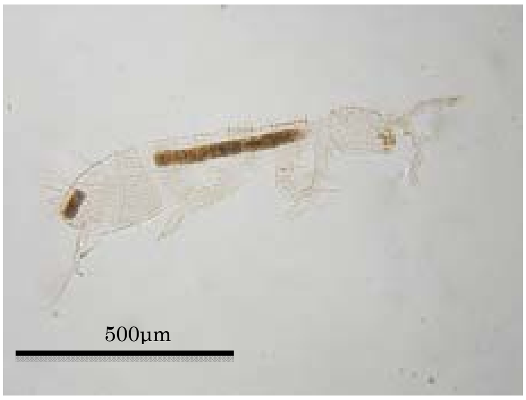

Photo 27. *Isotomiella minor* (Schaffer, 1896)

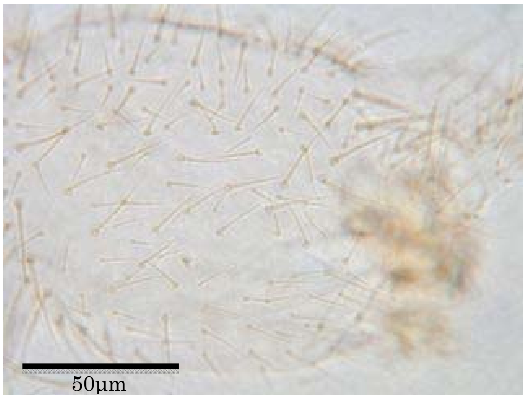

Photo 28. *I. minor*
Head segments.

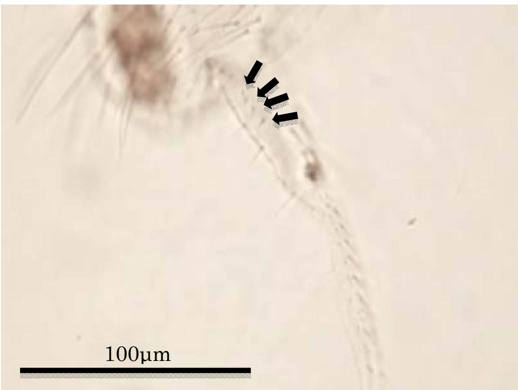

Photo 29. *I. minor*
Lateral manubrial chaetae.

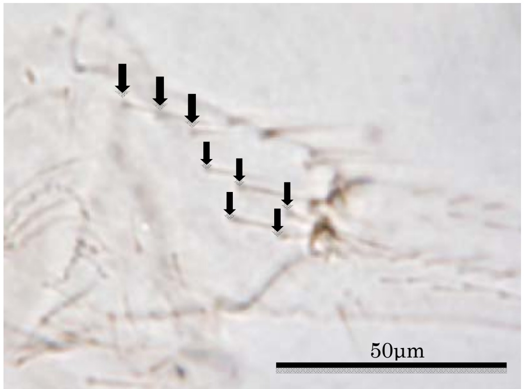

Photo 30. *I. minor*
Lateral manubrial chaetae.

Photo 31. *Pteronychella spatiosa* Uchida et Tamura, 1968

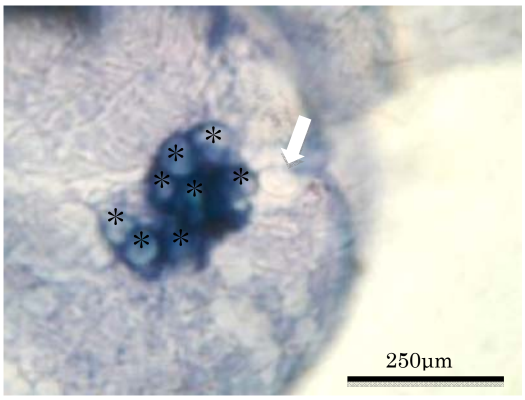

Photo 32. *P. spatiosa*
PAO (arrow) and eye (mark).

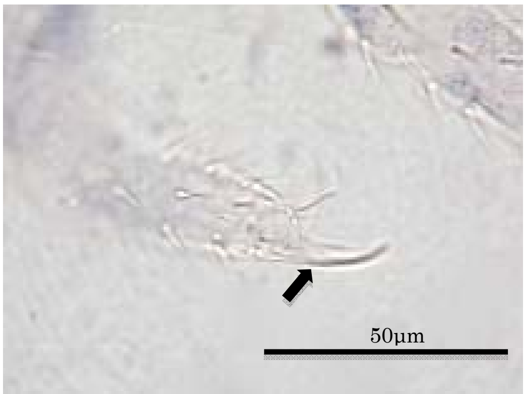

Photo 33. *P. spatiosa*
Hind leg and pseudonychia (Mark).

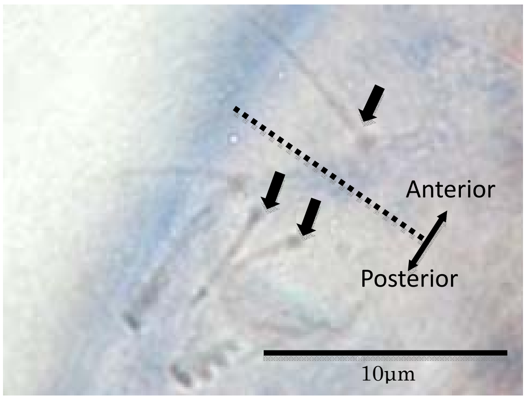

Photo 34. *P. spatiosa*
Setae on tenaculum.

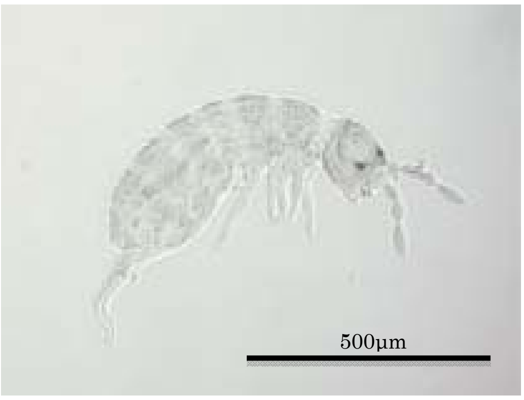

Photo 35. *Desoria dichaeta* (Yosii, 1969)

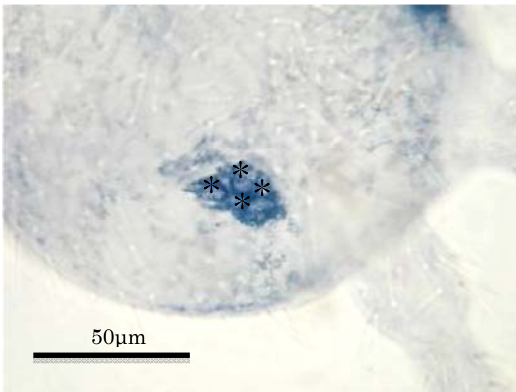

Photo 36. *D. dichaeta*
Head and eyes.

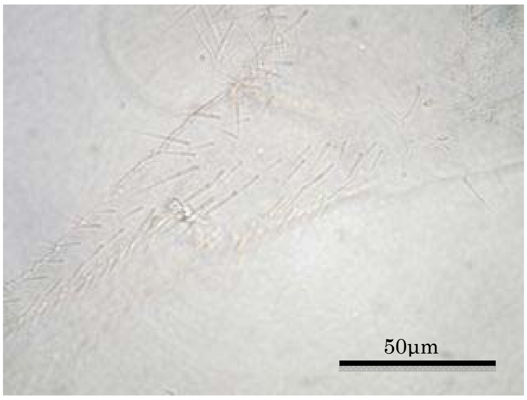

Photo 37. *D. dichaeta*
Anterior side of manubrium.

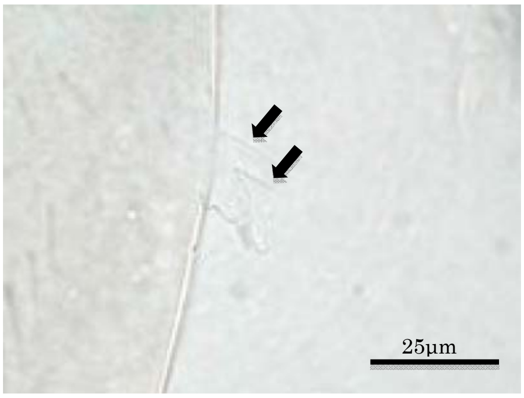

Photo 38. *D. dichaeta*
Tenaculum and chaeta (arrow).

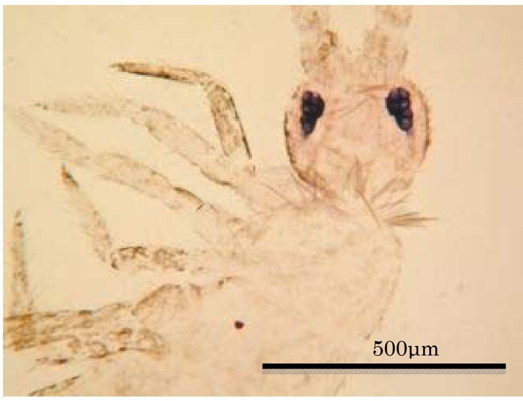

Photo 39. *Tomocerus (Tomocerus) ocreatus* Denis, 1948

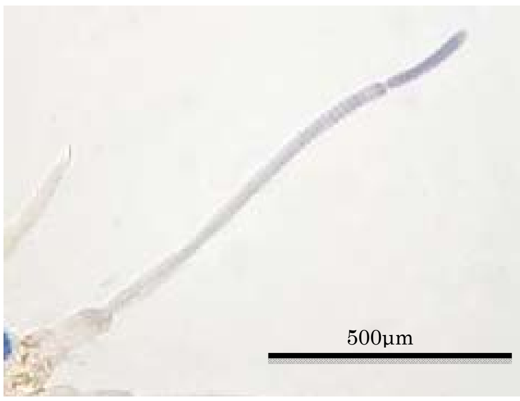

Photo 40. *T. (T.) ocreatus*
Antenna.

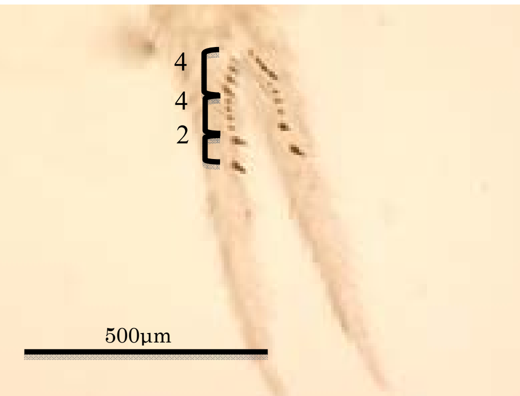

Photo 41. *T. (T.) ocreatus*
Dens and dental spins.

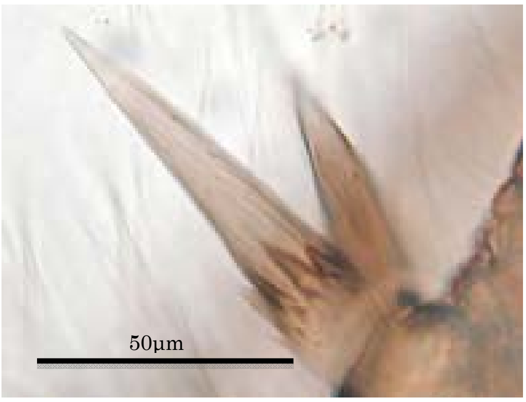

Photo 42. *T. (T.) ocreatus*
Dental spins.

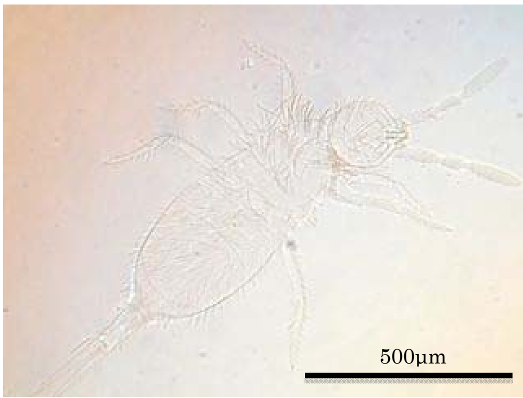

Photo 43. *Sinella (Coecobrya) dubiosa* Yosii, 1956

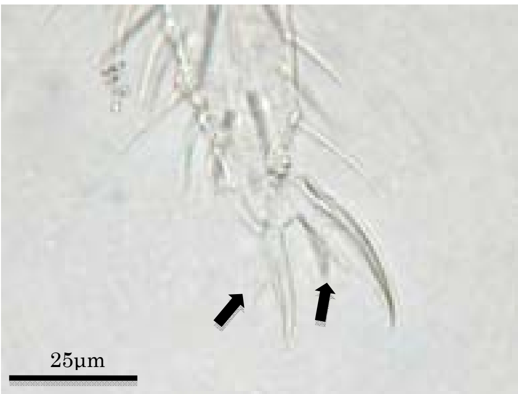

Photo 44. *S. (C.) dubiosa*
Fore claw and unguiculus (Arrow).

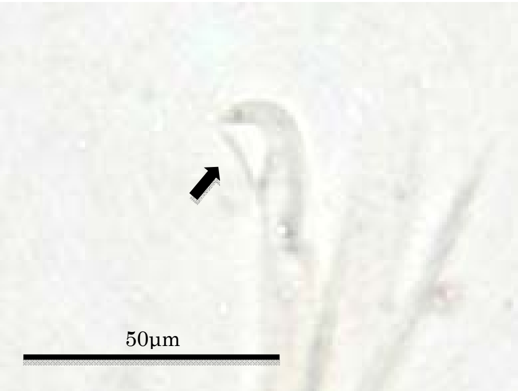

Photo 45. *S. (C.) dubiosa*
Mucro and spine (Arrow).

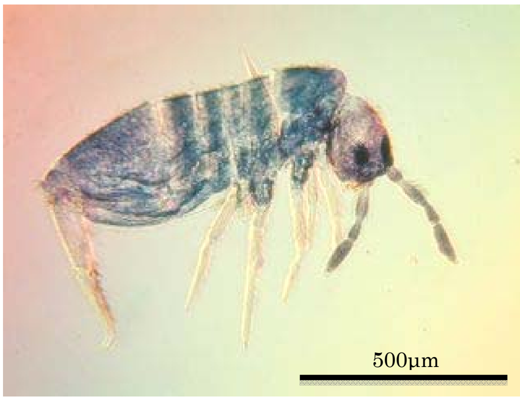

Photo 46. *Lepidocyrtus cyaneus* Tullberg, 1871

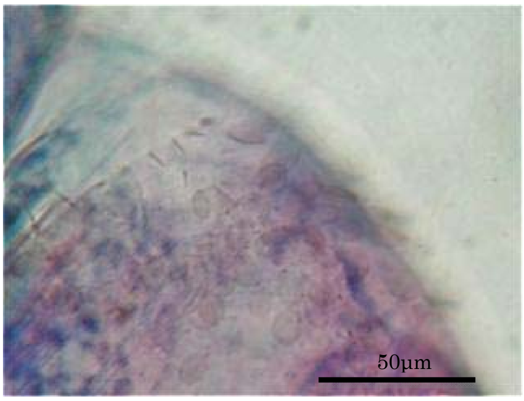

Photo 47. *L. cyaneus*
Scales on Th. II.

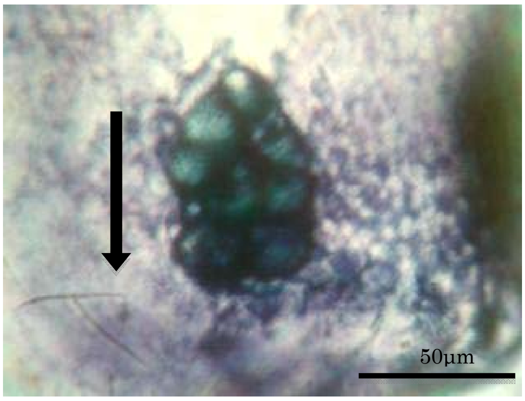

Photo 48. *L. cyaneus*
Eyes.