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

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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 m², about 30 years old), larch (Larix kaempferi) plantation (126 m², about 50 years old), and young, 6-year-old broad-leaved mixed stands (18.8 m², 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 CO₂ treatments: one is control (ambient CO₂) and the other has elevated CO₂ (500 ppm) via a FACE (Free Air CO₂ 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 cm²), 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 collembolan 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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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 CO2 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.


Table 1. Site description

<table>
<thead>
<tr>
<th>Stand</th>
<th>Age</th>
<th>Density / ha</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picea forest</td>
<td>30</td>
<td>4300</td>
<td><em>Picea glehnii</em></td>
</tr>
<tr>
<td>Larix forest</td>
<td>50</td>
<td>1200</td>
<td><em>Larix leptolepis</em></td>
</tr>
<tr>
<td>Young cool-temperate forest</td>
<td>6</td>
<td>4800</td>
<td>Betula platyphylla, Quercus crispula Fraxinus mandshurica, Ulmus davidiana</td>
</tr>
<tr>
<td>(Ambient CO2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young cool-temperate forest</td>
<td>6</td>
<td>1400</td>
<td><em>Kalopanax pictus</em>, <em>Fagus crenata</em> Tilia japonica, <em>Acer mono</em></td>
</tr>
<tr>
<td>(Elevated CO2)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Family</th>
<th>Picea forest</th>
<th>Larix forest</th>
<th>Young cool-temperate forest</th>
<th>Young cool-temperate forest</th>
<th>Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ambient CO₂</td>
<td>Elevated CO₂</td>
<td>species</td>
</tr>
<tr>
<td>Onychiurida</td>
<td>6250 (67)</td>
<td>4800 (14.5)</td>
<td>1400 (11.5)</td>
<td>800 (14)</td>
<td><em>Tullbergia yosii</em> Onychiurus (Protaphorura) <em>longisensillatus nutak</em> Onychiurus (Allonychiurus) conjungens</td>
</tr>
<tr>
<td>Pseudachorutida</td>
<td>400 (4.5)</td>
<td>150 (0.5)</td>
<td>250 (2)</td>
<td>450 (8)</td>
<td><em>Friesea</em> (<em>Friesea</em>) <em>japonica</em> Schaefferia <em>emucronata decemoculata</em></td>
</tr>
<tr>
<td>Hypogastrura</td>
<td>50 (0.5)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>50 (1)</td>
<td><em>Vitronura rosea</em></td>
</tr>
<tr>
<td>Neanurida</td>
<td>1400 (15)</td>
<td>27200 (84)</td>
<td>9400 (77.5)</td>
<td>2200 (40.5)</td>
<td><em>Folsomia diplophthalma</em> <em>Folsomia regularis</em> <em>Isotomiella minor</em> Desoria <em>dichaeta</em></td>
</tr>
<tr>
<td>Isotomidae</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>550 (4.5)</td>
<td>450 (8)</td>
<td><em>Tomocerus</em> (<em>Tomocerus</em>) <em>ocreatus</em> Sinella <em>dubiosa</em> Entomobrya sp Lepidocyrtus <em>cyaneus</em></td>
</tr>
<tr>
<td>Tomocerida</td>
<td>400 (4.5)</td>
<td>150 (0.5)</td>
<td>300 (2.5)</td>
<td>900 (16)</td>
<td><em>Megalothorax minimus</em></td>
</tr>
<tr>
<td>Entomobryida</td>
<td>700 (7.5)</td>
<td>150 (0.5)</td>
<td>150 (1)</td>
<td>200 (3.5)</td>
<td><em>Sminthurinus sp</em> <em>Ptenothrix sp</em></td>
</tr>
<tr>
<td>Sminthuridae</td>
<td>100 (1)</td>
<td>0 (0)</td>
<td>150 (1)</td>
<td>500 (9)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>6250 (67)</td>
<td>4800 (14.5)</td>
<td>1400 (11.5)</td>
<td>800 (14)</td>
<td></td>
</tr>
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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 (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007). The habitat of surface species which have a large jumping tail (Furca) was scarcely affected (Kaneko 2007).

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 2003). 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 2003). *F. regularis* 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.

Acknowledgements

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Atlas

Schaeffer emuiconata decemculata 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 posterior 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 CO₂). Body color is completely white (Photo. 24). This species has Folsomia-like 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 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 spines.

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

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

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

Photo 46. *Lepidocyrtus cyaneus* Tullberg, 1871

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

Photo 48. *L. cyaneus*
Eyes.