

Reassessment of type specimens of *Cordyceps* and its allies, described by Dr. Yosio Kobayasi and preserved in the mycological herbarium of the National Museum of Nature and Science (TNS). Part 3: *Cordyceps* s. l. on Cicadidae

Hiroki Sato · Sayaka Ban · Hayato Masuya ·
Tsuyoshi Hosoya

Received: 25 June 2011 / Accepted: 10 December 2011 / Published online: 26 January 2012
© The Mycological Society of Japan and Springer 2012

Abstract Twenty taxa of *Cordyceps* s. l. (belonging to three genera in the latest taxonomic system) from Cicadidae had been described by Kobayasi and Shimizu. Among them, 13 holotype specimens of *Cordyceps* were rediscovered from preserved specimens partially without ordering, and their registration numbers (TNS-F-number) were given: viz. (1) *Elaphocordyceps inegoensis* TNS-F-230289, (2) *Elaphocordyceps paradoxa* TNS-F-230313, (3) *Elaphocordyceps toriharamontana* TNS-F-230288, (4) *Ophiocordyceps heteropoda* TNS-F-230294, (5) *Ophiocordyceps longissima* TNS-F-230285, (6) *Ophiocordyceps prolifica* f. *terminalis* TNS-F-230295, (7) *Ophiocordyceps pseudolongissima* TNS-F-197983, (8) *Ophiocordyceps takaoensis* TNS-F-3026, (9) *Cordyceps kanzashiana* TNS-F-198015, (10) *Cordyceps kobayashii* Koval' (= *C. sinclairii* Kobayasi, not *C. sinclairii* Berk.) TNS-F-212384, (11) *Cordyceps minuta* TNS-F-11933, (12) *Cordyceps ramosopulvinata* TNS-F-197979, and (13) *Cordyceps ryogamimontana* TNS-F-230292. Two specimens were selected as lectotype: viz. (14)

Ophiocordyceps prolifica TNS-F-230300 and (15) *Ophiocordyceps yakusimensis* TNS-F-230287. A paratype specimen of (16) *Cordyceps pleuricapitata* TNS-F-197965, and an authentic specimen of (17) *Cordyceps imagamiana* TNS-F-197966, were also rediscovered.

Keywords *Elaphocordyceps* · Holotype · Lectotype · *Ophiocordyceps* · Paratype

Introduction

The genus *Cordyceps* sensu lato is one of the largest genera, including more than 500 species, in entomopathogenic Ascomycetes (data from Index Fungorum as of 2011; <http://www.speciesfungorum.org/Names/Names.asp>). Kobayasi and Shimizu described more than 150 species of *Cordyceps* and its allies (Kobayasi 1941, 1982a, b, 1983a, b; Kobayasi and Shimizu 1983a). Insects belonging to Cicadidae (cicadas) are one of the major hosts of *Cordyceps*, and Kobayasi and Shimizu described 20 taxa found from Cicadidae (Kobayasi 1939, 1941; Kobayasi and Shimizu 1963, 1982a, b, 1983a). However, they did not specify the specimen numbers of the type specimen. Thus, many researchers assumed that the type specimens were lost or at least not accessible. In the series of our reassessment of the type specimens of *Cordyceps* starting from Sato et al. (2010a, b), we cross-examined the information on the specimen labels of each species and those in the original paper to identify the holotype specimens. We also lectotypify the specimens when Kobayasi and Shimizu did not designate the holotype. We followed the procedure described in Sato et al. (2010a).

In most cases, the collection data (place, collector, date, original specimen number) in the papers correspond to the specimen labels, facilitating identification of the type.

H. Sato (✉)
Department of Forest Entomology,
Forestry and Forest Products Research Institute,
1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan
e-mail: hirokis@ffpri.affrc.go.jp

S. Ban
NITE Biological Resource Center,
2-5-8 Kazusakamatari, Kisarazu, Chiba 292-0818, Japan

H. Masuya
Forestry and Forest Products Research Institute,
1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan

T. Hosoya
National Museum of Nature and Science,
4-1-1 Amakubo, Tsukuba, Ibaraki 305-0005, Japan

Comparison of the morphology of the specimen with the figures in the original paper also showed strong support. We identify the specimen as a holotype when the collection data on the labels is correlated to the data in the original paper. When data on the label and in the paper were not in agreement, we gave interpretations with additional information. Recently, Sung et al. (2007) transferred several species of *Cordyceps* from Cicadidae, originally described by Kobayasi and Shimizu, to *Elaphocordyceps* G. H. Sung & Spatafora or to *Ophiocordyceps* Petch. We follow the taxonomic system of Sung et al. (2007).

Results and comments on the type determination are summarized in Table 1. Nomenclatural treatments are discussed in the following text.

Elaphocordyceps

1. *Elaphocordyceps inegoensis* (Kobayasi) G. H. Sung, J. M. Sung & Spatafora, Stud. Mycol. 57: 37. 2007.

≡ *C. inegoensis* Kobayasi, Bull. Nat. Sci. Mus. 6: 292. 1963.

Fig. 1 (Holotype TNS-F-230289)

2. *E. paradoxa* (Kobayasi) G. H. Sung, J. M. Sung & Spatafora, Stud. Mycol. 57: 37. 2007.

≡ *C. paradoxa* Kobayasi, Bull. Biogeogr. Soc. Jap. 9: 156. 1939.

Fig. 2 (Holotype TNS-F-230313)

3. *E. toriharamontana* (Kobayasi) G. H. Sung, J. M. Sung & Spatafora, Stud. Mycol. 57: 38. 2007

≡ *C. toriharamontana* Kobayasi, Bull. Nat. Sci. Mus. 6: 305. 1963.

Fig. 3 (Holotype TNS-F-230288)

Ophiocordyceps

4. *Ophiocordyceps heteropoda* (Kobayasi) G. H. Sung, J. M. Sung, Hywel-Jones & Spatafora, Stud. Mycol. 57: 43. 2007.

≡ *C. heteropoda* Kobayasi, Bull. Biogeogr. Soc. Jap. 9: 158. 1939.

Fig. 4 (Holotype TNS-F-230294)

A paratype was also found (TNS-F-200486).

5. *Ophiocordyceps longissima* (Kobayasi) G. H. Sung, J. M. Sung, Hywel-Jones & Spatafora, Stud. Mycol. 57: 44. 2007.

≡ *C. longissima* Kobayasi, Bull. Nat. Sci. Mus. 6: 300. 1963.

Fig. 5a, b (Holotype TNS-F-230285)

Two specimens were preserved in a single bottle, but they are regarded as a single specimen (ICBN Art. 8.2). We also found a paratype specimen (TNS-F-230297) based on the congruence of the data in the paper and those on the label. Another paratype shown in plate 41C in Kobayasi and Shimizu (1963) was not found.

6. *Ophiocordyceps prolifica* (Kobayasi) S. Ban, Sakane & Nakagiri, Mycoscience 50: 270, 2009.

≡ *C. prolifica* Kobayasi, Bull. Nat. Sci. Mus. 6: 289. 1963.

Fig. 6 (Lectotype TNS-F-230300)

Two specimens (TNS-F-230300, -230311), preserved in good condition, with the collection data (place, collector, date, original specimen number) identical to those in the original article (Kobayasi and Shimizu 1963), were found. Because the holotype was not designated, TNS-F-230300 was selected as a lectotype because its photograph was shown in plate 39A in Kobayasi and Shimizu (1963). Four more paratypes were also discovered (TNS-F-230298, -230299, -230301, -230302).

7. *Ophiocordyceps prolifica* f. *terminalis* (Kobayasi) S. Ban, Sakane & Nakagiri, Mycoscience 50: 270, 2009.

≡ *C. prolifica* f. *terminalis* Kobayasi, Bull. Nat. Sci. Mus. 6: 292. 1963.

Fig. 7 (Holotype TNS-F-230295)

8. *Ophiocordyceps pseudolongissima* (Kobayasi & Shimizu) G. H. Sung, J. M. Sung, Hywel-Jones & Spatafora, Stud. Mycol. 57: 46. 2007.

≡ *Cordyceps pseudolongissima* Kobayasi & Shimizu, Bull. Natn. Sci. Mus., Tokyo, Ser. B. 8: 119. 1982.

Fig. 8 (Holotype TNS-F-197983)

9. *Ophiocordyceps takaoensis* (Kobayasi) G. H. Sung, J. M. Sung, Hywel-Jones & Spatafora, Stud. Mycol. 57: 47. 2007.

≡ *C. sobolifera* (Hill) Berk. et Broome var. *takaoensis* Kobayasi, Bull. Biogeogr. Soc. Jap. 9: 165. 1939

≡ *Cordyceps takaoensis* Kobayasi, Sci. Rep. Tokyo Bunrika Daigaku Sect. B 84: 130. 1941.

Fig. 9 (Holotype TNS-F-3026)

10. *Ophiocordyceps yakusimensis* (Kobayasi) G. H. Sung, J. M. Sung, Hywel-Jones & Spatafora, Stud. Mycol. 57: 47. 2007.

≡ *C. yakusimensis* Kobayasi, Bull. Nat. Sci. Mus. 6: 302. 1963.

Fig. 10 (Lectotype TNS-F-230287)

Two specimens (TNS-F-230287, in formalin; TNS-F-230316, dried) with collection data identical to those in the original paper (Kobayasi and Shimizu 1963) were found. Photographs of both specimens were cited in the original

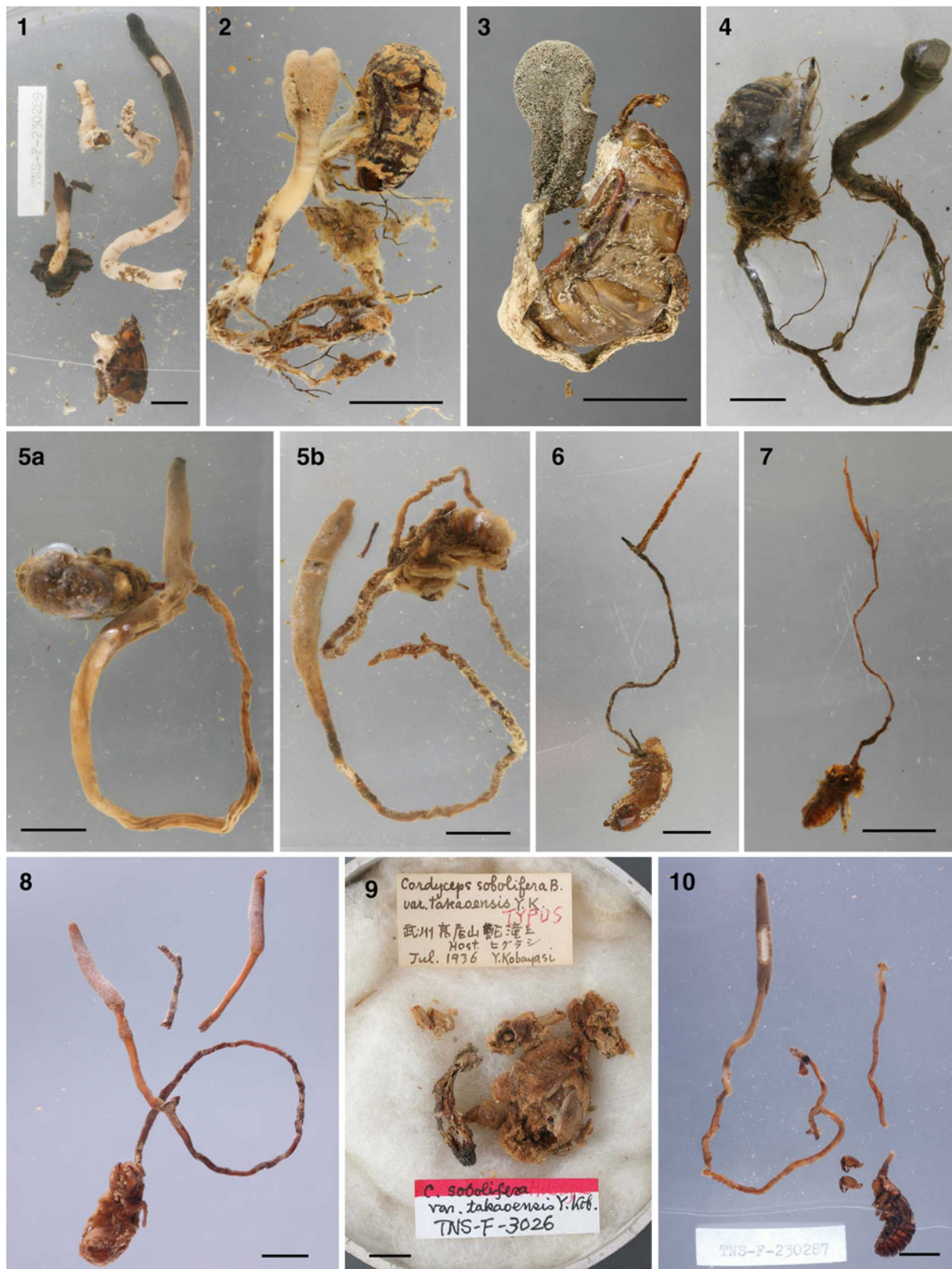
Table 1 List of rediscovered type specimens of *Cordyceps* species, s. l. from Cicadidae described by Dr. Kobayasi and Mr. Shimizu in the National Museum of Nature and Science (TNS)

Current name Japanese name	Consistency of		Determined status	Registration number (TNS-F-)	Preserved status	Comments	Citation
	Place	Leg. Date					
<i>Elaphocordyceps inegoensis</i> Ingoosemitake (Kobayasi and Shimizu 1983b)	○	○	○	TNS-F-230289	Formalin	Damaged but available for observation	Kobayasi and Shimizu (1963), Sung et al. (2007)
<i>E. paradoxa</i> Umemura-semitake (Kobayasi 1939)	○	○	○	TNS-F-230313	Formalin	Macromorphology of this specimen matched the photo in Kobayasi and Shimizu (1963; pl. 42B)	Kobayasi (1939), Kobayasi and Shimizu (1963), Sung et al. (2007)
<i>E. toriharanomontana</i> Tampo-ezozemitake (Kobayasi and Shimizu 1963)	○	○	○	TNS-F-230288	Dried	Shrunk by desiccation. Appeared to be identical to the specimen shown in Kobayasi and Shimizu (1963; pl. 42A)	Kobayasi and Shimizu (1963), Sung et al. (2007)
<i>Ophiocordyceps heteropoda</i> Oozemitake (Kobayasi and Shimizu 1939)	○	○	○	TNS-F-230294	Formalin	Macromorphology of this specimen matched the illustration in Kobayasi (1939; text-fig. 10). Paratype: TNS-F-200486	Kobayasi (1939), Sung et al. (2007)
<i>O. longissima</i> Ezoharuzemitake (Kobayasi and Shimizu 1963)	○	○	○	TNS-F-230285	Formalin	The collection site “Inego” is located in Miyagi prefecture, although Kobayasi and Shimizu (1963) misdescribed as it is in Fukushima prefecture	Kobayasi and Shimizu (1963), Sung et al. (2007)
<i>O. prolifica</i> Tubu-no-semitake (Kobayasi and Shimizu 1963)	○	○	○	TNS-F-230300	Formalin	Paratypes: TNS-F-230298, 230299, 230301, and 230302	Kobayasi and Shimizu (1963), Ban et al. (2009)
<i>O. prolifica</i> f. <i>terminalis</i> Hime-hadaka-semitake (Kobayasi and Shimizu 1963).	○	○	○	TNS-F-230295	Formalin	Macromorphology of this specimen matched the photo in Kobayasi and Shimizu (1963). Color illustration in Kobayasi and Shimizu (1983b; pl.13-2), Shimizu (1994; pl. 43)	Kobayasi and Shimizu (1963), Kobayasi and Shimizu (1983b), Shimizu (1994)
<i>O. pseudolongissima</i> Irimote-semitake (Kobayasi and Shimizu 1982b)	○	○	○	TNS-F-197983	Formalin	Original collection number was shown as “01-66” in Kobayasi and Shimizu (1982b) while “O. I. 60” on the label of this specimen is considered as a misinterpretation	Kobayasi and Shimizu (1982b), Sung et al. (2007)
<i>O. takaensis</i> Higurastake (Kobayasi 1939)	○	○	○	TNS-F-3026	Dried	Damaged and difficult to observe. An additional specimen will be required	Kobayasi (1939, 1941), Sung et al. (2007)

Table 1 continued

Current name Japanese name	Consistency of			Determined status	Registration number (TNS-F-)	Preserved status	Comments	Citation
	Place	Leg.	Date					
<i>O. yakusimensis</i> Yakushima-semitake (Kobayasi and Shimizu 1963)	○	○	○	–	TNS-F-230287	Formalin	Color illustration in Kobayasi and Shimizu (1983b; pl. 24-2), Shimizu (1994; pl.16)	Kobayasi and Shimizu (1963), Sung et al. (2007), Kobayasi and Shimizu (1983b), Shimizu (1994)
<i>Cordyceps kanzashiana</i> Kanzashi-semitake (Kobayasi and Shimizu 1982a)	○	–	○	×	TNS-F-198015	Formalin	Original collection number “O-I 239” was on the label, while it was cited as “O-I 239” in Kobayasi and Shimizu (1982a), considered as a misinterpretation. Color illustration of Fig. 11 (right) in Kobayasi and Shimizu (1983b; pl. 11-1), Shimizu (1994; pl. 37)	Kobayasi and Shimizu (1982a), Kobayasi and Shimizu (1983b), Shimizu (1994)
<i>C. kobayasi</i> Koval Tukutubousi-semitake (Kobayasi and Shimizu 1983b)	○	○	○	–	TNS-F-212384	Dried	Additional specimens will be required to compensate the description of specific characteristics	Kobayasi (1949), Kobayasi and Shimizu (1963, 1983b), Koval (1984), Sung et al. (2007)
<i>C. minuta</i> Kogome-semitake (Kobayasi and Shimizu 1963)	○	○	○	–	TNS-F-11933	Dried	Very fragile. An additional specimen will be required for scientific convenience	Kobayasi and Shimizu (1963), Koval (1984), Sung et al. (2007)
<i>C. ramosipulvinata</i> Tobishima-semitake (Kobayasi and Shimizu 1983a)	○	○	×	○	TNS-F-197979	Dried	Although the collection date was written as “VII. 19, 1980” on the label, while it was cited as “Aug. 19, 1980” in Kobayasi and Shimizu (1983a). We considered the correct date could be the date on the label, and the incongruence is due to a misconception. Color illustration in Kobayasi and Shimizu (1983b; pl. 13-3), Shimizu (1994; pl. 36)	Kobayasi and Shimizu (1983a), Sung et al. (2007), Kobayasi and Shimizu (1983b), Shimizu (1994)
<i>C. ryogaminomontana</i> Suzuki-semitake (Kobayasi and Shimizu 1963)	○	×	○	○	TNS-F-230292	Formalin	Although “Daisuke Shimizu” was on the label as the collector’s name, “Takekuni Suzuki” was referred in Kobayasi and Shimizu (1963). Shimizu (1994) mentioned that T. Suzuki discovered this species. Paratype: TNS-F-231014	Kobayasi and Shimizu (1963), Sung et al. (2007)
<i>C. pluricapitata</i> Usuki-tampossemitake (Kobayasi and Shimizu 1982a)	○	○	×	×	TNS-F-197965	Dried	Specimen information is not cited in the paper (Kobayasi and Shimizu 1982a)	Kobayasi and Shimizu (1982a), Sung et al. (2007)

○, Information between labels and original papers matched; ×, information did not match; –, no information on the label, or not cited in the paper although the number was on the label



Figs. 1–10 Specimens determined as holotype (H) or lectotype (L). **1** *Elaphocordyceps inegoensis* (H). **2** *Elaphocordyceps paradoxa* (H). **3** *Elaphocordyceps toriharamontana* (H). **4** *Ophiocordyceps heteropoda* (H). **5** *Ophiocordyceps longissima* (H): specimen **5a** is shown on left,

and specimen **5b** is shown on right, in plate 41-B in the original paper. **6** *Ophiocordyceps prolifica* (L). **7** *Ophiocordyceps prolifica* f. *terminalis* (H). **8** *Ophiocordyceps pseudolongissima* (H). **9** *Ophiocordyceps takaoensis* (H). **10** *Ophiocordyceps yakusimensis* (L). Bars **1–10** 10 mm

paper (Kobayasi and Shimizu 1963). Because those two specimens were stored separately, they are not regarded as a single specimen (ICBN Art. 8.2). One of the specimens, in better condition (TNS-F-230287), was selected as the lectotype, having good congruence with the photographs in the original article (Kobayasi and Shimizu 1963, plate 41D, left) in the macroscopic morphology.

Cordyceps s. l.

Sung et al. (2007) listed 175 species of *Cordyceps* s. l., including several Cicadidae-infecting species without

taxonomic treatment because of a lack of molecular data or paucity of other information, which were tentatively placed in the genus *Cordyceps*. The species below are in the group in such a situation.

11. *Cordyceps kanzashiana* Kobayasi & Shimizu, Bull. Natn. Sci. Mus. Tokyo, ser. B.8: 86. 1982.

Fig. 11 (Holotype TNS-F-198015)

Two specimens were kept in a single bottle, but they are regarded as a single specimen (ICBN Art. 8.2).

12. *Cordyceps kobayasii* Koval', Klavitsipital'nye Griby SSSR (Kiev) p. 178. 1984.



Figs. 11–16 Specimens determined as holotype (H) or paratype (P). **11** *Cordyceps kanzashiana* (H). **12** *Cordyceps kobayasii* (= *C. sinclairii* Kobayasi) (H). **13** *Cordyceps minuta* (H). **14** *Cordyceps*

ramosipulvinata (H). **15** *Cordyceps ryogamimontana* (H). **16** *Cordyceps pluricapitata* (P). Bars **11, 12, 14–16** 10 mm; **13** 5 mm

≡ *C. sinclairii* Kobayasi, Journ. Jap. Bot. 24: 176, 1949. nom. illeg. (Art. 53.1); non-*C. sinclairii* Berk. Fl. Nov.-Zeal. 2: 338. 1855

Fig. 12 (Holotype TNS-F-212384)

Six dried specimens were found in a box and numbered as TNS-F-212384 collectively. Five specimens were *Isaria cicadae* Miquel. One specimen with an immature stroma was used to describe *C. sinclairii* (Kobayasi 1949). As the description of *C. sinclairii* was based on an immature specimen, additional specimens are required to complete the description of specific characteristics.

Cordyceps sinclairii Kobayasi is a later homonym of that in Berkley (1855). Koval' (1984) gave the new scientific name *Cordyceps kobayasii* Koval' to this species.

13. *Cordyceps minuta* Kobayasi, Bull. Nat. Sci. Mus. 6: 294. 1963.

Fig. 13 (Holotype TNS-F-11933)

14. *Cordyceps ramosipulvinata* Kobayasi & Shimizu, Bull. Natn. Sci. Mus. Tokyo, ser. B. 9:2. 1983.

Fig. 14 (Holotype TNS-F-197979)

The epithet of this species was grammatically corrected from “ramosopulvinata” to “ramosipulvinata” by Sung et al. (2007).

15. *Cordyceps ryogamimontana* Kobayasi, Bull. Nat. Sci. Mus. 6: 303. 1963.

Fig. 15 (Holotype TNS-F-230292)

A paratype (TNS-F-231014) shown in plate 4G in Kobayasi and Shimizu (1963) was also found.

Specimens of other species from Cicadidae

Specimens of *C. pluricapitata* Kobayasi & Shimizu (TNS-F-197965, -198017), the name of which was corrected from “pleuricapitata” (Sung et al. 2007), were found. Although the collection date and original collection number of those two specimens did not correspond to the information of the holotype in the original paper (Kobayasi and Shimizu 1982a), TNS-F-197965 was shown in the photograph in the original paper (fig. 16D; Kobayasi and Shimizu 1982a), and is obviously regarded as a paratype of *C. pluricapitata* (Fig. 16).

A specimen identified as *C. imagamiana* Kobayasi & Shimizu (TNS-F-197966) by Kobayasi was also found. The collection date and collector's name did not correspond to those of the type specimen in their paper (Kobayasi and Shimizu 1983a), and it was recognized as an authentic specimen. Specimens of the three remaining taxa, *Cordyceps nipponica* Kobayasi, *C. owariensis* Kobayasi, and

C. polycephala Kobayasi & Shimizu, were not found in this survey.

Acknowledgments We are deeply grateful to Dr. Joseph Spatafora for giving us invaluable comments on this work, including correction of the English. We also thank Dr. Atsushi Ebihara for his advice on the International Code of Botanical Nomenclature.

References

- Ban S, Sakane T, Toyama K, Nakagiri A (2009) Teleomorph-anamorph relationships and reclassification of *Cordyceps cuboidea* and its allied species. Mycoscience 50:261–272
- Berkley MJ (1855) Supplementum. In: Hooker JD (ed) Flora Novae-Zelandiae Part II. Flowerless Plants. Published under the Authority of the Lords of the Admiralty, London, p 338. (Reprinted in 1963 by Weinheim JC. Wheldon & Wesley, Ltd. and Stechert-Hafner Service Agency, Inc., Codicote, Herts.)
- Kobayasi Y (1939) On the genus *Cordyceps* and its allies on Cicadidae from Japan. Bull Biogeogr Soc Jpn 9:145–176 (+ plates 1–3)
- Kobayasi Y (1941) The genus *Cordyceps* and its allies. Sci Rep Tokyo Bunrika Daigaku Sect B 84:53–260
- Kobayasi Y (1949) Several species of the genus *Cordyceps* and their conidial forms. J Jpn Bot 24:176–180
- Kobayasi Y (1982a) Some pyrenomycetous fungi found in the Amazon District. Trans Mycol Soc Jpn 23:111–117
- Kobayasi Y (1982b) Keys to the taxa of the genera *Cordyceps* and *Torrubiella*. Trans Mycol Soc Jpn 23:329–364
- Kobayasi Y (1983a) Miscellaneous notes of fungi (2). J Jpn Bot 58:174–177
- Kobayasi Y (1983b) Miscellaneous notes of fungi (3). J Jpn Bot 58:221–224
- Kobayasi Y, Shimizu D (1963) Monographic studies of *Cordyceps* 2. Group parasitic on Cicadidae. Bull Natl Sci Mus 6:286–314 (+Pl 39–43)
- Kobayasi Y, Shimizu D (1982a) *Cordyceps* species from Japan 4. Bull Natl Sci Mus Tokyo Ser B 8:79–91
- Kobayasi Y, Shimizu D (1982b) *Cordyceps* species from Japan 5. Bull Natl Sci Mus Tokyo Ser B 8:111–123
- Kobayasi Y, Shimizu D (1983a) *Cordyceps* species from Japan 6. Bull Natl Sci Mus Tokyo Ser B 9:1–21
- Kobayasi Y, Shimizu D (1983b) Iconography of vegetable wasps and plant worms. Hoikusha, Tokyo (in Japanese)
- Koval' EZ (1984) Klavitsipital'nye Griby SSSR. Naukova Dumka, Kiev (in Russian)
- Sato H, Ban S, Masuya H, Hosoya T (2010a) Reassessment of type specimens of *Cordyceps* and its allies described by Dr. Yosio Kobayasi preserved in mycological herbarium of the National Museum of Nature and Science (TNS). Part 1. The genus *Torrubiella*. Mycoscience 51:154–161
- Sato H, Ban S, Masuya H, Hosoya T (2010b) Reassessment of type specimens of *Cordyceps* and its allies described by Dr. Yosio Kobayasi, preserved in the National Museum of Nature and Science. Part 2. *Cordyceps* (*Elaphocordyceps*) on *Elaphomyces*. Mycoscience 51:387–390
- Shimizu D (1994) Color iconography of vegetable wasps and plant worms. Seibundo Shinkosha, Tokyo (in Japanese)
- Sung GH, Hywel-Jones NL, Sung JM, Luangsa-ard JJ, Shrestha B, Spatafora JW (2007) Phylogenetic classification of *Cordyceps* and the clavicipitaceous fungi. Stud Mycol 57:1–63