

SHORT COMMUNICATION

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New causal animal for the growth of *Hebeloma radicosum* (Agaricales): shrew, *Sorex* sp. (Mammalia, Insectivora)

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Abstract *Hebeloma radicosum* fructification occurred in 2003 in Hokkaido where Talpidae moles, known causal animals for *H. radicosum* growth, are not distributed. An excavation carried out in 2005 revealed a mass of deserted latrines and a collapsed nest in the soil. The latrines, being full of deteriorating ectomycorrhizas, were considered to have borne that fungal growth. The responsible animal was identified as a shrew (*Sorex*) species by the characteristics of hairs remaining in the soil. Thus, in addition to the moles (Insectivora, Talpidae) and the wood mouse (Rodentia, Muridae; in Europe), a shrew species (Insectivora, Soricidae) is found to cause *H. radicosum* growth.

Key words Ectomycorrhiza · Hair · Latrine · Mole · Nest

The agaric fungus with the rooting stipe, *Hebeloma radicosum* (Bull.: Fr.) Ricken (Cortinariaceae), has been known to grow specifically on the deserted latrines of fossorial small mammals, especially of moles (Insectivora, Talpidae: *Urotrichus*, *Euroscaptor*, *Mogera*, and *Talpa*). Namely, among 82 cases of *H. radicosum* growth hitherto studied, 78 occurred on the mole latrines and 4 on the wood mouse (Rodentia, Muridae: *Apodemus* in Europe) latrines (Sagara 1999; Sagara et al. 2006; Sagara, unpublished data). We report here a new case of *H. radicosum* growth that occurred on the latrine of a shrew (Insectivora, Soricidae: *Sorex*) species in Hokkaido, northern part of Japan. Hokkaido lacks the distribution of moles (Talpidae), the major causal animals, but has had one record of *H. radicosum* (Imai 1938;

this was the first report of this fungus from Japan). Therefore, the possible causal animal for this fungus in Hokkaido has long drawn special attention (Sagara 1989, 1998, 1999; Sagara et al. 2006).

The study site was located on a hill slope with an altitude of about 60 m and an inclination of about 10° NNW at Midorigaoka, Iwamizawa-shi, Hokkaido, 43°10'44" N, 141°47'22" E (Fig. 1A). The vegetation was dominated by *Quercus crispula* Blume with *Tilia japonica* Simk., *Magnolia obovata* Thunb., *Acer japonica* Thunb., *Prunus* spp., *Rhus ambigua* Lav., *Sasa* sp. (? *S. senanensis* (Franch. et Sav.) Rehder), etc. in its understories. One fruit body of *H. radicosum* and four fruit bodies in one cluster of the same fungus occurred on September 20, 2003, and September 28–October 13, 2003, respectively, at the same point by the side of a trail (Fig. 1A,B). The first find on September 20 (by M. Koyama) happened in the fungus foray held by Hokkaido Kinoko-no-kai (Anonymous 2004). These finds provided the second record for the past 65 years of this fungus from Hokkaido (Igarashi 2006).

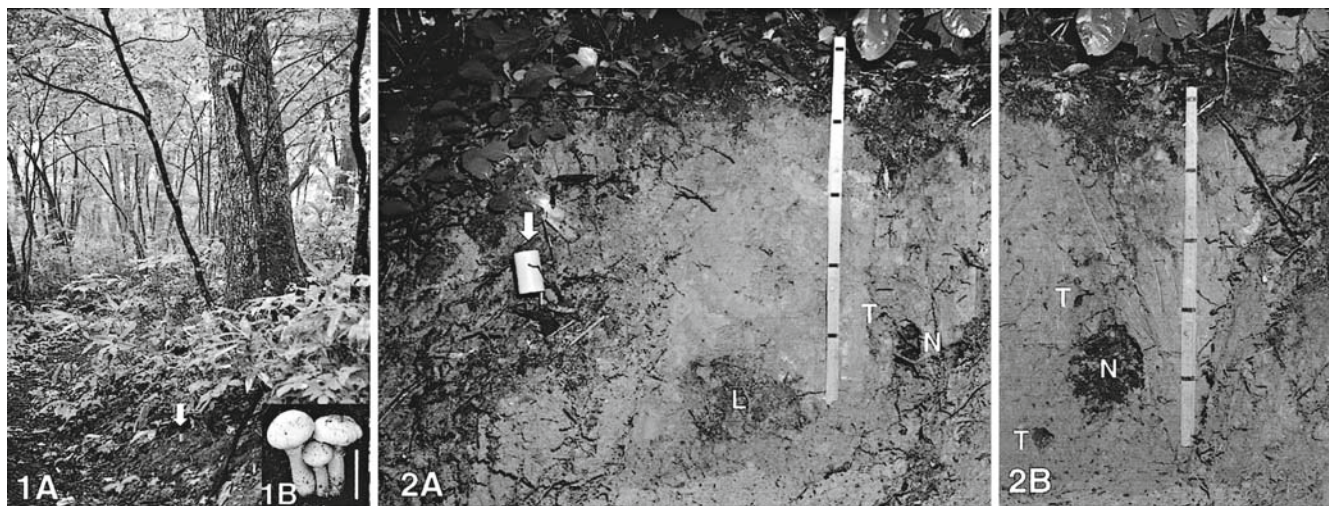
Research procedures hereafter followed Sagara (1998). To determine the cause of that fungal growth, we excavated the ground around the fructification point on August 3, 2005, nearly 2 years after finding the fungus, and searched for the nest as well as the latrines where the fungus should have had colonized. Throughout the excavation, we also investigated the nesting habits of the animal concerned. To identify this animal, we sorted out hairs remaining in the nest and latrines, which had been collected by the excavation, and examined their characteristics. We also taken the nesting habits into consideration in this identification. The fruit-body specimens from October 13 have been preserved at the personal herbarium of T. Igarashi as IG-30187, which will go to the Hokkaido University Museum, Sapporo, in the future (the specimen from September 20 has been lost). The collections from the excavation, i.e., the deserted latrines, the nest, and hair samples therefrom, have been deposited at the Kyoto University Museum, Kyoto, inclusively as package no. 107.

The excavation revealed a mass of deserted latrines at a depth of 30–40 cm (Fig. 2A). The latrines, resembling those

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Figs. 1, 2. Site of *Hebeloma radicosum* fructification at Iwamizawa, Hokkaido, and observations by excavation. **1A** *Quercus crispula* forest and the fructification point therein, marked with a film container (arrow; the point was roughly recalled). **1B** Fructification of *H. radicosum*. **2A** Soil profile under the recalled fructification point (arrow),

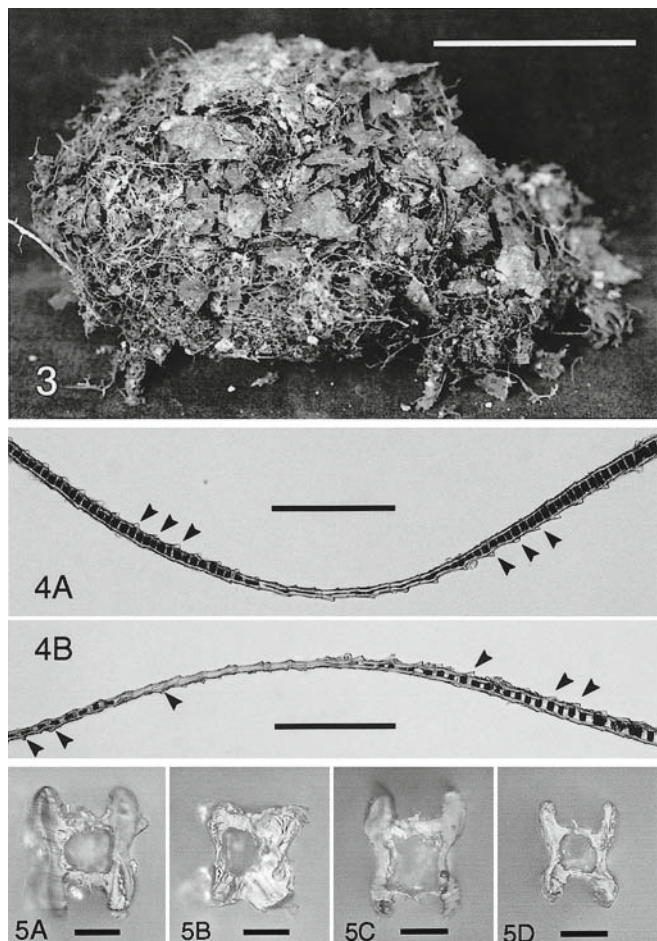
showing the deserted latrines (L), tunnel (T), and a part of the nest (N). **2B** Another profile after further digging, showing the tunnel (T) and the nest chamber with an old nest (N). Photographs **1A** taken on 3 August 2005; **1B** on 11 October 2003; **2A,B** on 3 August 2005. Bars **1B** 5 cm; **2A,B** 10-cm intervals

of Talpidae moles (Sagara 1999), were full of deteriorating ectomycorrhizas and invertebrate exoskeleton fragments excreted undigested by the animal. These mycorrhizas must have borne that *H. radicosum* fructification, as is found in Talpidae mole latrines (Sagara 1995, 1999). The predominance of *Q. crispula* trees at the site would be relevant to this observation, as they seem to act as ectomycorrhizal partners for *H. radicosum* (Sagara 1995, 1999). The excavation also revealed an old, collapsed nest that had obviously been abandoned (Figs. 2B, 3). The nest chamber containing this nest was subspherical, about 12 cm in horizontal diameter and 15 cm in vertical diameter. The tunnel connecting to the nest chamber measured 20×18 mm, 37×23 mm, and 28×22 mm (horizontal diameter \times vertical diameter) at different points. The tunnel system around the nest chamber exhibited the mole (Talpidae) type but not the mouse (Muridae, *Apodemus*) type. Namely, the nest chamber had a hole at its bottom, a hole that was not connected to the nest cavity (resting and sleeping place) but to a tunnel running beneath that bottom (Sagara 1998, 1999). The mouse tunnel system does not have such a structure (Sagara et al. 2006). The nest was made from fallen broad-leaves (Fig. 3). As the nest was quite old, it had been enclosed by tree rootlets absorbing nutrients from the decaying nest material (see fig. 19 in Sagara 1999).

Igarashi (2006) made an excavation with this very case at the time of fructification in 2003 but did not specify the animal involved. He observed the presence of a tunnel (2.8 cm diameter) and a pile of broken fallen leaves at a depth of 20 cm beneath the fruit bodies. The tunnel size is consistent with our observation. The true nature of the fallen leaf pile remains unsolved. It might have been an abandoned “rudimentary nest” (Churchfield 1990). Or, it could have been the nest material discarded on the way to the nest, as is occasionally observed in the nesting sites of Talpidae moles (Sagara, unpublished data).

The hairs found from the nest and latrines all showed the characteristics of moles (Talpidae) or shrews (Soricidae). Namely, in the fine hairs (= “awns” and “furhairs” in Sagara 1986), the scales protruded on one side between the constrictions and the protruding scales “crossed over” at the constrictions (Fig. 4A,B; Day 1966, Teerink 1991). Moles are not distributed here in Hokkaido and hence only shrews were to be considered. With shrews (Soricidae), four soricine shrew (*Sorex*) species and one crocidurine shrew (*Crocidura*) species are distributed in Hokkaido (Abe 2005). For European species, *Sorex* and *Crocidura* can be distinguished by the shape of a cross section taken at the thickest part of a fine hair (= awn, = GH2 sensu Teerink 1991), as it is “H-shaped” in *Sorex* but not so (rather rounded) in *Crocidura* (Teerink 1991). We verified that this also holds for Japanese counterparts (Fig. 5A,B), and found that the hairs from the present case showed the *Sorex* type but not the *Crocidura* type (Fig. 5C,D). Thus, both the latrine maker and the nest user could be identified as one of the *Sorex* species.

Identification to species within the shrew genus *Sorex* is somewhat difficult and remains undetermined. Among the four *Sorex* species distributed in Hokkaido, *Sorex minutissimus* Zimmerman may first be excluded, because this species does not seem to occur in the area around the study site (Abe 2005). *Sorex gracillimus* Thomas and *S. caecutiens* Laxmann may also be excluded because they are surface dwelling (Yokohata 1998). *Sorex unguiculatus* Dobson is likely, because it is semifossorial and almost comparable to *Urotrichus* (shrew-mole) species in having a larger body size with larger front feet, which suggests stronger digging ability (Yokohata 1998; *U. talpoides* is a known causal animal for *H. radicosum* growth, see Sagara 1999). Shrews may occupy and modify tunnels created by other small mammals more skilled in burrowing (Churchfield 1990). Therefore, we should not eliminate the possibility that a certain other animal, e.g., a mouse (Muridae) species, had



Figs. 3–5. Materials for identification of the causal animal. **3** Nest collected from the soil profile shown in Fig. 2B, with its entrance probably at right. **4A,B** Micrographs of the fine hairs detected from the latrines (**A**) and nest (**B**), showing the animal in question belongs to Talpidae or Soricidae because of the protrusion of scales (arrowheads) that are one-sided and reversed through a constriction. **5A–D** Micrographs of the cross sections of the fine hairs (“awns”; see text), showing the animal in question was a shrew species (Soricidae, *Sorex*) because of the “H-shape” in the sections (incident light microscopy): **A** hair from a *Sorex unguiculatus* specimen (collected by T. Kobayashi at Shibecha, Hokkaido); **B** hair from a *Crocodyria dzinezumi* specimen (collected by H. Abe at Tadami, Fukushima Pref.); **C** hair from the latrines studied; **D** hair from the nest studied. Both **C** and **D** show the same type as **A** (*Sorex* type: “H-shape”) but not **B**. Bars **3** 5 cm; **4A,B** 100 μ m; **5A–D** 10 μ m

originally constructed the nest and tunnel in question, although we could not find hairs other than the *Sorex* shrew hairs among the collected materials.

We now find that, in addition to moles (Talpidae: *Urotrichus*, *Euroscaptor*, *Mogera*, *Talpa*) and the wood mouse (Muridae: *Apodemus*), a shrew species (Soricidae: *Sorex*) can cause the growth of *H. radicosum*. Because shrews (Soricidae) belong to the order Insectivora to which moles (Talpidae) also do, there may be little surprise as to the range of causal animals. Instead, one may ask why the records of *H. radicosum* from Hokkaido are so scarce. And, why has such a *Sorex* shrew-*H. radicosum* association not been discovered until now despite the fact that *Sorex* shrews are, besides Hokkaido, so widely and abundantly distrib-

uted in the Northern Hemisphere (Churchfield 1990)? Answers might be sought as follows.

The geographic distribution range of *Sorex* shrews (Corbet 1978; Wilson and Ruff 1999) and that of the northern coniferous forests (Polunin 1960) almost overlap. It means that the *Sorex* shrew range is generally dominated by Pinaceae trees, which do not seem to act as mycorrhizal hosts for *H. radicosum* (Sagara 1995, 1999). Furthermore, in North America, *H. radicosum* is not possibly distributed whereas many *Sorex* species are. Thus, the coexistence of all three components – *Sorex* shrews, *H. radicosum*, and mycorrhizal host plants (Fagaceae, Betulaceae, or Salicaceae; Sagara 1999) – could occur rather rarely. This circumstance should reduce the chance of *H. radicosum* growth associated with *Sorex* shrews in the regions concerned. The amount of excrement deposition by *Sorex* shrews is possibly smaller than that by Talpidae moles because the former have a smaller body size and shorter lifespan (Churchfield 1990; Gorman and Stone 1990). This condition also could reduce the growth chance of *H. radicosum* in association with *Sorex* shrews, although little is known about the excretion habits of *Sorex* shrews relating to latrine making in the wild.

The present finding may stimulate investigations into the possible occurrence of similar *Sorex* shrew-*H. radicosum* associations in cooler regions besides Hokkaido. [Associations of *Sorex* shrews with *Hebeloma danicum* Gröger (syn. *H. spoliatum* (Fr.) Karst.) should also be possible there; see Sagara (1999) for *H. danicum*.] Furthermore, this finding may open a window to shrew ecology, as the discovery of the Talpidae mole-*H. radicosum* association has led to shedding light on the mole nesting ecology (Sagara 1998, 1999).

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