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The first fossil of *Ceratophyus* (Coleoptera, Geotrupidae) from the Middle Pleistocene Shiobara Group of Nasushiobara City, Tochigi Prefecture, Japan

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Abstract. A new fossil species of the genus *Ceratophyus* Fischer von Waldheim, 1824, was discovered in the Shiobara Group (Chibanian, ca. 0.3 Ma) of the Middle Pleistocene distributed in Nasushiobara City, Tochigi Prefecture, Japan. This fossil is female, large in size (ca. 25 mm), well preserved, and nearly completely preserved. The genus *Ceratophyus* is not distributed in modern Japan. This is the first discovery of a fossil of the genus *Ceratophyus* and the first report of a certain extinct species from the Shiobara Group. The genus *Ceratophyus* is now fragmentarily distributed in the Holarctic region of the world, but the discovery of the fossil suggests that the genus was widely distributed throughout the world during the Middle Pleistocene. Notably, the fossil was discovered by a student during a high school lesson from a rock brought into the classroom. We consider the examined fossil to be morphologically different from all known extant species of the genus, and therefore we describe it as *Ceratophyus yatagaii* sp. nov.

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Keywords: *Ceratophyus*, fossil insect, Geotrupidae, Middle Pleistocene, Shiobara Group

Introduction

Ceratophyus Fischer von Waldheim, 1824, is a coprophagous genus classified in the earth-boring scarab subfamily Geotrupinae (Scarabaeoidea: Geotrupidae), which is distributed in the Holarctic region (Zunino, 1973). A total of 14 species are known. Of these, six species—*C. alloini* Prunier, Tauzin and Rosset, 2016, *C. hoffmannseggii* (Fairmaire, 1856), *C. maghrebinicus* Hillert and Král, 2013, *C. martinezi* Lauffer, 1909, *C. rossii* Jekel, 1865 and *C. schaffrathi* Hillert and Král, 2013—are distributed in the Mediterranean region; one species, *C. polyceros* (Pallas, 1771), is distributed in the Central Palearctic; six species—*C. amdoensis* Král *et al.* 2020, *C. dauricus* Jekel, 1865, *C. kabaki* Nikolajev, 2007, *C. mesasiaticus* Medvedev and Nikolajev, 1974, *C. sinicus* Zunino, 1973 and *C. sulcicornis* (Fairmaire, 1887)—are distributed in the Eastern Palearctic, and only one species, *C. gopherinus* Cartwright, 1966, is distributed in the Nearctic (Cartwright, 1966; Hillert and Král, 2013; Prunier *et al.*, 2016; Král *et al.*, 2020; Schoolmeesters, 2023).

Fossils of the family Geotrupidae are very rare, and only 28 species have been reported so far, excluding those from the Holocene, such as in archaeological deposits (Mitchell, 2013). From Japan, *Phelotrupes auratus* (Motschulsky, 1857) have been reported from the Upper Pleistocene Nojiri-ko Formation (Fossil Insect Research Group for Nojiriko Excavation, 1987). Among them, no fossils of the genus *Ceratophyus* have been discovered.

The Shiobara Group of the Middle Pleistocene (ca. 0.3 Ma) is a conservation Lagerstätte composed of lacustrine deposits distributed in Nasushiobara City, Tochigi Prefecture. Well-preserved plant and insect fossils have been obtained from this region, and more than 100 species of insect fossils have been reported to date (Aiba, 2015; Aiba *et al.*, 2022; Takahashi and Aiba, 2023). A review of the geological and paleontological background can be found in Tuzino *et al.* (2009) and Aiba (2015). Aiba (1997) developed a science lesson plan on rocks from the Shiobara Group in which fossils were collected in the classroom. Many Japanese schools now incorporate this practice (Aiba, 2016). Recently, the *Ceratophyus* fossil

was discovered by a student during a science class in a senior high school. Through comparison of fossil species with extant species, it was identified as a new species and is described here. This is the first fossil discovery of the genus *Ceratophyus*.

Material and methods

The fossil was discovered by a student, Kouta Yatagai, during a high school (Keio Senior High School, 4-1-2, Hiyoshi, Kohoku-ku, Yokohama City, Kanagawa Prefecture, Japan) science lesson in September 2022. Naoki Matsumoto, a science teacher, then provided it to the authors. The studied specimen was deposited at the Keio Yochisha Science Museum, 2-35-1, Ebisu, Shibuya-ku, Tokyo, 150-0013, Japan, with repository number KYFSI209. Because many of the extant specimens for comparison are difficult to obtain, descriptions and figures from articles and photos from credible web pages were used. The material was examined using a Leica M205 C microscope (Leica Corporation, Wetzlar, Germany). Photographs and measurements were taken using a Leica MC170HD microscope with Leica Application Suite Version 4.1.3. Photographs were sharpened and adjusted for contrast and tonality using Adobe Photoshop™ version CS6 (Adobe Systems Incorporated, San Jose, CA, USA). The distribution records of the species were mapped using SimpleMappr (Shorthouse, 2010), and the morphological terminology followed that of Hillert and Král (2013).

Systematic paleontology

Order Coleoptera Linnaeus, 1758
 Family Geotrupidae Latreille, 1802
 Subfamily Geotrupinae, Latreille, 1802
 Genus *Ceratophyus* Fischer von Waldheim, 1824
Ceratophyus yatagaii sp. nov.
 [New Japanese name: Yatagai Tsunosenchikogane]

Figures 1, 2, 3, and 4A

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Type specimen.—Holotype, KYFSI209, almost complete female, consisting of two parts: a concave impression showing dorsal side (KYFSI209a: Figures 1A, 1B, 1C, 2B, 2C, and 3) and a convex counterpart exhibiting ventral side (KYFSI209b: Figure 2A, D).

Type locality and horizon.—The specimen was collected from siltstone laminites of the Middle Pleistocene Miyajima Formation of the Shiobara Group exposed in a fossil quarry located at the Konoha Fossil Museum

(36°58'52"N, 139°48'23"E) in Nasushiobara City, Tochigi Prefecture, Central Japan.

Etymology.—After Mr. Kouta Yatagai, fossil discoverer.

Diagnosis.—Large-sized, earth-boring scarab beetles. Apical protibial tooth elongated anteriorly and rounded at the apex. Apical spur long and conspicuous, protruding interior directed. Pronotum impunctate with broadly rounded anterior margin and distinct midline.

Description (female).—Body robust, strongly sclerotized throughout, approximately twice as long as wide. Scutum not preserved.

Head shown in Figure 1B. Mandibles protruding anteriorly, with broadly rounded, bisinuate external outline, apex bifid, and outer tooth longer than inner tooth (Figure 2C). Labrum transverse, anterior edge straight, and punctures not visible. Part of the galea and maxillary palps visible. Clypeus triangular, impunctate, with distinct longitudinal carina. Oblique keels above eyes distinct, reaching level of anterior outline of eyes. Right antenna (Figure 1C) entirely preserved, short, almost as long as mandible, brown throughout, with 11 antennomeres. Antennomere I (scape) swollen, 2.5 times as long as antennomere II. Antennomere II short, slightly widened apicad. Antennomere III long, 1.5 times as long as antennomere II. Antennomere IV and V of same length, slightly widened apicad. Antennomeres VI, VII, and VIII noticeably short, but details not visible. Club oblong, 1.5 times as long as wide, but details not visible.

Thorax (Figures 1A and 3). Pronotum distinctly transverse, broadest at middle, impunctate, with transverse protuberance anteriorly, all around entirely bordered, anterior angles broadly rounded, posterolateral angles rounded, and midline distinctly visible.

Elytra (Figures 1A, 2A, and 3) slightly longer than wide, broadest at middle, between inner suture and humerus with seven striae, all well impressed along entire length of elytron. Stria 1, 3, and 4 reaching apex of elytron, but stria 2 not. Interval slightly convex and impunctate.

Legs (Figures 1A, 2A, 2B, and 2D). Profemur (Figure 2A) not curved, swollen at middle; protibia (Figure 2A, D) conspicuous, with six teeth at outer margin. Apical protibial tooth elongated anteriorly and rounded at apex; Subapical protibial tooth widens at base and rounded at apex laterally; Third protibial tooth shortened, rounded at apex; Fourth to sixth protibial tooth gradually shortened, slightly acute at apex. Apical protibial spur long and conspicuous, longer than apical protibial tooth, with protruding interiorly. Mesocoxa and mesofemur preserved, but details not visible. Mesotibia armed markedly with three transverse external carinae. Mesotarsus preserved but metacoxa and metafemurs not. Metatibia slightly armed with three transverse external carinae

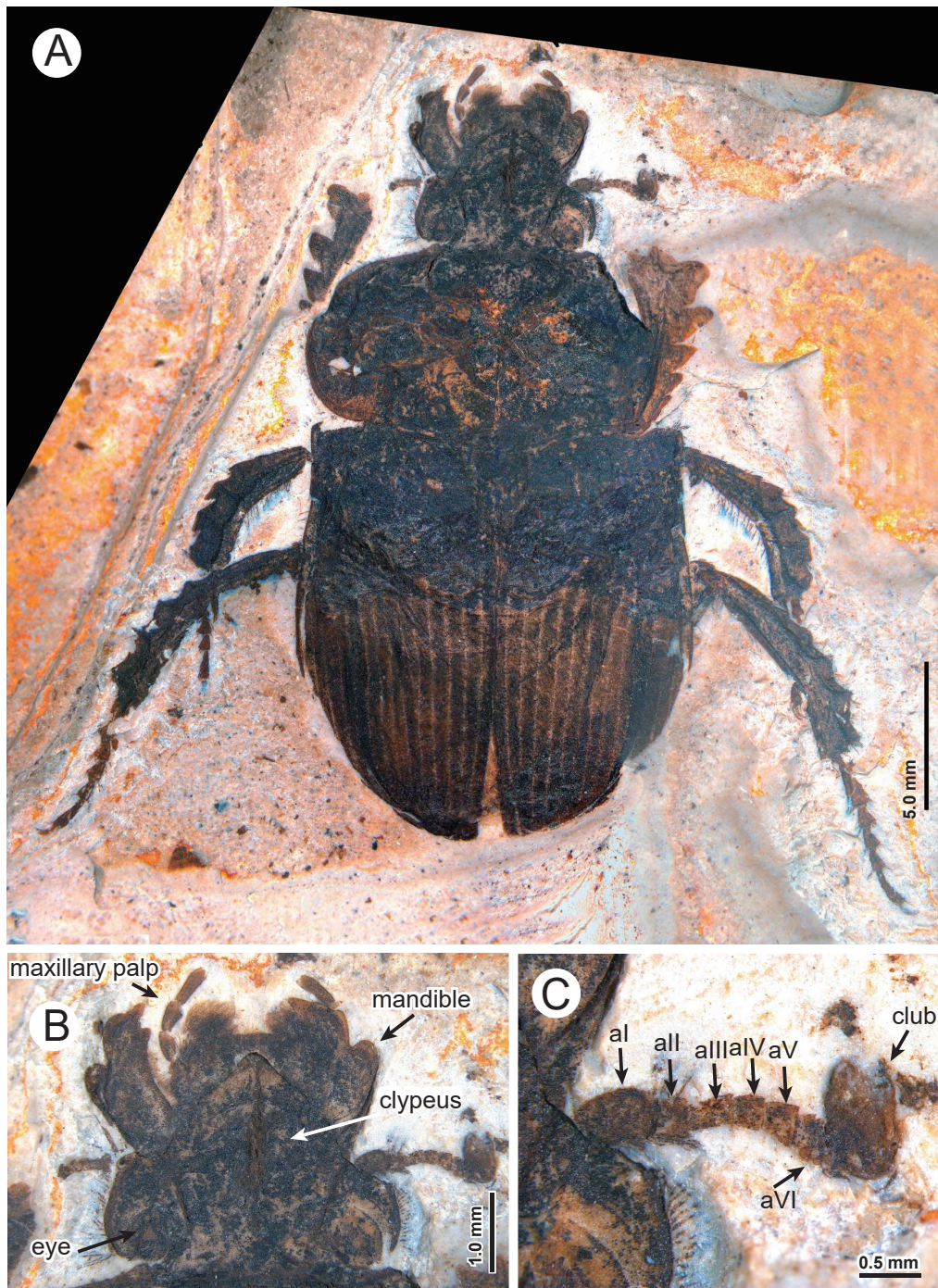


Figure 1. Photographs of *Ceratophyus yatagaii* sp. nov., holotype, KYFSI209a (female). **A**, dorsal view; **B**, enlarged head; **C**, enlarged right antenna. Abbreviations: aI–VI, antennomere I–VI.

(Figure 2B). Metatarsus longer than mesotarsus, with five tarsomeres.

Measurements (in mm): body length 24.52 (from anterior margin of labrum to elytra apex); head length 4.65; maximum width across compound eyes of head 5.87;

lengths of antennomeres I– VIII, club (IX–XI) were 0.68, 0.28, 0.39, 0.29, 0.29, 0.16, 0.07, 0.07, and 1.07, respectively; median length of pronotum 6.72; elytra length 13.52; and maximum width of elytra 13.12.

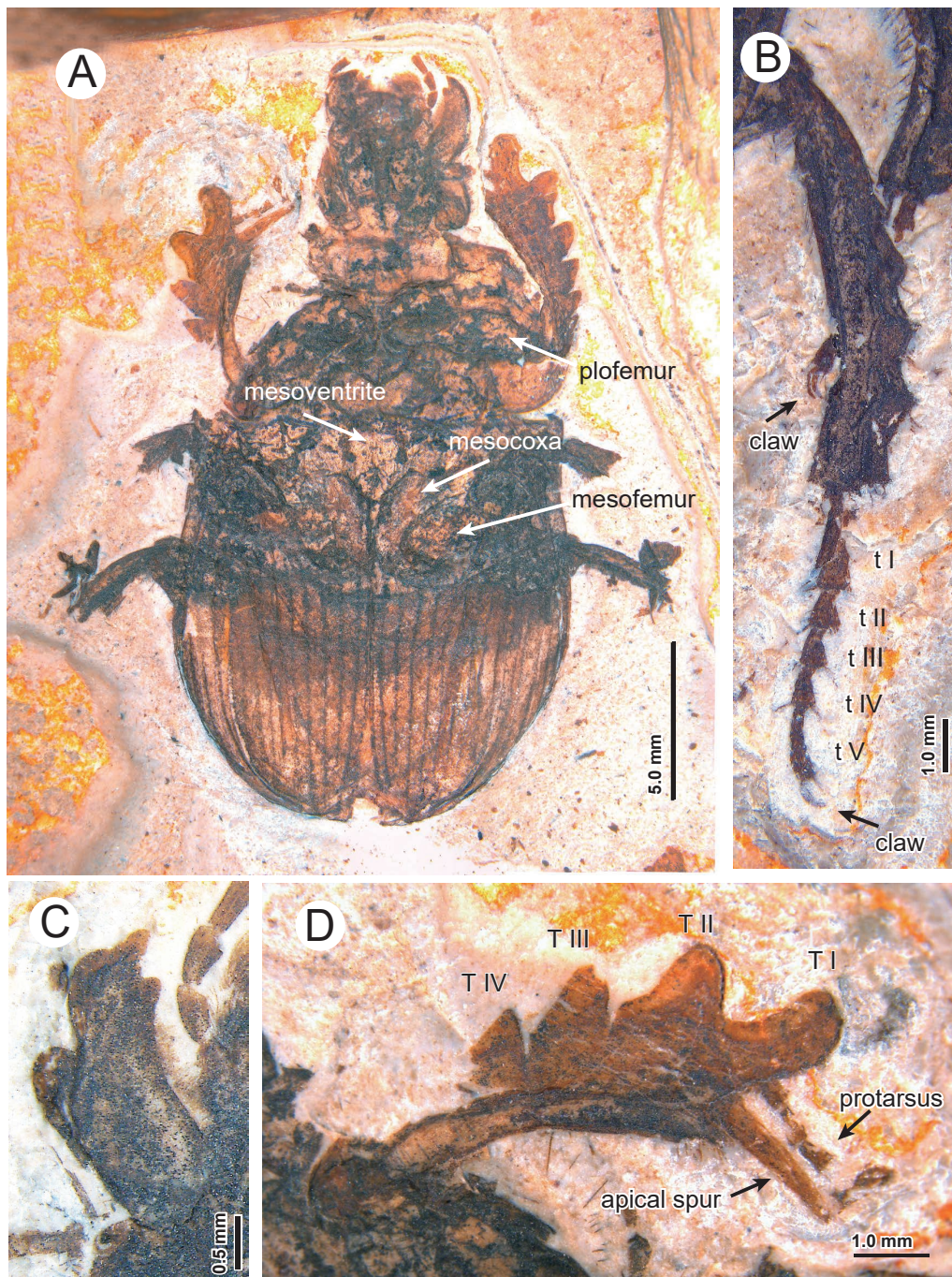


Figure 2. Photographs of *Ceratophyus yatagaii* sp. nov., holotype, KYFSI209 (female). **A**, ventral view; **B**, enlarged right hindleg; **C**, enlarged left mandible; **D**, enlarged right protibia. **A**, **D**, KYFSI209b, counterpart; **B**, **C**, KYFSI209a. Abbreviations: T I, apical protibial teeth; T II, subapical protibial teeth; T III, third protibial teeth; T IV, fourth protibial teeth; t I–V, tarsomere I–V.

Discussion

Morphological comparison

The fossil was clearly identified as belonging to the genus *Ceratophyus* because its mandibles protrude anteri-

orly with a broadly rounded bisinuate external outline and its transverse pronotum (Hillert and Král, 2013). Males of the genus *Ceratophyus* have horns on their pronotum, and females have a transverse protuberance anteriorly (Hillert and Král, 2013), indicating that the fossil is a female.

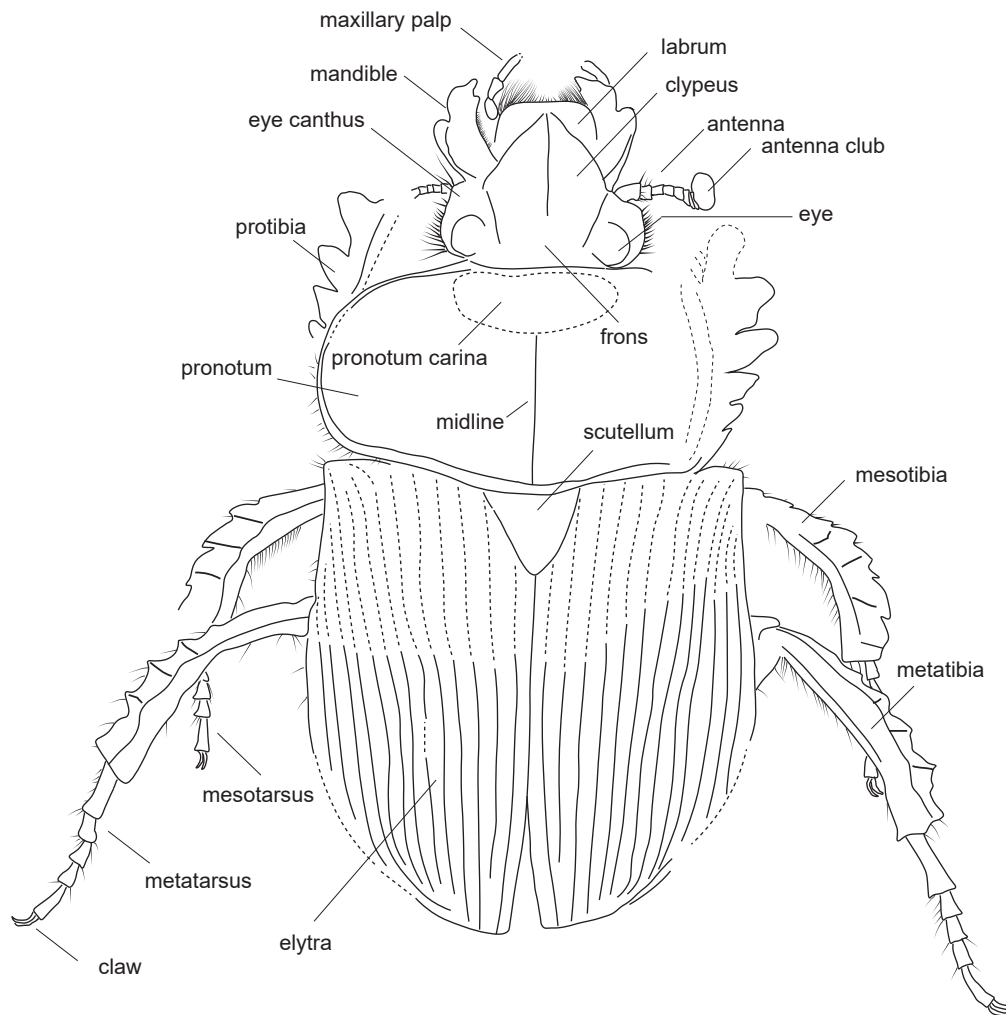


Figure 3. Line drawing of *Ceratophyus yatagaii* sp. nov., female holotype.

Fourteen species of the genus *Ceratophyus* known worldwide have been described, but the fossil is clearly distinguishable from them by the following: (1) Apical protibial tooth is elongated anteriorly and rounded at apex (Figure 4A). While in other species this is acute, tapering, pointing outwards (Figure 4B, C, E–H); the exceptional female of *C. schaffrathi* has a rounded anterior tip (Figure 4D), but is apparently smaller than the fossil. (2) Apical protibial spur is long and conspicuous, protruding interiad (Figure 4A). While in other species this is smaller and anteriorly directed (Figure 4B–H). (3) Anterior margin of pronotum is broadly rounded (Figure 4A). While in other species this is slightly constricted (Figure 4B–H). (4) The midline of the pronotum distinctly remarkable (Figure 4A), in contrast to those of other species, in which this is absent or indistinct (Figure 4B–H).

A female *C. amdoensis* has not yet been described because a female has not been previously found (Král *et*

al., 2020). However, it is not possible to identify the fossil as a female *C. amdoensis*. This is because the distribution of the genus *Ceratophyus* is narrow and restricted, as shown in Figure 5, and the fossil locality and distribution of *C. amdoensis* are far apart.

As a result, the fossil clearly did not match any of the extant species, and therefore it was identified as a new species. If male fossils are discovered in the future, more detailed comparisons with the present species will be possible.

World distribution of the genus *Ceratophyus* and significance of fossil

The current global distribution of the genus *Ceratophyus* is illustrated in Figure 5, based on previous studies (Cartwright, 1966; Hillert and Král, 2013; Prunier *et al.*, 2016; Král *et al.*, 2020). The distribution of the genus *Ceratophyus* is narrow and fragmented. Globally, the genus

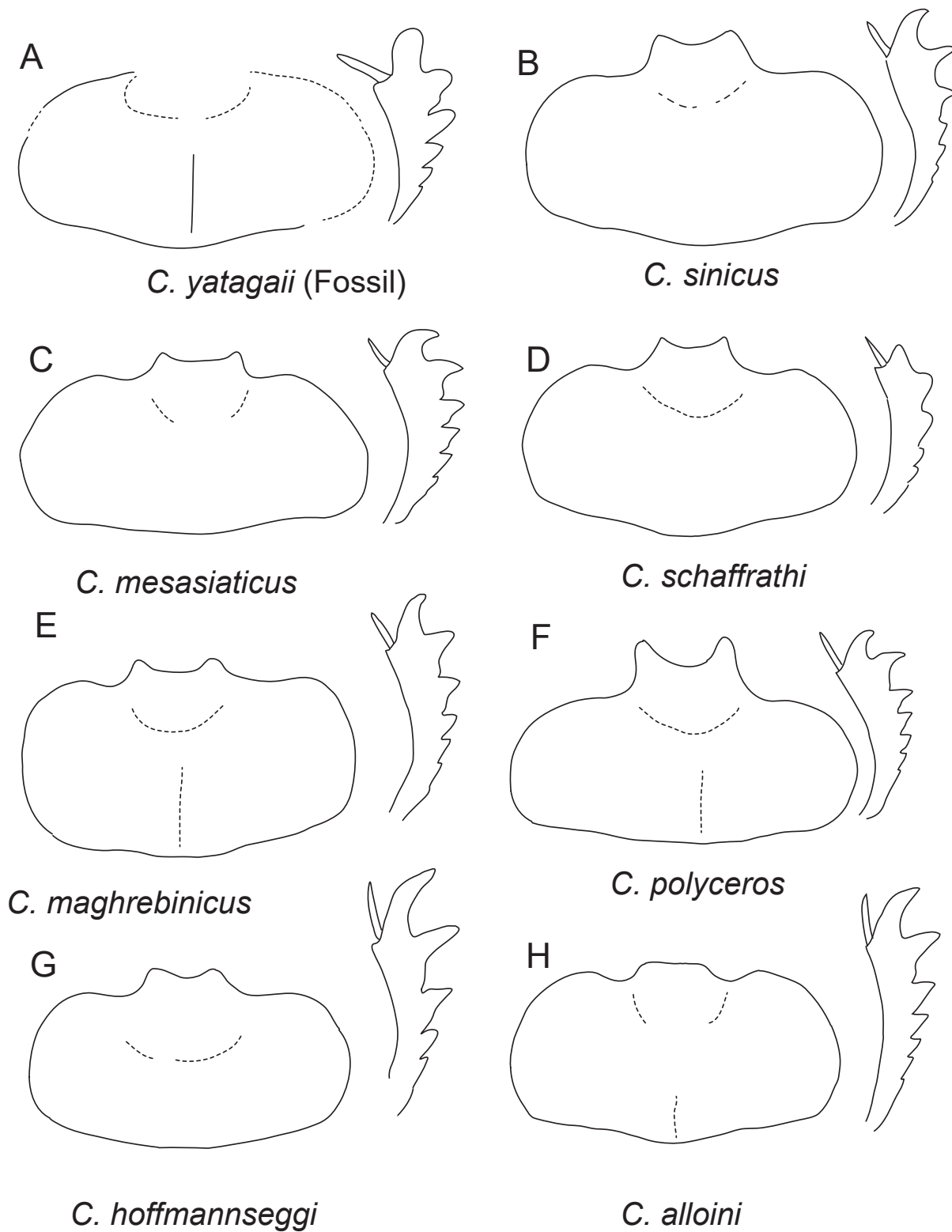


Figure 4. Comparison of pronotum and protibia of some females of genus *Ceratophyus*. **A**, *Ceratophyus yatagaii* sp. nov., this study; **B**, *C. sinicus* after Zicha *et al.* (2015); **C**, *C. mesasiaticus* after Zoological Institute RAS (2015–2020); **D**, *C. schaffrathi* after Hillert and Král (2013); **E**, *C. maghrebinicus* after Hillert and Král (2013); **F**, *C. polyceros* after Peter (2007–2023); **G**, *C. hoffmannseggii* after LMDI (2002–2023); **H**, *C. alloini* after LMDI (2002–2023).

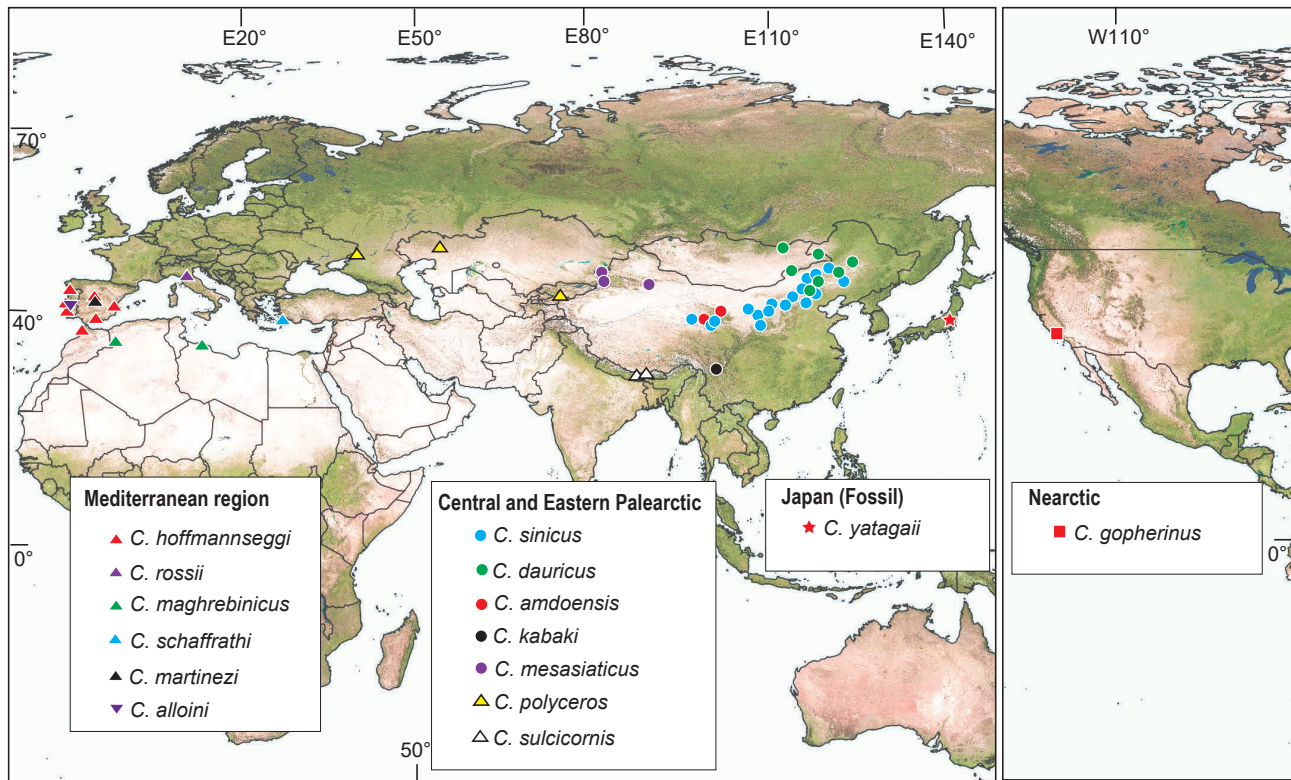


Figure 5. Map of world distribution of *Ceratophyus* species. circle, after Král *et al.* (2020); inverted triangle, after Prunier *et al.* (2016); square, after Cartwright (1966); star, this study; triangle, after Hillert and Král (2013).

Ceratophyus is distributed in three regions: along the Mediterranean and in the Central and Eastern Palearctic regions (Figure 5). The Mediterranean region is not very high in altitude and has a relatively warmer climate (Hillert and Král, 2013), whereas the Central and Eastern Palearctic regions are at higher latitudes or altitudes and have a colder and drier climate (Král *et al.*, 2020). The isolated, probably relict occurrence of *C. gopherinus* in the Nearctic region (California only) is also very interesting from a zoogeographic point of view. Based on the composition of plant fossils, the paleoclimate of the Middle Pleistocene Shiobara Group is considered to have been relatively wet and warm, with a predominance of tall deciduous forests (Onoe, 1989). However, the genus *Ceratophyus* is not distributed in modern Japan or neighboring countries in warmer areas. This suggests that *Ceratophyus* was widely distributed in East Asia during the relatively warm period of the Middle Pleistocene.

All insect fossils described from the Shiobara Group were identified as extant species (Aiba, 2015). However, some of these were not morphologically identical to any extant species and could not be identified as a species (e.g. Aiba *et al.*, 2019: Gomphidae gen. *et.* sp. indet.; Aiba, *et al.*, 2021: *Uhlerites* sp.). The discovery of this

new species suggests that more extinct species might be discovered in the Middle Pleistocene Shiobara Group in the future.

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Author contributions

H.A. initiated the study, drafted the manuscript, and compiled all figures. D.K. revised the manuscript and provided taxonomic input. All authors contributed to the writing of the paper.