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Author(s): Junji Moribe and Yasushi Yokohata

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Mixed distribution of *Mogera imaizumii* and *Mogera wogura* in the Tedoru Alluvial Fan in Ishikawa Prefecture, Japan

Junji Moribe** and Yasushi Yokohata*.*.*

Laboratory of Environmental Biology, Faculty of Education, Toyama University, Gofuku 3190, Toyama City, Toyama 930-8555, Japan

Abstract. Distributions of the lesser Japanese mole (*Mogera imaizumii*) and the larger Japanese mole (*Mogera wogura*) were researched in the Kanazawa Plain of Ishikawa Prefecture, Japan, from 2001 to 2002, based on the different diameters of their tunnels. *M. imaizumii* and *M. wogura* were found at 63 and 65 different sites, respectively. *M. imaizumii* is excluded from most areas colonized by *M. wogura*, but the two species were found together in the Tedoru Alluvial Fan. At this location, the tunnels of *M. imaizumii* were found in areas with harder soil at a depth of 0–20 cm, whereas those of *M. wogura* were found in areas with softer soil at the same depth. This is the first observed case of a mixed distribution of these two species of Japanese moles on a plain in a large geomorphological structure, such as an alluvial fan. This phenomenon may be attributable to the sediment characteristics in an alluvial fan, where various sediments with different diameters, from crude stone to fine clay, are distributed in a complex mosaic pattern.

Key words: alluvial fan, mixed distribution, *Mogera*, mole, soil hardness.

The lesser Japanese mole (*Mogera imaizumii*) is distributed mainly in eastern Honshu with some isolated areas in western Honshu and Shikoku, while the larger Japanese mole (*Mogera wogura*) inhabits western Honshu, Shikoku, and Kyushu. A strong competitive exclusion is known to occur between these two species (Abe 1967, 1968, 1974, 1999, 2001, 2010; Reviewed in Abe 1985; Nakagawa 1985; Nezu 1990; Yokohata 1998, 2009; Hosoda and Tsuyuguchi 2000; Saito et al. 2003). These studies have indicated that the larger species, *M. wogura*, is more dominant than the smaller species, *M. imaizumii*, in areas where these species are parapatrically distributed, such as the Kiso and Ina Valleys of Nagano Prefecture, central Japan. In these areas, *M. imaizumii* is completely excluded from habitats colonized by *M. wogura*. Studies on the competitive relationships between these two species have been performed in detail in Nagano and Shizuoka Prefectures in the southern parts of the boundary area, i.e., the area where the distributions of these two species meet. There have been only a few studies in the northern parts of the boundary area, such as the

Kanazawa Plain in Ishikawa Prefecture (Abe 1999, 2010).

In this study, we researched the distributions of these two species of moles in the Kanazawa Plain from 2001 to 2002. During the investigation, an area was identified where these two species have a mixed distribution in an alluvial fan. We describe the distribution pattern of these two species in that area and certain neighboring areas. The factors contributing to the mixed distribution are discussed.

Study area and methods

The Kanazawa Plain is located in the central region of Ishikawa Prefecture in Honshu, Japan (latitude 36°20' to 36°40'N, longitude 136°20' to 136°45'E), extending from the northeast to the southwest. The Tedoru River runs through the central part of the Kanazawa Plain from southeast to northwest, and forms a large alluvial fan. The lower edge of the Tedoru Alluvial Fan ends at the coast of the Sea of Japan (Fig. 1). The Tedoru Alluvial

*To whom correspondence should be addressed. E-mail: yokohata@sci.u-toyama.ac.jp

**Present address: Department of Oral Anatomy, Asahi University School of Dentistry, 1851 Hozumi, Mizuho City, Gifu 501-0296, Japan

***Present address: Graduate School of Science and Engineering, University of Toyama, Gofuku 3190, Toyama City, Toyama 930-8555, Japan

Fan contains various sediments with a range of diameters, from crude stone to fine clay. These sediments have been transported by great floods, caused by very large amounts of rainfall, as well as spring thaw water from nearby mountains. The various sediments are distributed in the Tedoru Alluvial Fan in complex mosaic patterns (Konno 1992; Konno et al. 1992). Other parts of the Kanazawa Plain have typical alluvial plains with uniform sediments.

A field survey was conducted from October 23 to December 12 in 2001 and from May 13 to 14 in 2002. The tunnels of *M. imaizumii* and *M. wogura* can be distinguished based on their diameters. In the Kanazawa Plain, the horizontal and vertical diameters of the tunnels of *M. imaizumii* are about 4.0–4.5 cm and 4.0 cm respectively. The horizontal and vertical diameters of tunnels of *M. wogura* are ≥ 5.0 cm and ≥ 4.0 cm, respectively (Abe 1999). At 128 different sites, which include various land use patterns such as rice fields, farmlands, parks, and dunes near seashores, the tunnels of moles were excavated, and their horizontal and vertical diameters were measured. The results of the measurements are represented as mean (*SD*) and range. Furthermore, soil hardness was measured at 2.5 cm depth intervals from 0 to 60 cm at 41 sites (19 and 22 sites of *M. imaizumii* and *M. wogura*, respectively), using an intrusive proctor needle (DIK-5520, Daiki-rika-kogyo, in Akagidai, Kounosu City, Saitama Prefecture, Japan) according to the method of Abe (2001). This measurement was repeated at least 10 times at each site, and the means and standard deviations were calculated for each 2.5 cm depth interval.

Additionally, two specimens of moles (Accession Nos. 00052 and 00058, obtained in 1983 and 1982, respectively, and deposited in Komatsu Municipal Museum in Komatsu City, Ishikawa Prefecture) from the western parts of the Kanazawa Plain were examined and identified. The differentiation between *M. imaizumii* and *M. wogura* is usually based on differences in the shape of the upper incisor row (Abe 1967), but the incisor row could not be observed in these specimens. On the other hand, the body sizes of these two species become very distinct in parapatric distribution areas of *Mogera* spp., such as the Ishikawa Plain (Abe 1967), so that the identification was based mainly on body size.

Results

Of the 128 sites, 63 were recognized as being inhabited by *M. imaizumii*, and 65 were recognized as being

inhabited by *M. wogura*. The horizontal and vertical diameters of the tunnels of *M. imaizumii* were 41.4 ± 1.9 mm (range, 39–47 mm) and 35.3 ± 1.3 mm (range, 33–39 mm), respectively, whereas those of *M. wogura* were $53.0 \text{ mm} \pm 3.3$ (range, 47–62 mm) and $44.7 \text{ mm} \pm 3.0$ (range, 40–52 mm), respectively. The northern distribution limit of *M. wogura* was found to be near Tsubata (Fig. 1), near the northern end of the Kanazawa Plain. This is similar to the results of Abe (1999, 2010), and most areas of the plain were occupied by this species. However, a mixed distribution of the two species was observed in the Tedoru Alluvial Fan (Fig. 1). The mixed distribution was more distinct in the southwestern region of the fan than in the northeastern region. Evidence for the distribution is indicated by the existence of fewer tunnels of *M. wogura* in the northeastern region. In Fig. 2, the soil hardness at 2.5 cm depth intervals is shown in three regions of the present study area: north of the Tedoru Alluvial Fan, in the Tedoru Alluvial Fan, and south of the fan. In the fan, the soil at a depth range of 0–20 cm was harder in areas inhabited by *M. imaizumii* than in areas inhabited by *M. wogura*. North of the fan, this tendency was not apparent, and there was no clear difference in soil hardness between the areas inhabited by the two species. South of the fan, where soil hardness of sites varied, only the tunnels of *M. wogura* were found, except for mountainous parts.

Areas inhabited by *M. imaizumii* were also recognized in the central and western regions of the Kanazawa Plain outside of the Tedoru Alluvial Fan (Fig. 1). These areas do not have alluvial soil but represent localized unusual environments such as sandy dunes near the coast or stony soil near riverbanks.

The total body length (TBL) and tail length (TL) of the mole specimens that have been deposited in the Komatsu Municipal Museum for Natural Science are 16.7 cm and 12.7 mm (specimen 00052), and 18.1 cm and 18.2 mm (specimen 00058), respectively. These measurements were largely identical to those of 5 individuals of *M. wogura* from the Ishikawa Plain (TBL: 16.5–19.6 cm, TL: 16.2–22.4 mm; Y. Yokohata, unpublished data); thus, both these specimens were identified as *M. wogura*. Their locations are shown in Fig. 1.

Discussion

The ecological relationship between *M. imaizumii* and *M. wogura* has been studied in various regions of central and western Honshu (see the Introduction).

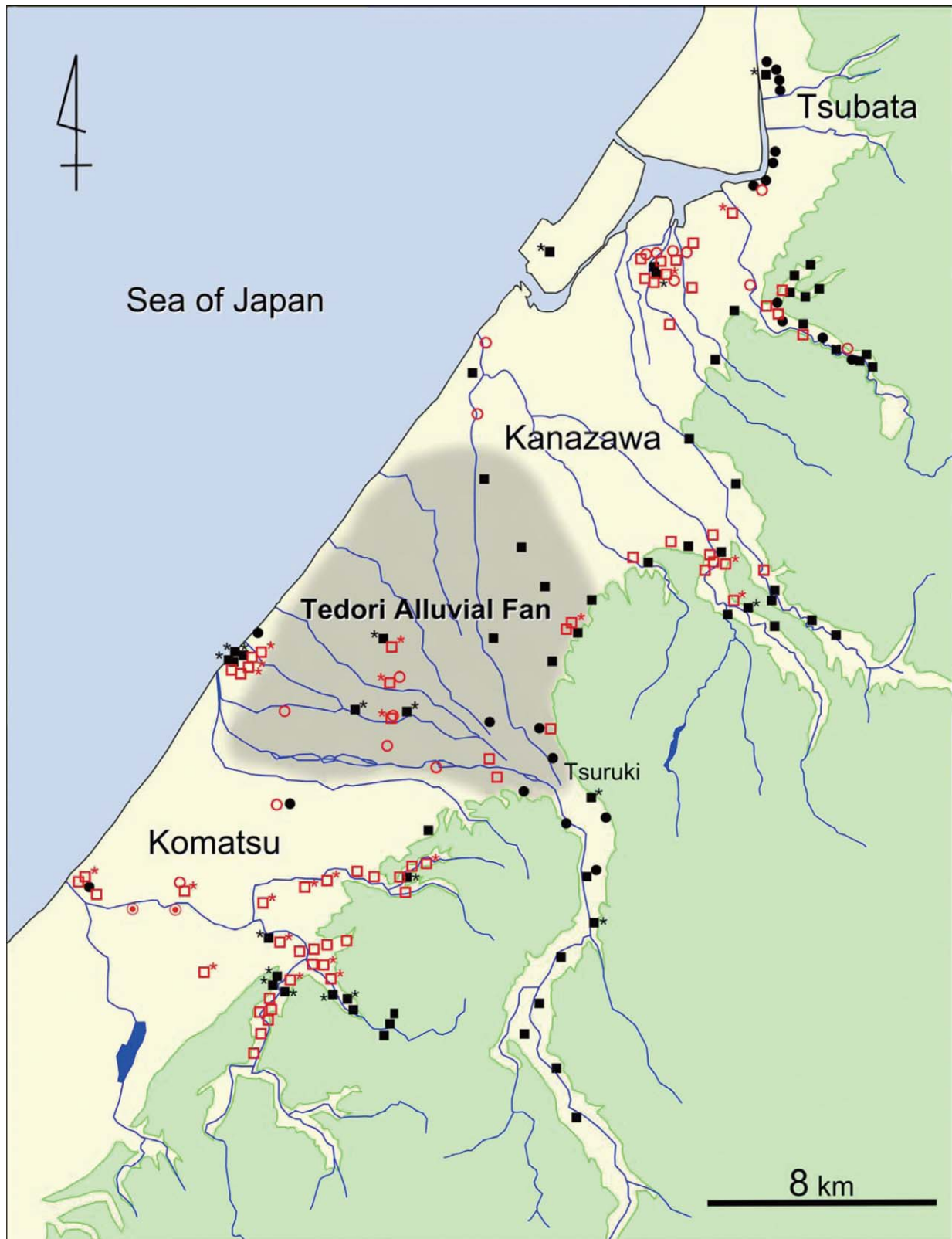


Fig. 1. Distribution of *Mogera imaizumii* and *M. wogura* in the Kanazawa Plain, Ishikawa Prefecture, Japan. The closed (black) and open (red) symbols represent *M. imaizumii* and *M. wogura*, respectively; squares and circles represent sites in this study and in Abe (1999), respectively; double (red) circles indicate the localities of two *M. wogura* specimens deposited in the Komatsu Municipal Museum. Asterisks indicate locations where soil hardness was measured.

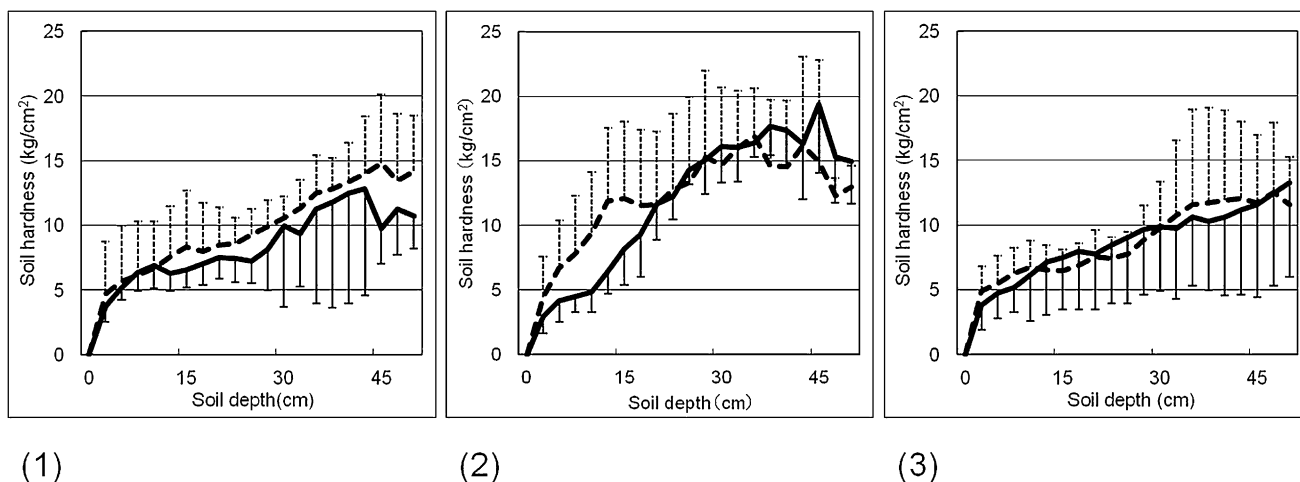


Fig. 2. Soil hardness at 2.5 cm depth intervals in habitats of *Mogera imaizumii* and *M. wogura*, in three regions of the Kanazawa Plain, Ishikawa Prefecture, Japan (dotted lines: *M. imaizumii*; solid lines: *M. wogura*); (1) South of the Tedor Alluvial Fan (5 *M. imaizumii* sites; 4 *M. wogura* sites); (2) Tedor Alluvial Fan (8 *M. imaizumii* sites; 5 *M. wogura* sites); (3) North of the Tedor Alluvial Fan (6 *M. imaizumii* sites; 13 *M. wogura* sites).

Some of these studies were conducted in alluvial plains, which have fertile and uniform soil. In such an environment, competitive exclusion of the inferior species, *M. imaizumii*, occurs throughout the area, resulting in the enlargement of the distribution area of the more dominant species, *M. wogura*. However, in this study, the two species were found together in the Tedor Alluvial Fan, where *M. imaizumii* and *M. wogura* were found in areas with harder and softer soil at 0–20 cm depth, respectively. Rich soil macrofauna generally exists at this depth range (Aoki 1973) and provides a source of food for the moles. Kashimura et al. (2010a, b) showed that most biomass of the soil macrofauna was found in a shallow soil layer (0–35 cm) in habitats of *M. imaizumii* and *M. wogura*. It is known that soil hardness represents an important factor influencing the distribution of the moles. This factor has an influence on habitat segregation and competitive exclusion (Abe 2001, 2010). In these studies, the competitive exclusion of *M. imaizumii* occurs easily in soft soil, while it does not occur in hard soil. The mixed distribution of the two species in the Tedor Alluvial Fan resembles the findings in Abe (2001), and indicates an apparent lack of competitive exclusion. On the other hand, it has been reported that the two species (and another species, *Euroscaptor mizura*) cohabitate the mountainous environment of Shizuoka and Kyoto Prefectures (Sagara et al. 1989; Saito et al. 2003). However, examples of mixed distribution of the two species in a plain in a large geomorphological structure, such as an alluvial fan, were not previously known. It is clear that the complex soil envi-

ronment of an alluvial fan makes it possible for the two species to cohabitate. Sagara et al. (1989) have indicated the possibility that physical factors of the mountainous habitat enable cohabitation of the species, and Saito et al. (2003) showed the habitat segregation of *M. imaizumii* and *M. wogura* between harder and softer soils in a mountainous environment, respectively.

However, there is a potential concern regarding the depth range with differences in soil hardness between the habitats of *M. imaizumii* and *M. wogura*. In the present study, the depth range where differences in soil hardness were measured was between 0 and 20 cm (Fig. 2). In contrast, differences in soil hardness between the habitats of the two species as reported in Abe (2001) were measured at a depth of 30–60 cm in the Agematsu and Kitaono regions of Nagano Prefecture. The reason for this difference is unclear, but it may, at least in part, be due to environmental differences between the alluvial fan (this study) and the mountain valleys (Abe 2001). Kashimura et al. (2010a, b) researched vertical distribution of, and seasonal changes in, the biomass of soil macrofauna, spatial utilization of *M. imaizumii*, and stomach contents of *M. wogura*. They showed that most of the biomass existed in a shallow layer (0–35 cm), as mentioned above, and estimated that the moles mainly used this layer for foraging. Their investigations were performed in plain habitat similar to that in the present study. This shallow layer is largely identical to the depth range in which differences in soil hardness were observed between areas inhabited by *M. imaizumii* and *M. wogura* in this study. Comparable studies in moun-

tainous habitats are necessary.

The Tedori Alluvial Fan is a very large alluvial fan extending from the coast to the borderline between mountains and a plain near Tsuruki (Fig. 1). This geographical feature was formed by large floods originating from heavy rains and spring runoff from nearby mountains. The large size of the alluvial plain may be essential for preventing exclusive distribution expansion by *M. wogura* and to retain the mixed distribution of the two species of moles over a long period of time. Hence, this phenomenon may be characteristic of regions with heavy snowfall in winter, such as Hokuriku District. Japanese moles show very unique and complicated distribution patterns, and these processes have interested many researchers, but areas where relevant and detailed studies have been conducted are few. To elucidate these processes, it will be necessary to conduct more studies in different environments and at various locations.

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