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ORIGINAL ARTICLE

Distribution of the Argentine ant, *Linepithema humile,* along the Seto Inland Sea, western Japan: Result of surveys in 2003–2005

Masayuki OKAUE[1†], Kazunori YAMAMOTO[1‡], Yoshifumi TOUYAMA[2], Takeshi KAMEYAMA[3], Mamoru TERAYAMA[4], Takashi SUGIYAMA[5], Kyouzou MURAKAMI[6] and Fuminori ITO[1]

[1]Laboratory of Entomology, Faculty of Agriculture, Kagawa University, Miki, [2]Shichifuku Co., Ltd, [3]Fukken Co., Ltd, Hikari-cho, Higashi-ku, Hiroshima, [4]Laboratory of Applied Entomology, Division of Agriculture and Agricultural Life Sciences, The University of Tokyo, Bunkyo-ku, Tokyo, [5]Fumakilla Limited, Co., Ltd, Ono-cho, Saeki-gun, and [6]Yahata-cho, Nada-ku, Kobe, Japan

Abstract

The distribution of the Argentine ant, *Linepithema humile,* was investigated in 65 cities or towns along the Seto Inland Sea, western Japan in 2003–2005. Our results include all available information of their distribution in Japan until 2005. Argentine ants have invaded Aichi Prefecture (Tahara-shi), Hyogo Prefecture (Kobe-shi), Hiroshima Prefecture (Hiroshima-shi, Fuchu-cho, Hatsukaichi-shi, Ono-cho and Otake-shi), and Yamaguchi Prefecture (Iwakuni-shi and Yanai-shi). The most widespread distribution was found around Hatsukaichi-shi including the westernmost part of Hiroshima-shi and the easternmost of Ono-cho.

Key words: biological invasion, dispersal, Formicidae, invasive ant.

INTRODUCTION

Biological invasions can severely disrupt native ecosystems, and therefore have received considerable attention (Lodge 1993). Investigations on the process of invasion and its mechanisms are important for the conservation of native ecosystems. However, detailed information on the establishment of new invaders and their initial spread is rarely obtained, because biological invasions are usually only recognized after they have become well established.

A highly invasive species, the Argentine ant *Linepithema humile* (Mayr), has invaded many areas of the world, including Europe, South Africa, Australia, continental United States and Hawaii, via human trade. The ecologic consequences of their invasion include negative effects on native ant species, other invertebrates, vertebrates, and plants (reviewed in Holway *et al*. 2002). The patterns of spread in the continental United States during the last hundred years have recently been reconstructed by Suarez *et al*. (2001), based on published accounts, museum surveys, personal surveys and unpublished personal communications. From this study, they confirmed that jump dispersal mediated by human activity is the primary mode of spread for Argentine ants. An actual process of their spread in invaded areas, however, has never been investigated to date.

Recently, Sugiyama (2000) reported invasion of the Argentine ant into Hatsukaichi-shi and Ono-cho, Hiroshima Prefecture, western Japan, as the first report of Argentine ant invasion into Asia (in this article, the suffix -shi refers to the Japanese way of indicating city names, and the suffix -cho likewise refers to the indication of town names). After Sugiyama (2000), the occurrence of the invasive ant has been reported from five cities or towns (Kobe-shi, Hiroshima-shi, Fuchu-cho, Yanai-shi, and Iwakuni-shi) along the Seto Inland Sea (Kameyama 2001; Touyama 2001, 2002; Miyake *et al*.

Correspondence: Fuminori Ito, Laboratory of Entomology, Faculty of Agriculture, Kagawa University, Miki, 761-0795 Japan. Email: ito@ag.kagawa-u.ac.jp

Present addresses: [†]Kamoike 4, Uozumi-cho, Akashi 674-0073, Japan. [‡]Makiyamashin-machi 1-26-503, Tobata-ku, Kitakyushu 804-0054, Japan.

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2002; Murakami 2002; Touyama *et al.* 2003). Furthermore, Argentine ants have been found in Tahara-shi (Fig. 1, no. 66), Aichi Prefecture in 2005 (the newspaper, "Chunichi Shinbun" 2005). A systematic survey of the current distribution of Argentine ants in Japan is necessary for understanding the invasion ecology of this ant and for the conservation of Japanese native ecosystems. Here we report on the distribution of Argentine ants in western Japan, based on investigations along the Seto Inland Sea from 2003 to 2005. In the future we may be able to track the actual spreading process of this invasive ant by repeating field surveys in the same area with the same methodology.

METHODS

We chose 65 cities or towns, including municipalities where Argentine ant invasion was already reported, along the Seto Inland Sea (Fig. 1). In each municipality, we visited 10–60 sites from March 2003 to May 2005. The number of sites was decided according to the size of the municipality or the invasion status. Most sites were urban parks located in residential quarters. At each site we examined bare ground and tree trunks for 10–30 min in order to determine the presence or absence of Argentine ants. An overall total of 948 sites were surveyed. Furthermore, if we received information on the occurrence of this species, we visited the locality for verification. In all, five areas were visited according to such information. The localities already published as invaded sites were also visited to confirm the occurrence of the ants. If we found an Argentine ant at a point, we investigated its surroundings to determine the approximate extent of their distribution. We define an "invaded area" as a local geographic region within which Argentine ants are continuously found. We estimated the maximum diameter of the distribution area (hereafter MD) for each invaded area by plotting the sites on a map. Owing to the recent municipal mergers, among 65 municipalities, the following towns in this article are now included in the neighbor city: Aio-cho (Yamaguchi Prefecture) is now included in Yamaguchi-shi, Ono-cho (Hiroshima Prefecture) in Hatsukaichi-shi, Mure-cho (Kagawa Prefecture) in Takamatsu-shi, and Hiketa-cho (Kagawa Prefecture) in Higashikagawa-shi.

RESULTS

No new invaded areas had been found by our extensive surveys in 65 municipalities over 3 years. Five (Table 1 and Fig. 2; nos 12, 15b, 15c, 15f and 15g) of the ten new distribution records shown in this paper were revealed by personal communications from house pest control companies which greatly contributed to our knowledge on the distribution of Argentine ants. The remaining five new localities were found during our research beside the quantitative survey. We visited only 10–60 sites in each municipality; therefore, small scale invasions which might have occurred between the studied sites were possibly missed. In other words, the scale of the distribution of Argentine ants at present is still small in most areas.

Argentine ants have, thus, been found in six cities and two towns (Yanai-shi, Iwakuni-shi, Otake-shi, Ono-cho, Hatsukaichi-shi, Hiroshima-shi, Fuchu-cho and Kobe-shi) along the Seto Inland Sea (Fig. 1). They have not yet invaded Shikoku Island, even though Shikoku Island is now connected by huge bridges with Honshu Island. Of the eight municipalities, all but Otake-shi had already been reported to have Argentine ant invasion. Excepting Kobe-shi, the distribution of Argentine ants is confined to a range of 60 km between Fuchu-cho (Hiroshima Prefecture) and Yanai-shi (Yamaguchi Prefecture) (Fig. 1). In each area, the distribution of Argentine ants was limited to a range of a few kilometers except in and around Hatsukaichi-shi (Table 1), where the maximum diameter was approximately 4.5 km. Along the Seto Inland Sea, Argentine ants were found in three prefectures. Details of distribution in each prefecture are described below.

Yamaguchi Prefecture

In Yanai-shi (Fig. 2, no. 10), Argentine ants were found in the same site as reported by Kameyama (2001), who collected *L. humile* workers in September 2001. The site is located in the suburb of Yanai-shi. The distribution range in 2003 was still limited to less than a few hundred meters along the Yanai-gawa river. Argentine ants had never been collected inside the urban area of Yanai-shi. Up to the present, Yanai-shi is now the westernmost record of Argentine ant distribution in Japan.

In Iwakuni-shi, Argentine ants were confirmed near Iwakuni JR station (Fig. 2, no. 11a) in 2001 (Touyama 2001). Here, Argentine ants were distributed over an MD of approximately 0.5 km. In addition to this area, a relatively wide distribution with an MD of approximately 0.9 km was found in Kuroiso (Fig. 2, no. 11b), which is located approximately 7.2 km south of Iwakuni JR station. The occurrence of Argentine ants in

Figure 1 Distribution of Argentine ants in Japan. (○) Argentine ants were not found in the present study, (●) Argentine ants were found. The occurrence of Argentine ants was checked in the following cities or towns. Figures in parentheses indicate number of study sites. **Yamaguchi Prefecture** 1, Shimonoseki-shi (20); 2, Onoda-shi (10); 3, Ube-shi (16); 4, Aio-cho (10); 5, Hofu-shi (10); 6, Shinnanyo-shi (10); 7, Tokuyama-shi (11); 8, Kudamatsu-shi (10); 9, Hikari-shi (10); 10, Yanai-shi (20); 11, Iwakuni-shi (38). **Hiroshima Prefecture** 12, Otake-shi (20); 13, Ono-cho (20); 14, Hatsukaichi-shi (60); 15, Hiroshima-shi (54); 16, Fuchu-cho (10); 17, Kaita-cho (10); 18, Kure-shi (10); 19, Akitsu-cho (12); 20, Takehara-shi (10); 21, Mihara-shi (10); 22, Onomichi-shi (11); 23, Fukuyama-shi (21). **Okayama Prefecture** 24, Kasaoka-shi (10); 25, Kurashiki-shi (10); 26, Tamano-shi (10); 27, Okayama-shi (10); 28, Bizen-shi (10). **Hyogo Prefecture** 29, Ako-shi (10); 30, Aioi-shi (10); 31, Himeji-shi (10); 32, Takasago-shi (13); 33, Kakogawa-shi (12); 34, Akashi-shi (12); 35, Kobe-shi (41); 36, Amagasaki-shi (13). **Osaka Metropolitan Prefecture** 37, Osaka-shi (54); 38, Sakai-shi (18), 39, Takaishi-shi (11); 40, Izumiotsu-shi (11); 41, Tadaoka-cho (10); 42, Kishiwada-shi (11); 43, Izumisano-shi (10); 44, Sennan-shi (10); 45, Hannan-shi (10). **Ehime Prefecture** 46, Uwajima-shi (10); 47, Yawatahama-shi (10); 48, Iyo-shi (10); 49, Matsuyama-shi (18); 50, Hojyo-shi (10); 51, Imabari-shi (10); 52, Toyo-shi (10); 53, Saijyo-shi (10); 54, Niihama-shi (10); 55, Shikokuchuo-shi (11). **Kagawa Prefecture** 56, Kanonji-shi (10); 57, Tadotsu-cho (10); 58, Marugame-shi (10); 59, Utazu-cho (10); 60, Sakaide-shi (10); 61, Takamatsu-shi (20); 62, Mure-cho (10); 63, Sanuki-shi (10); 64, Higashikagawa-shi (10); 65, Hiketa-cho (10). **Aichi Prefecture** 66, Tahara-shi. The following towns are now included in the neighboring city: Aio-cho (Yamaguchi Prefecture) in Yamaguchi-shi, Ono-cho (Hiroshima Prefecture) in Hatsukaichi-shi, Mure-cho (Kagawa Prefecture) in Takamatsu-shi, and Hiketa-cho (Kagawa Prefecture) in Higashikagawa-shi.

Table 1 Years when Argentine ants were first detected in cities or towns along Seto Inland Sea

No. in Fig. 2	Locality	Year of the first discovery	Maximum diameter of distribution range (year measured)	References
10	Yanai-shi	2001	300 m (2003)	Kameyama (2001)
11a	Kuroiso, Iwakuni-shi	2002	900 m (2003)	Nishisue *et al.* (2006)
11b	Motomachi, Iwakuni-shi	2001	500 m (2001)	Touyama (2001)
12	Higashisakae, Otake-shi	2004	1200 m (2004)	Present paper
13a	Gou, Ono-cho†	2004	1100 m (2004)	Present paper
13b	Umehara, Ono-cho†	1999	‡	Sugiyama (2000)
13c	Miyajimaguchi, Ono-cho†	2004	20 m (2004)	Present paper
14a	Ajina, Hatsukaichi-shi	2000	2000 m (2004)	Present paper
14b	Hatsukaichi-shi	1993	4500 m (2004)	Sugiyama (2000)
15a	Kairouen, Hiroshima-shi	2000	800 m (2004)	Touyama *et al.* (2003)
15b	Shinguen, Hiroshima-shi	2005	300 m (2005)	Present paper
15c	Inokuchi, Hiroshima-shi	2004	1000 m (2005)	Present paper
15d	Dejima, Hiroshima-shi	2000	1000 m (2000)	Present paper
15e	Ujina, Hiroshima-shi	1999	700 m (2000)	Touyama *et al.* (2003)
15f	Nakasuji, Hiroshima-shi	2005	360 m (2005)	Present paper
15g	Kaminobori-machi, Hiroshima-shi	2005	300 m (2005)	Present paper
15h	Onaga, Hiroshima-shi	2002	150 m (2002)	Touyama (2002)
16	Fuchu-cho	2002	900 m (2003)	Touyama (2005)
35§	Port Island, Kobe-shi	1999	2000 m (2001)	Murakami (2002)
35§	Maya Port, Kobe-shi	2002	500 m (2004)	Present paper

†Ono-cho is now included in Hatsukaichi-shi. ‡Argentine ants were found only inside building, and have already disappeared. §Numbers in Figure 1. The maximum diameter of distribution range in each area is also given.

Kuroiso area was reported in a newspaper article (Chugoku Shinbun 2003).

Hiroshima Prefecture

In and around Hatsukaichi-shi, Argentine ants were distributed from the easternmost point of Ono-cho (Fig. 2, no. 14a) to the westernmost of Hiroshima-shi, Saeki-ku (Fig. 2, no. 15a). Here the distribution was not continuous: we could recognize at least three discrete areas (the center of Hatsukaichi-shi (Fig. 2, no. 14b), Ajina (Fig. 2, no. 14a), and Kairouen (Fig. 2, no. 15a)). Among these, Argentine ants were widely distributed in the center of Hatsukaichi-shi, where the MD was approximately 4.5 km, while those of Kairoen and Ajina were approximately 0.8 km and 2 km, respectively. The distribution details around Hatsukaichi-shi will be reported elsewhere.

In Hiroshima-shi, beside Saeki-Ku, Argentine ants were known from seven distinct areas (Fig. 2, nos. 15b–h). The distribution of these areas was still small, 0.15–1 km MD in each area. Among the seven areas, four areas (Fig. 2, nos. 15b, 15c, 15f and 15g) have been known only since 2005 (Table 1).

In Fuchu-cho (Fig. 2, no. 16), Argentine ants were distributed in the suburban residential quarter in the hillside area with a MD of 0.8–0.9 km (Touyama 2005). They frequently inhabit stonewall cracks, and walk in procession along the roadside drain.

In Gou (Fig. 2, no. 13a), Ono-cho, which is located approximately 5.2 km west of the eastern edge of the Argentine ant distribution (near Ajina; Fig. 2, no. 14a) of Hatsukaichi, the ants were found in an area of approximately 500 ha with a MD of 1.1 km. Sugiyama (2000) reported the occurrence of Argentine ants in a private company in Umehara (Fig. 2, no. 13b), Ono-cho, where Argentine ants were found inside the building, but the infestation disappeared in 2001. In Miyajimaguchi (Fig. 2, no. 13c), we found Argentine ants in 2004. The range of distribution was very small, approximately 0.02 km MD. Between Miyajimaguchi (Fig. 2, no. 13c) and Ajina (Fig. 2, no. 14a), Argentine ants have not yet been found.

In Otake-shi (Fig. 2, no. 12), Argentine ants were found in Higashisakae to Minamisakae, where Argentine ants were widespread with an MD of 1.2 km. In addition to this area, the occurrence of Argentine ants in Tachido, approximately 1.8 km north of Higashisakae, was reported by a house pest control company. We visited this area according to this information, but the ants were not found.

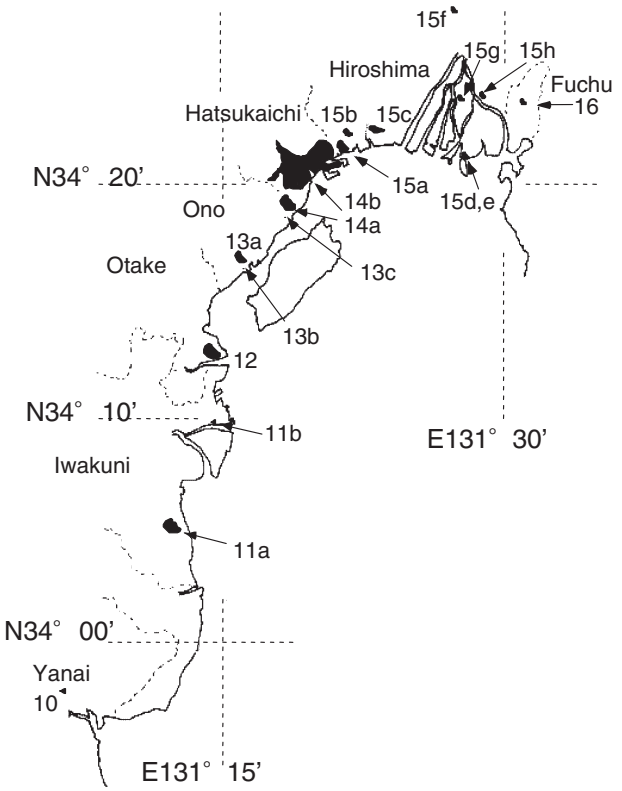

Figure 2 Overview of Argentine ant distribution in Hiroshima Prefecture and Yamaguchi Prefecture. Each broken curve indicates a boundary of a municipality. 10, Yanai-shi; 11, Iwakuni (a, Kuroiso; b, near JR Iwakuni station); 12, Otake-shi; 13, Ono-cho (a, Gou; b, Umehara; c, Miyajimaguchi); 14, Hatsukaichi-shi (a, Ajina; b, the center of city); 15, Hiroshima-shi (a, Kairouen; b, Shinguen; c, Inokuchi; d, Dejima; e, Ujina; f, Nakasuji; g, Kaminobori-machi; h, Onaga); 16, Fuchu-cho. Ono-cho is now included in Hatsukaichi-shi.

Hyogo Prefecture

In Kobe-shi (Fig. 1, no. 35), Argentine ants were found in the northern part of the Port Island and Maya Port (Fig. 1 and Table 1). Murakami (2002) reported that the ants were first found in the Port Island in 1999, and the MD of the distribution area was approximately 2 km in March of 2002. In 2002, he also found Argentine ants in Maya Port, approximately 2 km apart from the northernmost of Port Island, where the distribution was limited to an MD of approximately 0.5 km.

DISCUSSION

As reported in other countries, the distribution of Argentine ants in Japan is not continuous. They were found in at least 20 separate areas along the Seto Inland Sea. It has not been examined whether these areas correspond to separate invasions by Argentine ants. Except for Kobe-shi and Tahara-shi (Aichi Prefecture, which was not examined in the present study), it is reasonable to suppose that Argentine ants had spread from the initial invaded area, probably from Hatsukaichi-shi where there is a timber port, which frequently imports timbers from several countries.

The average distance from Hatsukaichi-shi to the other invaded cities is 106 km ± 99 km ($n = 8$), with a maximum of 450 km for Tahara-shi. Suarez *et al.* (2001) measured the yearly jump-dispersal distance of Argentine ants in the continental US by two ways: one distance was measured from New Orleans where Argentine ants were first reported in the US, and another was measured from the nearest occupied county. The average yearly distance in the continental US was 361.7 ± 416.8 km in the former model, and 160.5 ± 323.8 km in the latter model (Suarez *et al.* 2001). The figure of the former model in Japan by using the distances between Hatsukaichi Port to each invaded city or town is 12.2 ± 16 km per year. It is considerably shorter than both figures in the continental US. Although it is not known when Argentine ants arrived in Japan, their current distribution indicates that their invasion is still in its early stage. Future monitoring of the spread of this ant in western Japan will provide an important insight for understanding the process of biological invasions.

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