The search for domestic migration of the white-backed planthopper, *Sogatella furcifera* (Horváth) (Homoptera: Delphacidae), in Japan

Akira Otuka,1,*† Masaya Matsumura2 and Tomonari Watanabe1

1National Agricultural Research Center; Tsukuba, Ibaraki 305–8666, Japan
2National Agricultural Research Center for Kyushu Okinawa Region; Koshi, Kumamoto 861–1192, Japan

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Abstract

The possible domestic migration of the white-backed planthopper, *Sogatella furcifera*, in Japan was investigated. The next emigrating generation of immigrants during the Bai-u rainy season was selected for analysis. Four criteria were used to determine whether a migration was domestic: 1) a large catch peak in the net trap in northern Japan, 2) in the trap area, the absence of a preceding generation of catch insects based on the analysis of effective accumulated temperature, 3) suitable air currents for insects to migrate from western to northern Japan, as found by backward trajectory analysis, and 4) the presence of emigrating adults in rice fields in western Japan based on a field survey of the population density. The catch data obtained from a net trap in Akita city, Akita prefecture, from 1980 to 2006 showed four clear peaks exceeding 1,000 insects per day, and only one of these, occurring in early August 1987, was found to meet all criteria. The weather pattern was a low-pressure system in the Japan Sea moving northeastward, with a windy region from western to northern Japan. The possible effect of domestic migration in early August on rice crops in northern Japan was discussed.

Key words: *Sogatella furcifera*; domestic migration; migration simulation

INTRODUCTION

Rice planthoppers, the white-backed planthopper *Sogatella furcifera* and the brown planthopper *Nilaparvata lugens*, are the major insect pests of rice in Asia. In southern China, rice planthoppers gradually migrate northeastward from spring to summer (Cheng et al., 1979). These species are believed to immigrate into Japan from southern China mainly in the Bai-u rainy season, from late June to early July (Kisimoto, 1976). There are generally more immigrants in western Japan, including the island of Kyushu, located close to the source area, than in eastern regions (Kisimoto, 1971). The first-generation offspring of these species usually emerges one month after the immigrants arrive (Kuno, 1968). Most first-generation adults of *S. furcifera* molt into macropters (long-wing form) and fly out of paddy fields (Kuno, 1968). Here two questions arise: where do the macropterous adults migrate to, and is there any domestic migration from western Japan to other regions? Studies using two-dimensional backward trajectory analysis have suggested that domestic migration from Kyushu might have occurred (Araya et al., 1987; Sogawa, 1994, 1995); however, these studies investigated neither field data from source regions nor trap data from destination regions, and thus could not verify that the implied migration actually occurred. Therefore, knowledge about the domestic migration of rice planthoppers in Japan is currently very limited. If domestic migrations occur, it is important to evaluate their impact on rice crops in the destination regions.

This study searched for possible domestic migration events based on four factors: 1) catch data of a net trap in northern Japan to show the capture of immigrants, 2) no ancestral generation of immigrants in the trap area before days equivalent to one generation from the catch date, 3) backward
trajectory analysis to reveal atmospheric conditions favorable for domestic migration, and 4) field surveys of planthopper density in source regions to show possible emigration. If all the evidence is positive for a migration event, then the event is considered very likely to be domestic migration. The effect of domestic migration on rice production in northern Japan is also discussed.

MATERIALS AND METHODS

Net trap data at Akita. The net trap in Akita is the only trap available in the Tohoku region, a northern area on Honshu island (Fig. 1). A tow net 1.5 m deep with a 1-m ring was mounted to the top of a pole 10 m high. This net trap was located in Akita city (39.68°N, 140.12°E) before 1999, and was moved to a new location (39.52°N, 140.23°E) in the same city in 2000. Insects in the net trap were collected daily at 9 am and the catch number of S. furcifera was recorded. Catch number data in July and August from 1980 to 2006 (except 1989) were obtained from an Internet database service, the Japan Plant Protection Network (JPP-NET), provided by the Japan Plant Protection Association (Ueno, 2005). Data for 1989 were not available.

Effective accumulated temperature. A preceding generation of catch insects by the net trap in Akita was investigated. The date of its occurrence peak was estimated based on the effective accumulated temperature (EAT) in order to discriminate migratory catch peaks from local catches. The local population consists of descending generations of migratory immigrants because S. furcifera cannot overwinter in Japan. The developmental zero of 12.0°C and the effective accumulated temperature of 345.0 day · deg, 245 day · deg for oviposition to adult emergence and 100 day · deg for pre-oviposition, were applied to calculate the period of one generation (Kuno, 1968), and the occurrences of succeeding or preceding generations were estimated using the triangle method (Sakagami and Korenaga, 1981) with daily maximum and minimum temperatures at the nearest weather station (39.72°N, 140.10°E) in Akita city. Early catch dates in June or July were set as starting points for forward analysis, and a large catch peak in August was set for backward analysis.

Backward trajectory analysis. Three-dimensional backward trajectory analysis (BTA) (Otuka et al., 2005) was conducted to estimate the possible migration source for selected catch peaks in Akita. The starting times of the trajectories were set to every hour within 24 h of the catch date. For each starting time, 20 trajectories were calculated with different initial heights ranging from 100 to 2,000 m at an interval of 100 m above the trap site. Since S. furcifera fly slowly compared with typical wind speeds, it was assumed that S. furcifera move at the same velocity as the wind during migration; therefore, backward trajectories were calculated by the following equations:

\[
\begin{align*}
    x(t-1) &= x(t) - u(x, y, z, t) dt \\
    y(t-1) &= y(t) - v(x, y, z, t) dt \\
    z(t-1) &= z(t) - w(x, y, z, t) dt
\end{align*}
\]

where \((x, y, z)\) denote the insect position, \((u, v, w)\) the interpolated wind velocity, and \(t\) the calculation time step. One time step (\(dt\)) was set as 50 s. Wind speed was interpolated both spatially and temporally using simulated wind velocity output by a weather simulation model at intervals of 1 h.

Backward trajectories were terminated at dusk, 1900 or 2000 Japan Standard Time (JST) (depending on local sunset time), or at dawn, 500 JST, one or two days before the catch, when planthoppers were assumed to take off in the source areas. The terminal points of the trajectories were plotted on a map to determine the possible source areas.

Occurrence investigations in fields in Chikugo and Jyoetsu. The population densities of S. furcifera in rice fields were investigated at two sites,
Table 1. Parameters of field investigation methods at Chikugo and Jyoetsu

<table>
<thead>
<tr>
<th></th>
<th>Chikugo</th>
<th>Jyoetsu</th>
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<tbody>
<tr>
<td>Months</td>
<td>June–Sep</td>
<td>June–Sep</td>
</tr>
<tr>
<td>Field locations</td>
<td>Former Kyushu Agriculture Experimental Station in Chikugo, Fukuoka prefecture</td>
<td>Former Hokuriku Agriculture Experimental Station in Jyoetsu, Niigata prefecture</td>
</tr>
<tr>
<td>Rice variety</td>
<td>Reiho</td>
<td>Koshijiwase</td>
</tr>
<tr>
<td>Transplanting</td>
<td>Late June</td>
<td>Early June</td>
</tr>
<tr>
<td>Pest control</td>
<td>No chemicals</td>
<td>No chemicals</td>
</tr>
<tr>
<td>Insect counting</td>
<td>Direct counting</td>
<td>Direct counting in 1987; direct counting of immigration generation (IG) and FARM COP method (Carino et al., 1979) with a suction machine to collect later generations (LG) in 1991</td>
</tr>
<tr>
<td>Counting intervals</td>
<td>2–3 days</td>
<td>2–3 days for IG and 4–8 days for LG</td>
</tr>
<tr>
<td>Other monitoring</td>
<td>Two tow net traps with a 1 m ring mounted at 10 m above the ground (33.20°N, 130.48°E)</td>
<td>A light trap with a 60-W electric bulb (37.12°N, 138.27°E)</td>
</tr>
</tbody>
</table>

*Refer to Fig. 1 for the locations of these sites.

Chikugo and Jyoetsu (Fig. 1). These investigations were conducted in June to September from 1987 to 1990 in Chikugo and from 1987 to 1991 in Jyoetsu. Table 1 describes the field investigation method. The number of long-winged adults per 100 hills in rice fields without chemical controls was counted using the direct counting method and a suction method. At the same time, catch numbers in the net trap or light trap were investigated. Since no survey was conducted in Chikugo in 1991, the catch number in the net trap with a 1-m ring mounted at 10 m above the ground in Kawasoe (33.22°N, 130.31°E), Saga prefecture, was used. Kawasoe is located about 16 km west of Chikugo.

RESULTS

Net trap data in Akita

The daily catch number in the net trap in July and August during the 1980s and 1990s is shown in Figs. 2 and 3, respectively. Large peaks of over 1,000 per day appeared on four dates: 29 August 1983 (A), 5 August 1987 (B), 10 July 1991 (C), and 24 July 1991 (D). Catch numbers were generally larger in August than in July, but barely exceeded 500 per day even in August (Fig. 2); therefore, these four peaks were exceptional.

Trap data during the same months from 2000 to 2006 were not shown because the catch numbers were very small, with a maximum of only 115 on 11 August 2000. No clear large peak was recorded during these seven years.

EAT result

The estimated dates of the preceding generation’s occurrence peak for each of the four catch peaks described above are shown in Table 2. Peak A on 29 August 1983 was found to have a preceding generation on 3 August, when the catch number was 20. This suggests that a portion of the catch number of 3,127 on 29 August possibly included a newly emerged local population.

For peak B, a preceding generation was estimated to have peaked on 4 July, 1987; however, since there was no catch before 6 July in Akita (Fig. 2), peak B may not be due to a newly
emerged local population there. For peaks C and D, the estimated dates of the occurrence peak of preceding generations were 1 and 18 June, 1991; however, since the first catch in the 1991 season in Akita was recorded late, on 28 June (data not shown), no preceding generations for these peaks were found; therefore, peaks C and D were suggested not to be local.

Backward trajectory analysis method

The distribution of terminal points of the backward trajectories for the four catch peaks are shown in Fig. 4. For peak A (29 August 1983), possible source regions were found in western Japan and Korea (Fig. 4a,b). Depending on the flight time, the source region extended from an area along the Sea of Japan to southern Kyushu. Similar distribution patterns were found for peak B (5 August 1987) (Fig. 4c,d). Possible source regions ranged from the Japan Sea side of Honshu to Shikoku and northern Kyushu as well as southern Korea. The possible source region for peak C (10 July 1991) was estimated to be the western Honshu region along the Sea of Japan and northern Kyushu (Fig. 4e). Lastly, the possible source region for peak D (24 July 1991) was estimated to be the Korean Peninsula and eastern China (Fig. 4f).

Field occurrence data in Chikugo and Jyoetsu

The temporal changes of population densities of adult *S. furcifera* in rice fields in Joetsu and Kyushu (Chikugo and Kawasoe) are shown in Fig. 5. The figure also shows daily catch numbers in net traps in northern Kyushu and in the light trap in Jyoetsu. Figure 5a shows two clear peaks of both population density and daily catch number in Chikugo in 1987; both appeared in early July and early August. Based on field observations by one of the authors, the first and second peaks were due to immigration and the first emerging generation, respectively (Watanabe, unpublished data). A sudden increase in population density occurred on 3 August and peaked on 7 August. In Jyoetsu, a slight increase in population density is seen around 10 July, when small catch numbers were recorded (Fig. 5b). The population density started to increase on 29 July and clearly peaked on 7 August. This peak was due to the first emerging generation. These results indicate that there were emigrating populations in northern Kyushu and Jyoetsu in early August 1987.

In 1991, there were visible changes in the catch in mid-June and early July in Kawasoe (Fig. 5c), and small catches of 1 or 2 insects from 3 to 6 June, which were attributable to immigration from overseas. In northern Kyushu, rice seedlings are transplanted mainly in late June, and thus there were no emigrating adults in northern Kyushu in early July 1991.

The population density in Jyoetsu started to increase on 1 July and peaked on 15 July due to immigration, based on field observations conducted by one of the authors (Fig. 5d) (Matsumura, 1997). This indicates that peak C on 10 July 1991 may not be attributable to domestic migration.

For the peak in 1983, although there are no density data from the field, many light traps in western Japan and Korea indicated that the population of *S. furcifera* increased in late June and early July.

**Table 2.** Estimation of a preceding generation for distinct catches (>1,000 insects/day) of *S. furcifera* in Akita from 1980 to 2006

<table>
<thead>
<tr>
<th>Date of catcha</th>
<th>Date of preceding generationb</th>
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<tbody>
<tr>
<td>29-Aug-1983 (A)</td>
<td>3-Aug-1983</td>
</tr>
<tr>
<td>5-Aug-1987 (B)</td>
<td>4-July-1987</td>
</tr>
<tr>
<td>10-July-1991 (C)</td>
<td>1-June-1991</td>
</tr>
<tr>
<td>24-July-1991 (D)</td>
<td>18-June-1991</td>
</tr>
</tbody>
</table>

a The catch peaks are named alphabetically as shown in parentheses.
b The dates were estimated based on the effective accumulated temperature. The developmental zero of 12.0°C and the effective accumulated temperature for one generation of 345.0 day · deg were used (Kuno, 1968).
Japan showed daily catch numbers of more than 1,000 *S. furcifera* in late July and late August, according to the JPP-NET database (Ueno, 2005). This implies that emigration from western Japan possibly occurred in late August.

The results are summarized in Table 3.

**DISCUSSION**

Among the four large catch peaks, only peak B in 1987 met all four conditions (Table 3). This indicates that a domestic migration event must have occurred from 3 to 5 August 1987, during which *S. furcifera* moved from western Japan to Akita.

Since peak A does not meet condition 2, it is possible that this peak was attributable, at least in part, to a local population; however, since this peak was much larger than average levels in late August, it remains possible that the peak was migratory. If so, the possible sources were western Japan, where
Fig. 5. Temporal change in occurrence of *S. furcifera* in Chikugo and Jyoetsu (see locations in Fig. 1). The bar indicates population density (the number of adults per 100 hills) in a paddy. The line chart of black and white squares shows the catch number by the net trap in Chikugo or by the light trap in Jyoetsu.

Table 3. Summary of the results

<table>
<thead>
<tr>
<th>Survey and analysis</th>
<th>Trap catch peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Catch peak of <em>S. furcifera</em> larger than 1,000 insects/day at Akita</td>
<td>+</td>
</tr>
<tr>
<td>2. Absence of a preceding generation of catch insects in Akita based on the analysis of effective accumulated temperature</td>
<td>-</td>
</tr>
<tr>
<td>3. Suitable air currents for insects to migrate from western to northern Japan, as found by backward trajectory analysis (estimated source area)</td>
<td>+ (WJ)</td>
</tr>
<tr>
<td>4. Presence of emigrating adults in rice fields in western Japan based on a field survey of the population density</td>
<td>(+)</td>
</tr>
</tbody>
</table>

+/−: positive/negative, WJ: western Japan, K: Korea, ND: no available data.
emigrating populations generally occurred in this time period (conditions 3 and 4). Based on this discussion, it is likely that peak A in 1983 was a domestic migration.

Peak C appeared on 10 July 1991. If this peak was caused by a domestic migration, the previous generation must have occurred in early June in western Japan (Table 2); however, there was no such preceding generation in Saga or other prefectures in western Japan (Fig. 5c). The peak may therefore have been due to an overseas migration. The estimated source for peak D was found to be Korea and this was therefore not a domestic migration.

Of the four outstanding catch peaks from the net trap in summer at Akita, one peak must have been and another might have been domestic migration. There were only two events in 26 years. In both events, the meteorological conditions were similar: a low-pressure system moved over the Japan Sea or the continent and large-gradient isobars ran north-eastward, causing winds to blow parallel to Japan. Such a pressure pattern is rare in August, when a strong high-pressure system located over the Pacific Ocean typically covers Japan. This is why there were very few domestic migration events.

What is the impact of first-generation domestic migration on the rice crop in northern Japan? Iitomi and Niiyama (2001) investigated rice damage caused by *S. furcifera* released at a rate of five adult-pairs per hill to rice in five different growth stages: 26, 16, and 6 days before heading, and 5 and 15 days after heading (DAH). Since the rice plants were transplanted on 15 May and reached the heading stage on July 31, the latter two rice stages corresponded to early to mid-August, when first-generation domestic migration is expected. The results showed that for experimental plots of 5 and 15 DAH, the percentage of ripened grains and the weight of 1,000 kernels were low, and yield loss was evident (Iitomi and Niiyama, 2001); for example, the yield loss of the 5 DAH plot reached 25 percent of the control, and the weight of 1,000 kernels in the 5 DAH plot was 5 percent lower than that of the control. Although immigrant densities in rice fields in past domestic migration events are unknown, Iitomi and Niiyama’s (2001) results suggested that domestic migration could affect rice in the ripening stage and possibly degrade yielding factors in cases of sufficiently large migration.

Recently, however, the occurrence of *S. furcifera* in northern Japan has been very low. For example, the average total number of *S. furcifera* in the net trap in Akita in August for the five years from 2003 to 2007 was 101, which is 4 percent of that from 1983 to 1987 (2,525); therefore, the recent risk from domestic migration of *S. furcifera* seems very limited. To control rice plantshoppers, neonicotinoid and phenylpyrazole insecticides, such as imidacloprid and fipronil, have been used since the mid-1990s in East Asia (Matsumura et al., 2008). In Japan, imidacloprid and fipronil have been used exclusively for seedling box treatment, and these chemicals have successfully controlled rice plantshoppers from the mid-1990s to the early 2000s, as the population densities of *S. furcifera* and *N. lugens* have been relatively low (Watanabe et al., 2007). This situation suggests that domestic migration of *S. furcifera* from western to northern Japan has been limited in recent years, corresponding to the small catch numbers by traps in northern Japan.

Since 2003, however, rice plantshoppers showing some resistance against neonicotinoid have been found in many East Asian countries, including Japan (Matsumura et al., 2008). A severe outbreak of *N. lugens* actually occurred in Kyushu in 2005. If rice plantshoppers became highly resistant to these insecticides in western Japan, then the population densities could increase and subsequent domestic migration might increase, affecting rice production in northern Japan. Careful monitoring of rice plantshoppers should therefore be continued.

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