INTRODUCTION

Locusts are potentially the most destructive pest insects in the world. The desert locust, Schistocerca gregaria Forskål, and the migratory locust, Locusta migratoria L., are the two major species. They show phase polymorphism in which various traits change in response to population density (Uvarov, 1977). Locusts at the low density called the “solitary phase” cause little damage to agricultural crops, but as the population density increases their morphology, physiology and behavior change greatly. Over several generations under high-density conditions, they turn into gregarious locusts. Nymphs in the gregarious phase show an aggregating behavior and move in bands to seek food, whereas adults swarm and migrate over long distances. Because of their economic importance, numerous studies have been carried out, as summarized in the classical textbooks written by Uvarov (1966, 1977). Recent findings and accomplishments have been reviewed in several books and articles (e.g., Chapman and Joern, 1990; Pener, 1991; The Panos Institute, 1993; Krall et al., 1997; Hunter, 2004). In spite of such efforts and dedication by scientists and agricultural experts, locust outbreaks often occur in various parts of the planet, and the locusts are still regarded as serious pests. The present paper describes the occurrence of locust (L. migratoria) outbreaks, effective control and the status of the migrants in terms of phase polymorphism in the northwestern part of China.

MATERIALS AND METHODS

Insects. Several subspecies of L. migratoria (Uvarov, 1966, 1977) have been recognized. In China, three of them are known: L. m. manilensis Meyen is widely distributed in the eastern region, L. m. tibetensis Chen in Tibet and Qinghai, and L. m. migratoria L. throughout the northern, northeastern and northwestern regions (Chen, 1999). They are mainly separated by morphological characteristics that may be modified by environmental
conditions. The locusts collected in this study may be categorized into *L. m. migratoria*, but here we will call it *L. migratoria*.

**Study sites.** Locust outbreaks have been recently recorded in Jiminay County, Altay Prefecture, the Xingjian Uygur Autonomous Region, China. The town of Jiminay (47°N; 86°E) is located 25 km southeast of the border of the Republic of Kazakhstan (Fig. 1). In this prefecture, wheat, corn, sunflower, soy bean and melon are grown by irrigating the farming lands. Some minor pests such as aphids, noctuid moths, mites, and nematodes are found, but they do not require any particular control. Locusts (*L. migratoria*) are the only, but very serious pest insect in this area.

**Samplings.** When we arrived at Jiminay County on August 18, 2004, the outbreaks had already ended. We thus visited one of the sites where swarms of locusts landed and were sprayed about 3 wk earlier. It was a semi-arid area located about 30 km northeast of Jiminay. Because of its dry climate, locust remains were well preserved. They were found in an area of approximately 6,000 m² where small bushes occurred sparsely. Locust remains covered half of the area and formed a thick layer (about 5 cm) (Fig. 2a). A total of 1,121 remains were sampled. No live locust was found. This sampling site will be called the high-density (HD) site for convenience.

Another sampling was made in a wheat field (ca. 50 ha) 10 km east of Jiminay on August 19, 2004. Ten persons collected a total of 50 adults with insect nets or hands during a 2-h sampling period. The locust density was much lower than 0.1 individual/m², and this site will be called the low-
density (LD) site.

**Morphometric measurements.** To determine the classical morphometric ratios (e.g., $F/C$ and $E/F$ ratios; $F=$hind femur length; $C=$maximum head width; $E=$elytron length) often used for studies of phase polyphenism (Dirsh, 1953; Uvarov, 1966), $C$, $E$ and $F$ were measured using a digital caliper (Mitsutoyo Co., Japan). A total of 100 sprayed locusts collected at the HD site and all individuals (15 females and 35 males) collected at the LD site were measured. Thirty males and 30 females from the former were photographed with a scanner (Epson 2000, Japan) and a personal computer (MA10T, NEC, Japan) to determine $H'/$$H$ ($H=$the height of pronotum; $H'=$the distance from the upper ridge to the intersection between the lines showing height and length of pronotum, respectively) according to a previously described method (Tanaka et al., 2002). This ratio indicates if the ridge of pronotum is convex ($>0$), flat ($=0$), or concave ($<0$). In this study, the frequencies of individuals with convex, flat, and concave shapes of the pronotum were determined as well as the mean $H'/H$ ratios. Some individuals collected at the LD site were killed and transported to NIAS at Ohwashi to determine their $H'/H$.

**Information about locust control.** To investigate the occurrence of outbreaks and the control methods used for locusts in Jiminay County, information was collected from local entomologists, officers, and unpublished newsletters at the Agricultural Bureau of Jiminay County (ABJ) and the Agricultural Technical Advice Center of Altay Prefecture (ATACA).

**RESULTS AND DISCUSSION**

**Outbreaks**

No locust outbreaks were recorded at Jiminay County for several years until 2003. In July 2003, swarms of adult locusts landed at various sites in the northern part of Jiminay (Fig. 2b). They came from the north, but the exact location of their breeding habitat had not been identified. However, because mass breeding had not been observed in the northern part of Jiminay County, it is believed that the locusts had emerged as adults in Kazakhstan and flew to China. The area infested was 36,670 ha and they caused a 42% reduction in grass production. Migrants were mostly controlled by spray, but some survived and deposited eggs that over-wintered later.

A scene of hundreds of sexually mature locusts mating and ovipositing in and near wheat fields was video-recorded in July 2003 by ABJ. In 2004, huge numbers of hatchlings appeared after thawing and grew in the grazing land and pastures. Little rain fell in the spring. On May 22, hopper density reached 1,500 individuals/m$^2$. At Beishawo, one of the most heavily infested areas in Jiminay County, approximately 20,000 ha of grazing land was infested with locusts and the highest density reached more than 10,000 individuals/m$^2$ for early stadium nymphs. Locust swarms also attacked farming and grazing lands. According to the August issue of Jiminay newsletters (ABJ, unpublished), swarms of locusts migrated at night from Kazakhstan to Jiminay County four times during the period from July 17 to Aug. 6. The locust density monitored seven times during that period was 110/m$^2$ on average, with the highest density of 3,000 adults/m$^2$ on July 18.

We visited one of the sites where migrants landed and were killed by spraying 3 wk earlier. From a thick layer of locust remains (Fig. 2a), a sample was collected to determine the sex ratio. The ratio (females/males) for two samples was 0.969 ($n=636$) and 0.998 ($n=485$). These ratios, as well as the combined ratio (0.998; $n=1,121$), were not statistically deviant from 1 ($\chi^2$ test; $p>0.05$).

**Locust control**

During the spring and summer periods of 2004, a total of 4,200 personnel were involved in spraying insecticides to control locust populations in Jiminay County. Spraying was made on both grazing and farming lands. A total of 245.2 t of insecticides were sprayed over 325,000 ha. Detailed information for the grazing land could not be obtained.

On the farming land, a total of 270 personnel sprayed insecticides using a total of 49 spraying vehicles (Fig. 2c) and conventional spraying by men (Fig. 2d) over an area of 3,264 ha during the period from July 17 to August 6. The total cost amounted to 487,000 yuan (40,000 US dollars).

On both the farming and grazing lands, the insecticides used were Fiproni and Cypermethrin (Liu, F.-S. and Hou, X.-J., personal communications). In some areas, baiting was used to attract
locusts for spraying. The main strategy was to find areas with high locust density during the daytime and to spray these areas with insecticides in the morning (4–9 am) when locusts are the least active due to the low temperature. No spraying was conducted from aircraft.

The management of locusts requires a rapid response and a coordinated effort so that locust populations of increasing density can be found and controlled before they cause serious damage to agriculture. The occurrence of locust swarms and outbreaks in Jiminay County is usually reported to ABJ by landowners, farmers, or local experts who monitor the locust population density in certain farming fields every week during the growing season (Fig. 3). The information is passed on to ATACA, located at the Agricultural Bureau of Altay Prefecture (ABAP) in the city of Altay, where the data are analyzed and a control strategy is decided by the Locust Control Office of the Prefecture (LCOP) under the supervision of the Agricultural Department of the Province and the Agricultural Ministry of China. An LCOP consisting of about 10 experts for locust control was organized in 2003 at ATACA. A similar team is also present at the Stock Farming Bureau of Altay (SFBA) for the locust control on grazing lands.

One of the problems in controlling locusts in the Xinjinan Uygur Autonomous Region is that the area is huge and any spraying over a wide range of area by aircraft can cause serious harm to the livestock grazing there. Thus, spotting areas with high locust density becomes important, although it is practically impossible to spot all swarms and dense populations. Once spotted, however, such areas may be sprayed manually or by using vehicles.

Symmons (1997) has pointed out that the current problems associated with locust control are not control methods, but mainly logistical, organizational, financial and political. The main problems associated with locust control in the Xinjinan Uygur Autonomous Region are the lack of enough equipment and financial support for control and constant locust monitoring. Further improvement of the locust monitoring and control system with constant and increased financial support will help reduce damage to agriculture and the environment. New approaches to predict locust hatching using degree-day modeling, and to locate locust swarms using weather information and aircraft may help improve the efficiency of locust control. Control measures without using insecticides should also be explored to protect the environment. A special problem in Jiminay County is that swarms of locusts grown in the neighboring country appear to cause substantial damage to pastures and crops. However, this problem is currently being discussed between the two countries (Wu, X.-G., personal communications).

**Morphometrics of locusts**

The mean values of \( C \) (head width), \( F \) (hind femur length) and \( E \) (elytron length) were larger for the locusts from the HD site than for those from the LD site, although a significant difference was obtained only in \( E \) for males (Table 1). Both \( F/C \) and \( E/F \) ratios were significantly different between the sexes of each sample and between the two samples in each sex. More importantly, relatively small \( F/C \) ratios and large \( E/F \) ratios characteristic of gregarious forms were found for the locusts collected at the HD site, which is consistent with the fact that they were migrants. The \( F/C \) ratio for gregarious populations of \( L. migratoria \) in countries ranges from 2.85 to 3.14 and that for solitarious
the LD site showed a much wider range covering the locusts from the HD site, whereas those from that the range of variation was relatively small for (Mann-Whitney sites when the data for the two sexes were pooled proportion of individuals having different pronotum with a mean \( H'/H \) ratio of \(-0.015 \) and \(-0.014 \) for the females and males, respectively, whereas the proportion of such individuals was slightly smaller at the LD site. Both the mean \( H'/H \) ratio and proportion of individuals having different pronotum shapes were significantly different between the two sites when the data for the two sexes were pooled (Mann-Whitney \( U \)-test for the former and \( \chi^2 \) test for the latter; \( p<0.05 \); Table 2). Figure 3 plots individual \( E/F \) ratios against \( F/C \) ratios, which showed that the range of variation was relatively small for the locusts from the HD site, whereas those from the LD site showed a much wider range covering the former. It is possible that those individuals with large \( E/F \) and small \( F/C \) values in the latter were migrants that escaped from spraying and dispersed to this wheat field. Those with large \( F/C \) values and small \( E/F \), on the other hand, might have grown up there or came from adjacent habitats where the population density was slightly higher than at this site, thus producing intermediate morphometric ratios that may be regarded as transient forms. A few individuals of this sample showed a considerably large \( F/C \) ratio and a very small \( E/F \) ratio (Fig. 4). Their values were similar to those \( (F/C=3.46-3.69; \ E/F=1.87-1.90) \) reported for solitarious populations in northern China (calculated based on Table 2 of Farrow and Colless, 1980). These individuals also showed a distinctly convex shape of pronotum \( (H'/H \) ratio=0.10-0.11; Fig. 5a), which is characteristic of solitarious forms (Uvarov, 1966). Therefore, the sample collected at the LD site appeared to have consisted of a mixture of gregarious, transient and solitarious forms.

Table 1. Morphometric measurements (mean±SD) of locusts (\( L. \) migratoria) collected at high-density and low-density sites in Jiminay, Altay Prefecture, the Xingjian Uygur Autonomous Region, China, in 2004

<table>
<thead>
<tr>
<th>Collection site</th>
<th>Maximum head width (C) (mm)</th>
<th>Hind femur length ( (F) ) (mm)</th>
<th>Elytron length ( (E) ) (mm)</th>
<th>( F/C^* )</th>
<th>( E/F^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-density site</td>
<td>( \varphi ) 8.25±0.39 a (50)</td>
<td>25.05±1.15 a (50)</td>
<td>53.55±1.99 a (50)</td>
<td>3.03±0.09 (50)</td>
<td>2.14±0.07 (50)</td>
</tr>
<tr>
<td></td>
<td>( \delta ) 7.72±0.33 bc (50)</td>
<td>23.95±1.07 b (50)</td>
<td>50.26±2.06 b (50)</td>
<td>3.10±0.08 (50)</td>
<td>2.10±0.07 (50)</td>
</tr>
<tr>
<td>Low-density site</td>
<td>( \varphi ) 8.01±0.39 ab (15)</td>
<td>24.99±1.50 a (15)</td>
<td>51.72±2.00 ab (14)</td>
<td>3.12±0.16 (15)</td>
<td>2.07±0.10 (14)</td>
</tr>
<tr>
<td></td>
<td>( \delta ) 7.46±0.50 c (35)</td>
<td>23.84±1.45 b (35)</td>
<td>48.87±2.96 c (35)</td>
<td>3.20±0.15 (35)</td>
<td>2.01±0.08 (35)</td>
</tr>
</tbody>
</table>

Different letters after mean±SD indicate significant differences by multiple comparison using Scheffé’s test \((p<0.05)\).

* Means in each column are significantly different between the two sexes for each site and between the two sites for each sex using the Mann-Whitney \( U \)-test \((p<0.05)\).

Table 2. Measurements (mean±SD) of pronotum for the adults of \( L. \) migratoria collected at high-density and low-density sites in Jiminay, Altay Prefecture, the Xingjian Uygur Autonomous Region, China, in 2004

<table>
<thead>
<tr>
<th>Collection site</th>
<th>% of individuals with pronotum shape of</th>
<th>( H'/H ) ratio</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>concave</td>
<td>flat</td>
<td>convex</td>
</tr>
<tr>
<td>High-density site</td>
<td>( \varphi ) 56.7</td>
<td>23.3</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>( \delta ) 56.7</td>
<td>30.0</td>
<td>13.3</td>
</tr>
<tr>
<td>Low-density site</td>
<td>( \varphi ) 50.0</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>( \delta ) 30.0</td>
<td>20.0</td>
<td>50.0</td>
</tr>
</tbody>
</table>

* The mean was significantly different between the two sites for each sex (Mann-Whitney \( U \)-test; \( p<0.05 \)).

Body color

Boby-color polyphenism is common in locusts ones from 3.01 to 3.94 (calculated based on data by Farrow and Colless, 1980). The corresponding range for \( E/F \) ratios was from 1.95 to 2.19 for gregarious populations and from 1.68 to 1.91 for solitarious ones (calculated based on data by Farrow and Colless, 1980). When evaluated by the \( E/F \) ratios that do not overlap between the two phases, the locusts collected at the two sites in Jiminay had reached morphometric ratios (2.01–2.14; Table 1) typical for gregarious forms. Most individuals at the HD site had either concave or flat pronotum with a mean \( H'/H \) ratio of \(-0.015 \) and \(-0.014 \) for the females and males, respectively, whereas the proportion of such individuals was slightly smaller at the LD site. Both the mean \( H'/H \) ratio and proportion of individuals having different pronotum shapes were significantly different between the two sites when the data for the two sexes were pooled (Mann-Whitney \( U \)-test for the former and \( \chi^2 \) test for the latter; \( p<0.05 \); Table 2).
and grasshoppers (Faure, 1932; Uvarov, 1966, 1977; Pener, 1991). *L. migratoria* shows green-brown polyphenism at low density where adults are either greenish or brownish in color. At high density, on the other hand, adults are all brownish and males turn yellow when they become sexually mature. The sample collected at the LD site contained both greenish (Fig. 5a and b) and brownish individuals (Fig. 5c). The proportion of greenish adults was 33.3% \((n=15)\) and 57.4% \((n=35)\) in females and males, respectively. However, the morphometric characteristics of the greenish adults were not necessarily of the solitarious phase. Some showed a flat or concaved shapes of the pronotum (Fig. 5b) and morphometric ratios typical for gregarious forms (e.g., \(F/C\) ratio=3.03–3.05; \(E/F=2.07–2.11\)). No significant difference was found in either ratio between the greenish and brownish individuals of either sex (Mann-Whitney U-test; \(p>0.05\)). All specimens collected at the HD site had already changed their body color because 3 wk had passed since they were sprayed. Most of them had turned shiny brown, but a few had retained a green coloration. It is not likely that the proportion of greenish individuals in this sample represented the original proportion. Another sample collected at the same site earlier by ABJ was preserved in better condition, and it contained 26.6% of greenish adults \((n=150)\), indicating that some migrants were greenish in color.

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**REFERENCES**


