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AN OVERVIEW OF THE RED IMPORTED FIRE ANT (HYMENOPTERA: FORMICIDAE) IN MAINLAND CHINA

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ABSTRACT

The red imported fire ant, *Solenopsis invicta* Buren is a serious invasive insect that is native to South America. Its presence was officially announced in mainland China in Jan 2005. To date, it has been identified in 4 provinces in mainland China (Guangdong, Guangxi, Hunan, Fujian) in a total of 31 municipal districts. The total area reported to be infested by *S. invicta* in late 2006 was about 7,120 ha, mainly in Guangdong Province (6,332 ha). Most of the reported human stings are in the heavily infested area around Wuchuan City. The most commonly reported reactions have been abnormal redness of the skin, sterile pustules, hives, pain, and/or fever. It has been predicted that most of mainland China is viable habitat for red imported fire ants, including 25 of 31 provinces. The probable northern limit of expansion reaches Shandong, Tianjing, south Henan, and Shanxi provinces. Traditional and new insecticides including the bait N-butyl perfluorooctane sulfonamide and the contact insecticide Yichaoqing have been developed and used to control *S. invicta*. The Ministry of Agriculture and the Chinese government have established an 8-year eradication program (2006 to 2013) for *S. invicta* in China.

KeyWords: *Solenopsis invicta*, distribution, infestation, damage, invasion biology, control, management

RÉSUMÉN

La hormiga brava roja, *Solenopsis invicta* Buren es un serio insecto invasor nativo de América del Sur. Su presencia se detectó en el territorio continental de China en 2005. Hasta el momento, se lo identificó en cuatro provincias (Guangdong, Guangxi, Hunan, Fujian) en un total de 31 distritos (municipal). El área total infestada con *S. invicta* a fines de 2006 era aproximadamente de 7,120 ha, principalmente en la provincia de Guangdong (6,332 ha). La mayor parte de las picaduras a seres humanos fueron informadas en un área altamente infestada en los alrededores de la ciudad de Wuchuan. Las reacciones más comúnmente informadas han sido enrojecimiento de la piel, pústulas, ronchas, dolor y/o fiebre. Se estima que la mayor parte del territorio continental de China es un ambiente apropiado para las hormigas bravas, incluyendo 25 de las 31 provincias. El límite norte probable de expansión llega a las provincias de Shandong, Tianjing, sur de Henan y Shanxi. Insecticidas tradicionales y nuevos incluyendo el cebo N-butil perfluorooctano sulfonamida y el insecticida de contacto Yichaoqing han sido desarrollados y usados para controlar a *S. invicta*. El Ministerio de Agricultura y el gobierno de China coinciden en que la máxima prioridad es tratar de erradicar y controlar a la plaga estableciendo un programa de erradicación de 8 años (2006 al 2013).

Translation provided by Juan A. Briano.

The red imported fire ant, *Solenopsis invicta* Buren is a serious invasive insect native to South America (Tschinkel 2006). It is included in the World Conservation Union's Top 100 list of invasive species and is considered the worst of the ant species listed (<http://www.issg.org/database/>). Since *S. invicta* was unintentionally introduced into the United States from South America in the 1930s, more than 1.3 million km² have been infested (USDA-APHIS Quarantine Map, 2006), and

it has become a major economic, social, and ecological pest, costing Americans 5-6 billion U.S. dollars per year (Lard et al. 2001; Pereira et al. 2002).

Solenopsis invicta was first detected in Australia in Feb 2001 and subsequent surveys delimited an infestation of over 300 km² (Vanderwoude et al. 2004). The Queensland Department of Primary Industries and Fisheries established a Fire Ant Control Centre (FACC) in mid 2001 to eradicate the ant from Australia. This eradication pro-

gram has eliminated over 99% of the original colonies; however, eliminating the last fraction of a percent will be the most difficult part of the program. Red imported fire ants were found in New Zealand in 2001, 2004, and 2006 (Bissmire 2006), in Taiwan in 2003 (<http://www.fireant-tw.org>) and in Hong Kong and Macao in 2005 (Xinhua news report, 30 Jan 2005; Common Talk Weekly, 23 Feb 2005). In 2005, the pest was also reported in mainland China (Zhang & Li 2005), but no details of infested locations were supplied. It has been predicted that most of mainland China will be viable habitat for red imported fire ants (Morrison et al. 2004).

Solenopsis invicta Reported Areas

The first official report of *S. invicta* in mainland China came in an announcement by the Ministry of Agriculture (MOA) of the People's Republic

of China on 17 Jan 2005 (Announcement of The Ministry of Agriculture of P. R. China, No. 453). The announcement noted that *S. invicta* had been found in parts of Wuchuan City (Guangdong Province), was a recent introduction to mainland China, and had harmful impacts on the environment. Subsequently, all information about *S. invicta* discoveries were made public by MOA's official announcements and its official website (<http://www.agri.gov.cn>). Known infestations of *S. invicta* are listed in Table 1 and localities are illustrated in Fig. 1.

Solenopsis invicta has been found in 4 provinces in mainland China: Guangdong (where the first invasion in mainland China was detected), Guangxi and Hunan (8 May 2006), and Fujian (22 Nov 2005). Sixteen municipalities have been invaded by *S. invicta*, of which 11 (Dongguan, Guangzhou, Heyuan, Huizhou, Maoming, Shenzhen, Zhanjiang, Zhongshan, Yunfu, Zhuhai, and

TABLE 1. *SOLENOPSIS INVICTA* REPORTS IN MAINLAND CHINA DURING 2005 (EXCLUDING TAIWAN, HONG KONG AND MACAO).

Reported date	Locality			Information source
	Province	Municipality	Municipal district	
17 Jan	Guangdong	Zhanjiang	Wuchuan City	MOA ^a
18 Apr	Guangdong	Guangzhou	Panyu District Nansha District	www.agri.gov.cn
	Guangdong	Shenzhen	Baoan District Luohu District Nanshan District Yantian District Futian District Longgang District	www.agri.gov.cn
	Guangdong	Zhuhai	Doumen District Xiangzhou District Jinwan District	www.agri.gov.cn
	Guangdong	Huizhou	Huicheng District Boluo County	www.agri.gov.cn
	Guangdong	Dongguan	Dongguan City	www.agri.gov.cn
	Guangdong	Zhongshan	Zhongshan City	www.agri.gov.cn
8 May	Guangxi ^b	Nanning	Yongxin District	MOA
	Guangxi	Yulin	Luchuan County	MOA
	Hunan	Zhangjiajie	Yongding District	MOA
28 Jul	Guangxi	Wuzhou	Cenxi City	www.agri.gov.cn
25 Aug	Guangxi	Yulin	Beiliu City	www.agri.gov.cn
31 Aug	Guangdong	Yunfu	Yangchun City	www.agri.gov.cn
	Guangdong	Maoming	Gaozhou City Dianbai County	www.agri.gov.cn
8 Sep	Guangdong	Heyuan	Lianping County Dongyuan County	www.agri.gov.cn
22 Sep	Guangdong	Maoming	Maogang District Maonan District	www.agri.gov.cn
22 Nov	Fujian	Longyan	Shanghang County Xinluo District	MOA
Nov	Guangdong	Meizhou	Dapu County	Lu et al. 2007

^aMOA means the Ministry of Agriculture of the People's Republic of China.

^bGuangxi means the Guangxi Zhuang Autonomous Region.

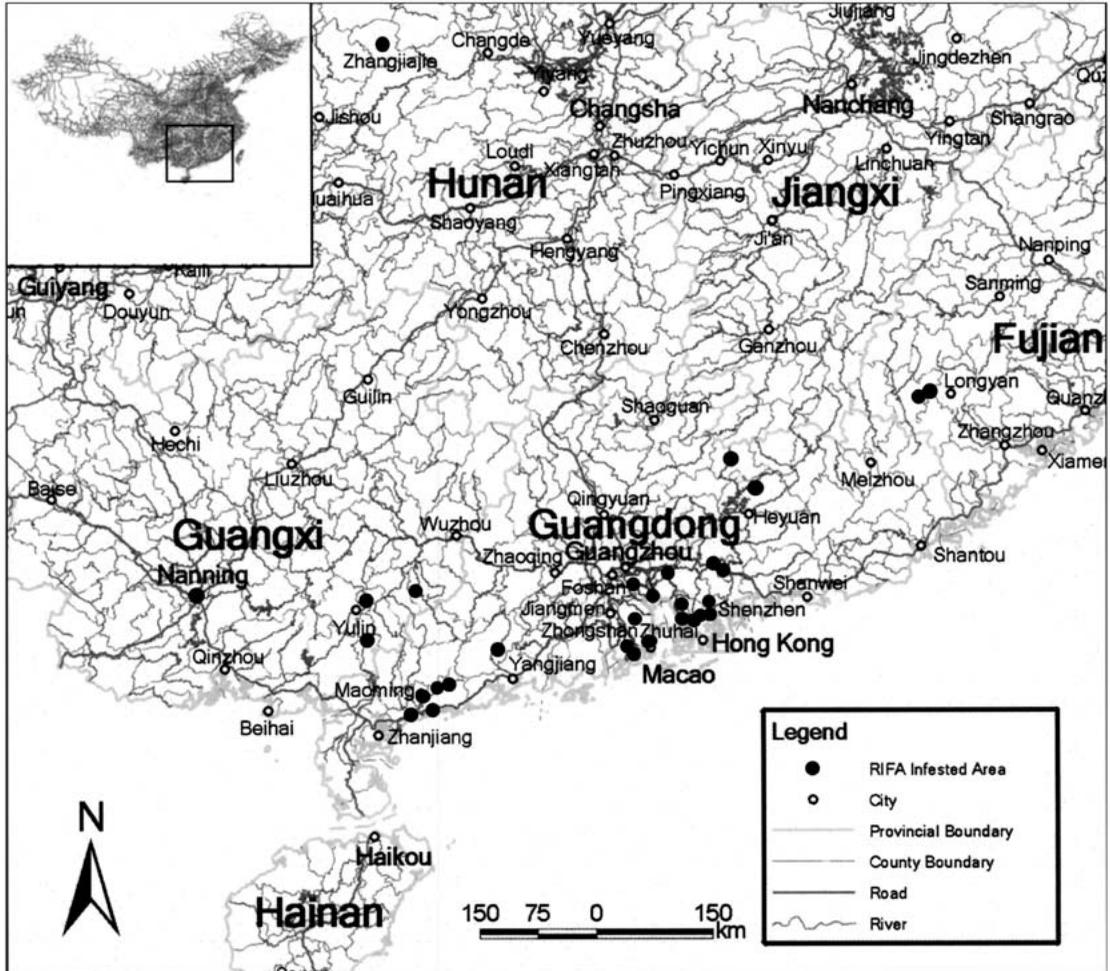


Fig. 1. Map showing localities of mainland China infested by *Solenopsis invicta* in 2005. The black dots are the infested areas.

Meizhou) are in Guangdong, 3 (Nanning, Wuzhou and Yulin) are in Guangxi, plus Zhangjiajie (Hunan) and Longyan (Fujian). Altogether, 31 municipal districts have been invaded by *S. invicta* of which 24 are in Guangdong.

In 2005, the total area reported to be infested by *S. invicta* in mainland China was about 7,120 ha (Table 2). This ant had infested at least 6,332 ha in Guangdong, 557 ha in Guangxi, 193 ha in Fujian, and 33 ha in Hunan. The 2 largest reported areas in Guangdong are Panyu (3716 ha) and Wuchuan (2074 ha). Generally, infestations are only a small fraction of total land area (Table 2).

Typical Damage

In Wuchuan City, *S. invicta* built mounds at high densities on sloping wasteland, grasslands, and ridges of fields covered with weeds causing impacts on agricultural production, human

health, and daily life. Investigations in Shenzhen, Huizhou, Wuchuan, and Zhuhai (Lei et al. 2005) indicated that *S. invicta* also nested in open sunny areas, fallow land, roadsides, gardens, the base of plants, and close to ponds, rivers, dams, and other areas of water. Reports of *S. invicta* stings disturbing agricultural activities, hurting livestock, and damaging agricultural production were supplied but without detailed case information.

By early 2005 when *S. invicta* was first announced in Guangdong, the ant had seriously affected trade. According to Guangzhou Customs District, about 1 million potted flowers and oranges ready for export to Hong Kong for the Spring Festival had to be detained because of quarantine problems relating to *S. invicta* (Da 2005).

Probably the most serious issues stemming from *S. invicta* are impacts on human health (de-Shazo et al. 1990; Goddard et al. 2002). Liu et al. (2005a) observed the process by which *S. invicta*

TABLE 2. AREA KNOWN TO BE INFESTED BY *SOLENOPSIS INVICTA* BEFORE TREATMENT, 2005.

Locality		Territory area (ha)	<i>S. invicta</i> infested area (ha)	<i>S. invicta</i> infested percentage
Province	Municipality (municipal district)			
Guangdong	Zhanjiang (Wuchuan)	84,800	2,074	2.45
	Zhuhai (Doumen, Xiangzhou, Jinwan)	165,300	210	0.13
	Heyuan (Lianping, Dongyuan)	636,500	200	0.03
	Huizhou (Huicheng)	140,000	100	0.07
	Huizhou (Boluo)	8,900	33	0.37
	Meizhou (Dapu)	13,300	2.5	<0.01
	Guangzhou (Panyu, Nansha); Shenzhen (Baoan, Luohu, Nanshan, Yantian, Futian, Longgang); Dongguan (Dongguan); Zhongshan (Zhongshan); Fuyun (Yangchun); Maoming (Gaozhou, Dianbai, Maogang, Maonan)	1,784,050	3,715	0.21
Guangxi	Nanning (Yongxin); Wuzhou (Cenxi); Yulin (Luchuan, Beiliu)	1,682,000	557	0.03
Fujian	Longyan (Xinluo)	1,180	180	15.25
	Longyan (Shanghang)	14,760	13	0.09
Hunan	Zhangjiajie (Yongding)	951,800	33	<0.01
Total	16 Municipalities (31 Municipal Districts)	5,482,590	7,118	0.13

stings, and indicated that an effective antidote to the toxins in *S. invicta* stings has not yet been developed. Analysis of epidemiological investigations of stings by red imported fire ants in Wuchuan found 416 of 4894 people in 5 villages had been stung (8.5%). The first reported sting occurred in 1999 when 4 cases were reported, 5 cases in 2000, 21 in 2001, 64 in 2002, 126 in 2003, and 186 from Jan to Sep in 2004. Most reported stings occurred between Jun and Sep when the fire ants are most active and people are working the fields. Of 416 cases, almost all reported sterile white pustules (96.6%) or pain (95.9%). Abnormal skin reddening and hives were reported. There were 43 cases of fever (10.3%), 19 cases had a headache (4.6%), 39 manifested distended lymph nodes (9.4%), and 4 patients had systemic anaphylaxis (1.0%) (Rong 2005). The dates of these cases indicate that *S. invicta* invaded Wuchuan at least 7 years before its detection was reported.

Besides Wuchuan, other infested regions in mainland China also report similar cases. During our investigations, we found the following cases:

- (1) A Huang Fugen couple was stung by *S. invicta* while gathering bananas in Jiuwangmiao in Nansha District in Guangzhou, Guangdong. They were sent to hospital for 2 weeks which cost them their wages for the entire period.
- (2) A child had reactions of fever and shock after being stung by *S. invicta* in Shaluowan in Nansha District in Guangzhou, Guangdong. He was sent to hospital and accepted medical treatment. Six children in the same village reported a fever after being stung by *S. invicta*.

- (3) A child fell into a nest of *S. invicta* in Lianping, Guangdong in 2005. He was seriously stung and sent to hospital for treatment.
- (4) A director of Shenzhen Agricultural Bureau in Guangdong had a shock reaction after being stung by *S. invicta*, and a division director of Shenzhen Animal and Plant Quarantine Bureau found a nest of *S. invicta* in a flowerpot in the roof garden of his house.
- (5) A 2-year old boy was stung by *S. invicta* in Shibunear Nanning in Guangxi, and sent to hospital, which cost his family more than \$100 in medical costs.
- (6) Cases of shock after being stung by *S. invicta* also occurred in Zhangjiajie, Hunan.

Precaution and Response

In Dec 2004, an article entitled "Red imported fire ant from South America invaded Taiwan causing panic; Scholars in mainland China remind government of taking strict precautions against its invasion" was published on the front page of *Science Times* (Wang 2004). This was the earliest article appealing for vigilance and drawing attention to the threat of *S. invicta* in mainland China.

Soon after the Ministry of Agriculture announced the discovery of *S. invicta* in mainland China, a number of papers were quickly published about this pest. Zhang et al. (2005a) published an article discussing the damage potential, identification, and control methods for *S. invicta*. Specialists in plant quarantine (Chen et al.

2005b; Zheng et al. 2005; Zhou 2005b), forestry (Zhen et al. 2005), sanitation (Fan & Zhen 2005; Zhang et al. 2005b; Zheng et al. 2005b;), infested provinces (Wen & Du 2005), ant research (Zhou 2005a) and public education (Zhang & Mai 2005) all wrote articles on the identification of and appropriate precautions against *S. invicta*.

Solenopsis invicta is a new invasive pest in China, so evaluation of control techniques of *S. invicta* from scientists in other regions is important, especially those from the USA, Australia, and Taiwan. The National Agriculture Technique Extension & Service Center of China (NATESC) and the Institute of Zoology, Chinese Academy of Sciences (IOZ), collected and organized relevant information, and published *Red Imported Fire Ant*, a book which discussed research into and control methods for *S. invicta* (Wang & Zhang 2005). Later, many articles added related knowledge about *S. invicta* including damage potential (Tan 2005; Liu et al. 2005c), biological characteristics (Jiang et al. 2005), control methods (Gao & Gao 2005; Zhen et al. 2005; Liu et al. 2005b; Ren et al. 2005), and quarantine techniques (Chen et al. 2005b). Papers on control experiences from Australia and Taiwan (Lin et al. 2005a; Zhou & Cai 2005) were also published.

After the discovery of *S. invicta* in China, it became important to know how much loss the ant would cause to the environment, economy, and society. Xue Dayong et al. (2005) from the Chinese Academy of Sciences predicted the potential distribution of *S. invicta* in China (by Climex and GARP analysis) and suggested this pest was likely to survive and cause damage in most areas of southeast China with a northern limit of spread reaching Shandong, Tianjing, south Henan and Shanxi—a potential distribution across 25 provinces. Other articles also reported the potential impact on the environment and tackled the problem of risk analysis (Zhen & Zhao 2005; Yang et al. 2005).

Many scientists carried out various studies immediately after the discovery of *S. invicta* in mainland China. A key problem was the need for unambiguous identification of *S. invicta*. Several morphological characteristics are important and these were the simplest way to identify and distinguish the ant from other related species of *Solenopsis* (Zhang et al. 2005a; Zeng & Lu 2005; Chen et al. 2005a; Lin et al. 2005b). To aid precise identification, the microstructures of *S. invicta* were carefully inspected (Gao & Luo 2005). *Cyt b* genes from 2 populations of *S. invicta* (from Florida, USA and Wuchuan, Guangdong, China) and 4 populations of *S. geminata* (Fabricius) from Guangdong were sequenced (Zeng et al. 2005b). There were 61 variable sites between these 2 species. No variable site was found between the 2 populations in *S. invicta*. The result of restriction fragment length polymorphism tests (RFLP)

showed there was 1 restrictive site detected by restriction endonucleases *MspI* in the amplified segments of *S. geminata* but none in *S. invicta*. So the PCR-RFLP method could be used as a powerful tool for identification of these 2 species.

Research on Control Techniques

Experiments by Luo et al. (2006) indicated a bait with N-butyl perfluorooctane sulfonamide (N-BPS) caused mortality in ants beginning 3 d after application both inside and outside nest mounds and the rate of mortality increased to 81.5% after 21 d. So the application of N-BPS was considered to replace the bait step in the two-step method which is extensively used in other countries (Drees et al. 2000). Whether N-BPS is consistently effective can only be determined after further experiments, and the long-term effect is determined by appropriate application conditions and levels. Recently, professors from South China Agricultural University developed a new contact insecticide to control *S. invicta*—Yichaoqing (Anonymous 2005). One mL of this contact insecticide diluted in water to 1,500-2,000 mL can be used to drench mounds. When *S. invicta* contact this insecticide, they immediately lose the ability to move, and die in a few minutes. Control of *S. invicta* is not only dependent on the use of several insecticides, but on other important factors. Zeng et al. (2005a) discussed surveillance and control methods for *S. invicta*. This book integrated the facts of the incursion into China with necessary background about identification, spread, and biology, also offering precautions and treatment methods after a sting (Zeng et al. 2005a). This book is one of the most valuable references in China at present.

Activities of Officials and Research Organizations

Solenopsis invicta was declared subject to entry plant quarantine in P. R. China on 17 Jan 2005 (*Announcement of The Ministry of Agriculture of P. R. China*, No. 453) and also a national plant quarantine pest, based on the *Law of the People's Republic of China on the Entry and Exit Animal and Plant Quarantine and Regulations of Plant Quarantine*. At the same time, the *Announcement on Printing and Issuing Urgent Precautionary Project for Prevention and Control Red Imported Fire Ant* (AAC [2005] No. 1, www.agri.gov.cn) was promulgated. An *Announcement on Enhancing Surveillance of Remaining Pesticide on Exit Plant Food in Red Imported Fire Ant-Infested Areas* (GAOSIIQCFC [2005] No. 60, www.agri.gov.cn) was promulgated by the General Administration of Quality Supervision, Inspection and Quarantine of P. R. China on 28 Jan 2005. An *Announcement on Enhancing Surveillance and Quarantine for Red Imported Fire Ant*

(OC [2005] No. 7, www.agri.gov.cn) was promulgated by the State Forestry Administration, P. R. China on 28 Jan 2005. The *Announcement on enhancing surveillance and control of events of red imported fire ant harming people* (HOU [2005] No. 54, www.agri.gov.cn) was promulgated by Ministry of Health, P. R. China on 15 Mar 2005. The *Announcement on printing and issuing national eradication program, propagandizing and training plan* (AOA [2005] No. 51, <http://www.agri.gov.cn>) was promulgated by the Ministry of Agriculture (MOA) on 12 Sep 2005.

NATESC (in charge of pest control technique within MOA) established a column discussing red imported fire ant control on the Agriculture Information Web (<http://www.natesc.gov.cn>), which covers work situations, related regulations, research, training, control techniques, and alien species information.

Legislator Deputy of the National People's Congress (NPC) of China and professor of entomology, Zhang Zhongning, gave a talk entitled: "Upping the ante when fighting harmful insects" on 14 Mar 2005. He recommended that quick and effective measures be taken to stop red fire ants from making inroads into central and northern China. This speech was presented at the ongoing session of the National People's Congress in Mar 2005, the country's highest legislative body. Professor Zhang suggested quarantine control be tightened to prevent the ant from invading an even larger area of the country. The legislator also proposed accelerating the enactment of a law on the importation of alien invasive species.

The Red Imported Fire Ant Research Center was established at the South China Agricultural University on 8 Jul 2005. Entomologist Professor Zeng Ling (who first found and identified *S. invicta* in China) was appointed director of this center. This center cooperated with MOA and related departments in Guangdong on the investigation, surveillance, and control of *S. invicta*. Effective work has been carried out to control this pest in mainland China (including Hong Kong and Macao). Advanced research on surveillance and control of *S. invicta* is also in progress at this research center.

On 1 Mar 2005, the Alien Pest Identification and Precaution Technique Center was established by the Chinese Academy of Sciences and the Institute of Animal and Plant Quarantine of the Chinese Academy of Inspection and Quarantine (*S. invicta* is also one of the key projects for the Knowledge Innovation Program of Chinese Academy of Sciences—Alien Species Research Project Group). A seminar on *S. invicta* precautions and control was held in Beijing, and was the first high level seminar on *S. invicta* in mainland China. Chief directors from MOA, the Chinese Academy of Sciences (CAS), the General Administration of Quality Supervision, Inspection and

Quarantine, the National Natural Science Foundation, and specialists from the Chinese Academy of Agricultural Sciences, the Chinese Academy of Inspection and Quarantine, China Agricultural University, Beijing Forestry University, and Beijing Normal University discussed the serious impact of *S. invicta* on agriculture and forestry development, public properties, and public health, as well as control strategies and techniques. They also discussed how to carry out scientific research, and how to raise public awareness of the pest. In this seminar, Zhang Runzhi (Alien Species Research Project—CAS Major Innovation Program) together with Zeng Ling (South China Agricultural University) and Chen Hongjun (Chinese Academy of Inspection and Quarantine), spoke on damage, infestation, control and quarantine, respectively. After the seminar, attendees made suggestions to related national departments.

Government Control Policies

Solenopsis invicta spreads quickly through natural means, and can easily travel long distances with human assistance, unless humans rigorously control and quarantine the ant. The original mechanism of *S. invicta*'s introduction into China is not known as yet, but it surely must have been introduced with freight. On 9 Mar 2005, Zengcheng Entry-Exit Inspection and Quarantine in Guangdong first intercepted *S. invicta* in imported waste paper (Chen et al. 2005c). Although they did not reveal the origin of the imported waste paper, this discovery was enough to suggest *S. invicta* was likely to invade other susceptible areas in China. Imports from countries and regions infested by *S. invicta* which frequently trade with China need to be scrutinized and appropriate precautions taken.

Solenopsis invicta has settled in China causing economic damage and threatening human health. The authors agree with Luo (2005) that China is able to control or locally eradicate *S. invicta* in some areas. Luo also suggested that eradication of all *S. invicta* colonies was almost impossible at this stage. The number of infested municipal districts is up to 31 and it would be very hard to completely eradicate *S. invicta*.

Different regions of China may require different control strategies. For example, those counties where infested areas are very small may have the ability to eradicate the ant locally. Zhang et al. (2005a) outlined a strategy for controlling *S. invicta* as follows: (1) China should make a clear political decision to control *S. invicta*. It must be eradicated from those areas with small infested areas, while areas with large infestations or in areas where it is difficult to eradicate within 2-3 years should introduce containment measures to gradually reduce the infested area, (2) The inva-

sion of *S. invicta* is a national issue, so most of the funds required to manage it should be supported by national finance, and (3) National cooperation should be built up. The government, managers, researchers and public should work together, which can help control it better.

An 8-year eradication program designed by MOA is in progress (The Eradicating Program for *Solenopsis invicta* in China 2005-2013). A summary of the official plans are as follows: In 2005 extensive surveys and detection activity for *S. invicta* will be carried out in high risk and infested areas, and all infested areas in China will be investigated. Eradication techniques will be developed and safe effective baits and insecticides will be determined as soon as possible. Educational materials and CDs will be manufactured and distributed. Moderate public education will be achieved through the media. Handbooks about control techniques will be published. Staff will be trained in techniques to deliver extensive surveys and controls. One hundred temporary plant quarantine checkpoints will be established immediately and effective quarantine and eradication measures undertaken in infested areas.

During 2006-2008 the exact distribution of *S. invicta* in China will be defined. The infested areas and areas to be monitored will be mapped with GPS systems to facilitate rigorous monitoring. Over 90% of active nests and colonies of *S. invicta* in the current infested areas will be eradicated, and new infested areas effectively controlled. One national and 3 provincial control and management centers will be founded, and 1 control and research laboratory will be established. More than 100 temporary checkpoints in infested and high risk areas will be founded. Publicity and training will be carried out in infested areas, and the public will be encouraged to take part in the control program. Integrated eradication methods based on control methods will be made. A complete surveillance and control management system will be developed, and the eradication plan will be managed scientifically. Eradication will be taken in infested areas. *S. invicta* will be eradicated in isolated spots in 2006 and over 90% of mounds in continuously infested areas will be destroyed by 2008. All isolated infestations will be placed under surveillance and the success of their eradication declared after careful surveillance from 2006-2008.

During 2009-2010, all the infested and monitoring areas will be monitored rigorously, and effective containment and eradication measurements taken. Over 99% of mounds and colonies will be eliminated in existing infested areas, and over 95% of mounds and colonies in newly-infested areas will be killed. Publicity and training will be carried out in infested areas and the public will be encouraged to take part in the control program. Eradication techniques and the control

management system will be further improved. Areas with small infestations will be monitored for 2 years, and the success of local eradication will be declared wherever *S. invicta* can no longer be found.

During 2011-2013, all mounds and colonies will be eradicated in all infested areas. Control methods for *S. invicta* will be improved including methods of application and formulations for baits and active ingredients. Surveillance and monitoring will be reinforced in eradicated areas and potential high risk areas. Remnant mounds will be completely eradicated, and large continuously infested areas will be monitored for 2 years. If possible, the success of complete eradication will be declared in China by 2013.

The authors believe that this program will play an important role in controlling the spread of *S. invicta* in China. Even if it cannot be totally eradicated from mainland China, some regions may succeed in eradicating *S. invicta* locally. Should eradication eventually not prove feasible, the plans summarized above will function as aggressive containment and should greatly slow the spread of this pest into other areas of China. However, considering the size of the infestation, plans also need to be made for long-term quarantine and IPM management of this serious pest.

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LITERATURE CITED

- ANONYMOUS. 2005. South China agricultural university developed an effective pesticide, Yichaoqing for red imported fire ant [in Chinese]. *New Pesticides & Novel Pesticides* 3: 31.
- CHEN, N. Z., Z. W. SHI, AND X. G. MA. 2005a. Identification of red imported fire ant and important related species [in Chinese]. *Chinese Bull. Entomol.* 42: 341-345.

- CHEN, N. Z., Z. W. SHI, AND S. F. ZHANG. 2005b. Practice and research of quarantine and occurrence of *Solenopsis invicta* [in Chinese]. *Plant Quarantine* 19: 90-93.
- CHEN, Y., Q. TAN, AND X. H. LIN. 2005c. The first interception of red imported fire ant in imported waste paper in Zengcheng entry-exit inspection and quarantine [in Chinese]. *Great Economy & Trade* 4: 92.
- DA, G. 2005. One million potted flowers ready for exporting to Hong Kong for Spring Festival had to be detained. *Flowers* 3: 47.
- DESHAZO, R. D., B. T. BUTCHER, AND W. A. BANKS. 1990. Reactions to the stings of the imported fire ant. *New England J. Med.* 323: 462-466.
- DREES, B. M., C. L. BARR, S. B. VINSON, R. E. GOLD, M. E. MERCHANT, N. RIGGS, L. LENNON, S. RUSSELL, P. NESTER, D. KOSTROUN, B. SPARKS, D. POLLET, D. SHANKLIN, K. VAIL, K. FLANDERS, P. M. HORTON, D. OI, P. L. KOEHLER, AND J. T. VOGT. 2000. Managing Imported Fire Ants in Urban Areas. *Texas A&M Univ. Bull. B-6043*, 20 pp.
- FAN, D. H., AND J. N. ZHEN. 2005. Being aware of damages of public health from red imported fire ant [in Chinese]. *China Inspection and Quarantine* 6: 63.
- GAO, X. W., AND H. R. GAO. 2005. Chemical control methods of alien species red imported fire ant [in Chinese]. *Plant Protection*, 31: 14-17.
- GAO, Y., AND L. Z. LUO. 2005. Antennal morphology and sensilla of the fire ants, *Solenopsis invicta* Buren invaded southern China observed with scanning electron microscopy [in Chinese]. *Acta Entomol. Sinica* 48: 986-992.
- GODDARD, J., J. JARRATT, AND R. D. DESHAZO. 2002. Recommendations for prevention and management of fire ant infestation of health care facilities. *South. Med. J.* 95: 627-633.
- JIANG, S. H., D. LIU, AND G. J. LI. 2005a. Invasion, damages and prevention of red imported fire ant [in Chinese]. *J. Shenzhen Polytechnic* 2: 33-36.
- JIANG, S. H., D. LIU, AND G. J. LI. 2005b. A review: the biology of red imported fire ant (*Solenopsis invicta* Buren) [in Chinese]. *J. SW Agricul. Univ. (Nat. Sci.)*, 27: 312-315.
- LARD, C. F., C. HALL, AND V. SALIN. 2001. The economic impact of the red imported fire ant on the home-scape, landscape, and the urbanscape of selected metroplexes of Texas. Dept. of Agricul. Economics, Texas A&M Univ., College Station, TX. Faculty Paper Series; FP 01-3.
- LEI, Z. R., L. Z. LUO, Y. Q. ZHENG, D. F. CHENG, H. Z. YUAN, AND A. C. CAO. 2005. Investigation on dangerous alien invasive species, *Solenopsis invicta* Buren [in Chinese]. *Plant Protection* 31(3): 64-66.
- LIN, F. R., F. X. WANG, AND X. L. WU. 2005a. Experiences of control red imported fire ant in Australia. China [in Chinese] *Plant Protection* 25: 41-42.
- LIN, L. F., J. H. DUAN, W. C. LU, J. R. YI, X. C. ZHANG, AND S. W. CAI. 2005b. Morphological characteristic and identification of red fire ant in Wuchuan, Guangdong [in Chinese]. *Chinese J. Vector Biol. Contr.* 16: 174-177.
- LIU, D., S. H. JIANG, AND G. J. LI. 2005a. Changes of symptom caused by a sting of the red imported fire ant (*Solenopsis invicta*) [in Chinese]. *Chinese Bull. Entomol.* 42: 453-454.
- LIU, D., S. H. JIANG, AND G. A. ZHANG. 2005b. Research progress of red imported fire ant (*Solenopsis invicta* Buren) management methods [in Chinese]. *J. Huazhong Agricul. Univ.* 24: 417-422.
- LIU, Z. J., Z. B. LIU, AND Z. J. LIU. 2005c. Alien effective control methods and damages of red imported fire ant [in Chinese]. *Pesticide Sci. & Admin.* 26(7): 29-31.
- LU, Y. Y., G. W. LIANG, AND L. ZENG. 2007. Study on expansion pattern of red imported fire ant, *Solenopsis invicta* Buren, in South China [in Chinese]. *Scientia Agricultura Sinica* 40: (in press).
- LUO, L. Z. 2005. Considerations and suggestions on managing the red imported fire ant, *Solenopsis invicta* Buren in China [in Chinese]. *Plant Protection* 31(2): 5-8.
- LUO, L. Z., G. L. QIN, M. B. WANG, Q. D. PENG, AND H. R. LIU. 2006. Controlling the fire ant, *Solenopsis invicta* by N-BPS bait in Southern China [in Chinese]. *Plant Protection*, 32(1): 22-26.
- MORRISON, L. W., S. D. PORTER, E. DANIELS, AND M. D. KORZUKHIN. 2004. Potential global range expansion of the invasive fire ant, *Solenopsis invicta*. *Biol. Invasions* 6:183-191 [http://www.ars.usda.gov/Research/docs.htm?docid=9168&page=3].
- BISSMIRE, S. 2006. Red imported fire ants found at Whirinaki. *Biosecurity* 69:9.
- PEREIRA, R. M., D. F. WILLIAMS, J. J. BECNEL, AND D. H. OI. 2002. Yellow-head disease caused by a newly discovered *Mattesia* sp. in populations of the red imported fire ant, *Solenopsis invicta*. *J. Invertebr. Pathol.* 81: 45-48.
- REN, D. S., Q. Y. LIU, F. X. MENG, H. X. WU, AND D. M. LI. 2005. Red imported fire ant and its integrated management [in Chinese]. *Chinese J. Vector Biol. & Contr.* 16: 319-323.
- RONG, J. D. 2005. Surveys of injuries of people by red imported fire ants in Wuchuan [in Chinese]. *Chinese J. Pest Contr.* 21: 265-266.
- TAN, S. J. 2005. Introduction of harm of red imported fire ant to people and its control measures [in Chinese]. *Sichuan J. Animal* 24: 230-236.
- TSCHINKEL, W. R. 2006. *The Fire Ants*. Belknap Press of Harvard University Press, Cambridge, MA, USA.
- VANDERWOUDE C., M. ELSON-HARRIS, J. R. HARGREAVES, E. HARRIS, AND K. P. PLOWMAN. 2004. An overview of the red imported fire ant (*Solenopsis invicta* Buren) eradication plan for Australia. *Records of the South Australian Museum Monograph Series* 7: 11-16.
- WANG, F. X., AND R. Z. ZHANG. 2005. *Red imported fire ant*. Chinese Agriculture Press, Beijing, China. 375 pp.
- WANG, X. J. 2004. Red imported fire ant from South America invaded Taiwan causing panic; Scholars in mainland China remind government of taking strict precautions against its invasion. *Science Times*, Dec. 3. p.1.
- WEN, Y. X., H. L. DU, AND L. F. ZHENG. 2005. Red imported fire ant, a pest worth vigilance [in Chinese]. *Jilin Agricul.* 17: 22.
- WOJCICK, D. P., C. R. ALLEN, R. J. BRENNER, E. A. FORYS, D. P. JOUVENAZ, AND R. S. LUTZ. 2000. Red imported fire ants: impact on biodiversity. *Amer. Entomol.* 46: 240-247.
- XUE, D. Y., H. M. LI, H. X. HAN, AND R. Z. ZHANG. 2005. A prediction of potential distribution area of *Solenopsis invicta* in China [in Chinese]. *Chinese Bull. Entomol.* 42: 57-60.
- YANG, W. D., D. J. YU, AND Z. L. CHEN. 2005. Effects of red imported fire ant on agricultural ecological environment, society and economy [in Chinese]. *Plant Protection*, 31(5): 75-77.

- ZENG, L., Y. Y. LU, AND Z. N. CHEN. 2005a. Management and surveillance of red imported fire ant. Guangdong Science & Technique Press, Guangzhou, China. 106 pp.
- ZENG, L., Y. Y. LU, X. F. HE, W. Q. ZHANG, AND G. W. LIAN. 2005b. Identification of red imported fire ant *Solenopsis invicta* to invade mainland China and infestation in Wuchuan, Guangdong [in Chinese]. Chinese Bull. Entomol. 42: 144-148.
- ZHANG, R. Z., AND Y. C. LI. 2005. Red imported fire ant in China. pp.18. Proceedings of the 5th Asia Pacific congress of Entomology, Jeju, Korea.
- ZHANG, R. Z., AND G. Q. MAI. 2005. Red imported fire ant, a dangerous invasive insect [in Chinese]. Civilization 6: 20-21.
- ZHANG, R. Z., AND D. Y. XUE. 2005. What is the best strategy to against the invasion of red imported fire ant in China [in Chinese]. Bull. Chinese Acad. Sci. 20: 283-287.
- ZHANG, R. Z., L. REN, AND N. LIU. 2005a. An introduction and strict precautions against red imported fire ant, *Solenopsis invicta*, for its potential invasion to the mainland of China [in Chinese]. Chinese Bull. Entomol. 42: 6-10.
- ZHANG, S. H., D. H. ZHANG, AND C. Y. MA. 2005b. A new invasive pest, red imported fire ant, *Solenopsis invicta*. Chinese J. Hygienic Insecticides & Equipments 11: 216-219.
- ZHENG, H., AND Y. X. ZHAO. 2005. Alien pest risk analysis and control countermeasure of *Solenopsis invicta* Buren [in Chinese]. Forest Res. 18: 479-483.
- ZHENG, H., X. L. NIU, AND X. T. ZHANG. 2005a. Precaution of two quarantine pests [in Chinese]. Forest Pests and Disease 24(4): 41-44.
- ZHENG, J. N., D. H. FAN, H. X. SHI, Y. Y. LU, AND J. L. QIU. 2005b. Control and research of *Solenopsis invicta* Buren [in Chinese]. Chinese J. Hygienic Insecticides & Equipment 11: 186-189.
- ZHOU, S. Y. 2005a. Introduction and precaution of red imported fire ant [in Chinese]. Guangxi Plant Protection 18(2): 20-21.
- ZHOU, W. C., AND K. Z. CAI. 2005. Alien invasive species, red imported fire ant in Taiwan. Taiwan Agricul. Res. 2005 10(1): 39-41.
- ZHOU, W. C. 2005b. Strict precautions against red imported fire ant for its potential invasion to mainland China [in Chinese]. Fujian Agricul. 3: 17.