MIGRATION PREDICTION AND INSECTICIDE RESISTANCE MONITORING FOR RICE PLANTHOPPERS

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ABSTRACT

The three rice planthoppers: the brown planthopper (BPH), *Nilaparvata lugens*, the whitebacked planthopper (WBPH), *Sogatella furcifera*, and the small brown planthopper (SBPH), *Laodelphax striatellus*, are serious pests of rice throughout Asia. The northern limit of continuously breeding populations of BPH and WBPH is located around the Red River Delta in Vietnam and Hainan Island in China, where rice, their only host plant, is cultivated all year round. Neither of the two species is able to overwinter successfully in temperate areas (Japan, Korea, and most areas of China), and colonization occurs annually following long-distance migration from the overwintering areas. Thus, occurrence of these two species of rice planthoppers in temperate areas is highly dependent on populations in the overwintering areas. In contrast, SBPH is able to overwinter in the temperate zone of East Asia, including Japan and China. SBPH transmits the Rice stripe virus to rice plants, which causes rice stripe disease.

To achieve high-precision migration prediction for BPH and WBPH, a real-time prediction system was developed (Otuka et al., 2005, 2006; Furuno et al., 2005). In this system, the latest meteorological data are supplied online to an advanced numerical weather prediction model, MM5. The model forecasts 3-dimensional atmospheric fields at one-hour intervals. In these fields, a planthopper migration simulation model, GEARN, calculates movement of a number of modeled planthoppers and predicts their relative aerial density at three-hour intervals. The results are converted to maps and are available on the web (http://agri.narc.affrc.go.jp/) since 2004. The maps of relative aerial density provide information about the timing and area of migrations over the next two days.

SBPH were believed to be largely indigenous, unlike migratory rice planthoppers such as BPH and WBPH. However, recent shift of rice cultivars from hybrid rice to japonica varieties those were susceptible to SBPH in eastern China caused outbreaks of this species and its density peaked in 2005. Consequently, overseas migrations in early June started to appear in East Asia (Otuka et al., 2010; Syobu et al., 2011). To estimate possible immigrations in advance, a new prediction method for the overseas migration of SBPH from eastern China to Japan and Korea has been developed (Otuka et al., 2012). The method consists of two techniques: estimation of emigration period in the source region and migration simulation. The emigration period was estimated with the calculation of effective accumulated temperature for the insect using real-time daily surface temperatures in the source areas. During the emigration period, migration simulations were performed two times a day, or at every dawn and dusk. The prediction method was evaluated with a cross-validation technique against four-year events from 2008 to 2011. The result showed that the emigration periods included the mass migration events in 2008, 09 and 11 as well as an emigration peak in the source in 2010. The method was successfully predicted those events.

Since 2005, outbreaks of BPH and WBPH have occurred in East Asian countries such as Vietnam, China, and Japan. Outbreaks of SBPH have also occurred in eastern China and western Japan since mid-2000s. These outbreaks are closely related to the development of insecticide resistance in the populations in these regions. Thus, insecticide susceptibilities in BPH, WBPH, and SBPH collected from East and Southeast Asian countries were determined and compared.

Insecticide susceptibility in BPH and WBPH was evaluated by a topical application method on insects collected from East Asia (Japan, China, and Taiwan), Vietnam, and Philippines (Matsumura et al., 2008). Species-specific changes in insecticide susceptibility were identified: imidacloprid resistance in BPH and fipronil resistance in WBPH. Topical LD_{50} values for imidacloprid in the BPH populations collected from East Asia and Vietnam were significantly higher than those from the Philippines, suggesting that resistance to imidacloprid has developed in BPH in East Asia and Vietnam, but not in the Philippines. In contrast, almost all the WBPH populations had extremely large LD_{50} values for fipronil, suggesting that resistance to this insecticide is widespread in WBPH populations across East and Southeast Asia. Insecticide

resistance of southern Vietnam against imidacloprid is higher than those of northern Vietnam and east Asian, and is increasing from 2006 to 2010 (Matsumura et al., 2008; Matsumura & Sanada-Morimura, 2010; Matsumura et al., unpublished).

The insecticide susceptibility of SBPH was also evaluated using insects collected in East Asia and Vietnam from 2006 to 2008. The SBPH populations in Jiangsu Province, China showed resistance only to imidacloprid, whereas populations collected from western Japan showed resistance only to fipronil. In contrast, the populations in China (Fujian Province), Taiwan, and Vietnam were highly susceptible to both imidacloprid and fipronil. These results suggest that area-specific insecticide resistance has developed in East Asian SBPH.

SBPH populations were believed to be largely indigenous, unlike migratory rice planthoppers such as BPH and WBPH. However, traps in western Kyushu, Japan recorded large catches of SBPH in early June, 2008. A backward trajectory analysis indicated that the migration source was probably Jiangsu Province, China (Otuka et al., 2010). The insecticide susceptibilities of populations collected in rice fields of western Kyushu before and after the trapping period, and the presumed migration source region (Jiangsu) were determined and compared. Both the Chinese and migrant populations showed resistance only to imidacloprid, whereas the Japanese local populations collected before the trap catch showed resistance only to fipronil. Because SBPH is able to overwinter successfully in Japan, it is feasible that intercrossing between immigrant and domestic populations produces different characteristics in insecticide resistance in local populations in Japan. Indeed, some SBPH populations in western Japan developed insecticide resistance to both imidacloprid and fipronil after 2009 (Sanada-Morimura et al., 2011). This may be a typical example of insect migration from an overseas population altering the insecticide resistance of local (domestic) populations of SBPH.

KEYWORDS

migration prediction, overseas migration, insecticide resistance, brown planthopper

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Otuka, A. et al., 2012: Applied Entomology and Zoology, 47, in press.
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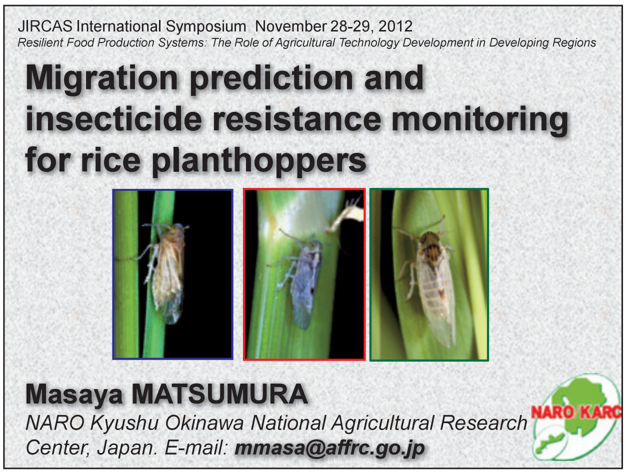
JIRCAS International Symposium November 28-29, 2012
Resilient Food Production Systems: The Role of Agricultural Technology Development in Developing Regions
Migration prediction and insecticide resistance monitoring for rice planthoppers
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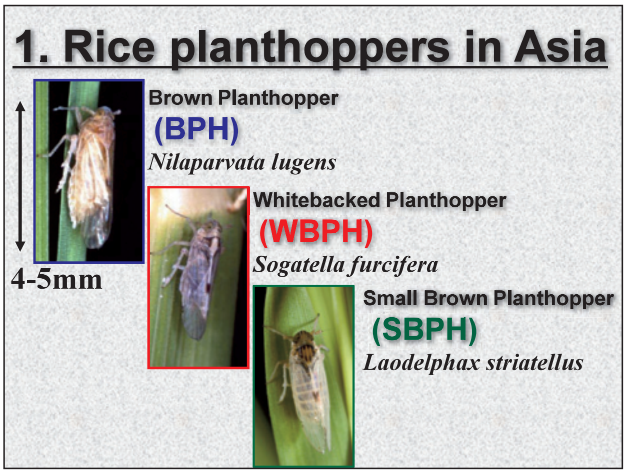
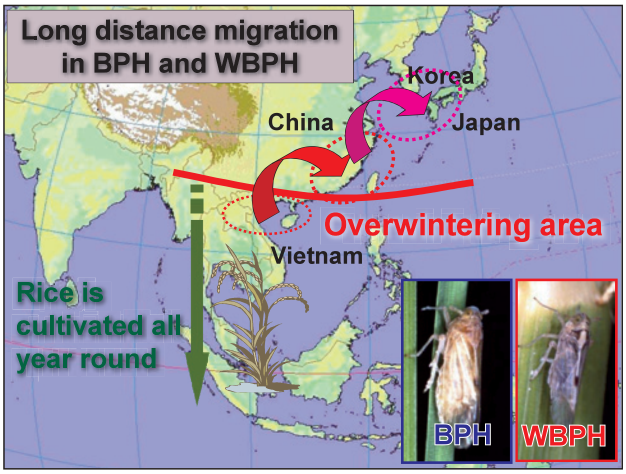
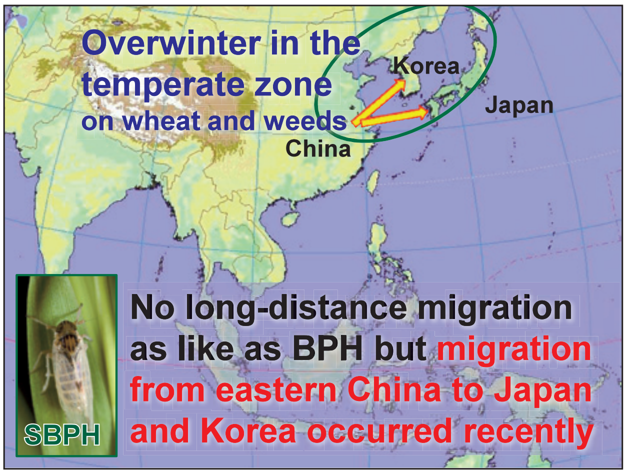

1. Rice planthoppers in Asia
Brown Planthopper
(BPH)
Nilaparvata lugens
4-5mm
Whitebacked Planthopper
(WBPH)
Sogatella furcifera
Small Brown Planthopper
(SBPH)
Laodelphax striatellus

2


Long distance migration in BPH and WBPH
Korea
China
Japan
Overwintering area
Vietnam
Rice is cultivated all year round
BPH
WBPH

3


Overwinter in the temperate zone
on wheat and weeds
Korea
Japan
China
SBPH
No long-distance migration as like as BPH but migration from eastern China to Japan and Korea occurred recently

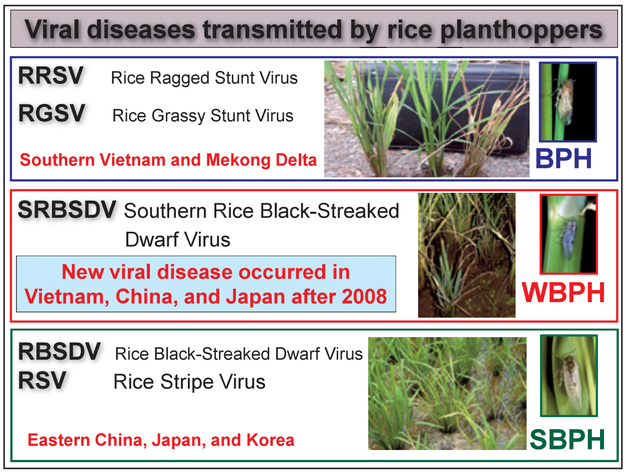
4


"Hopperburn" damage by the brown planthopper
October 2005 in Fukuoka, Japan
BPH

5


Outbreaks of WBPH on forage rice
(Indica rice variety) in Japan (2009.7.24)
WBPH

6



Viral diseases transmitted by rice planthoppers
RRSV Rice Ragged Stunt Virus
RGSV Rice Grassy Stunt Virus
Southern Vietnam and Mekong Delta
BPH
SRBSDV Southern Rice Black-Streaked Dwarf Virus
New viral disease occurred in Vietnam, China, and Japan after 2008
WBPH
RBSDV Rice Black-Streaked Dwarf Virus
RSV Rice Stripe Virus
Eastern China, Japan, and Korea
SBPH

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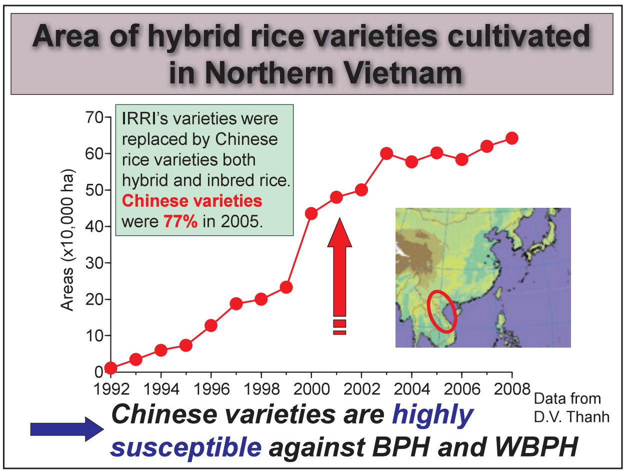

Area of hybrid rice varieties cultivated in Northern Vietnam
Areas (x10,000 ha)
0
10
20
30
40
50
60
70
IRRI's varieties were replaced by Chinese rice varieties both hybrid and inbred rice.
Chinese varieties were 77% in 2005.
1992
1994
1996
1998
2000
2002
2004
2006
2008
Data from D.V. Thanh
Chinese varieties are highly susceptible against BPH and WBPH

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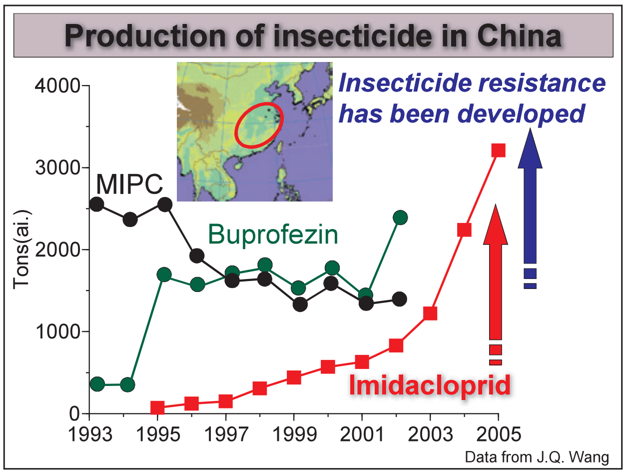
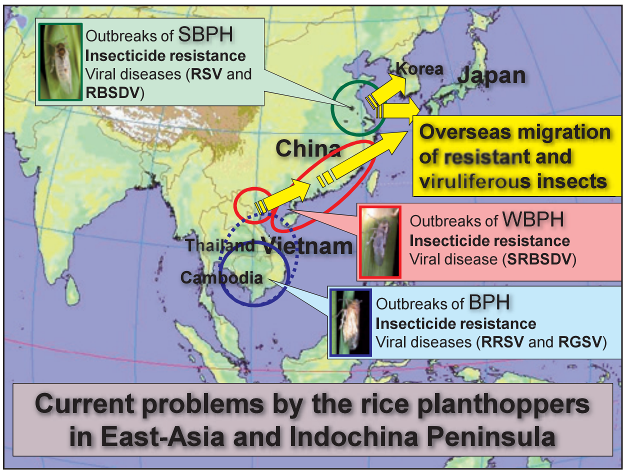


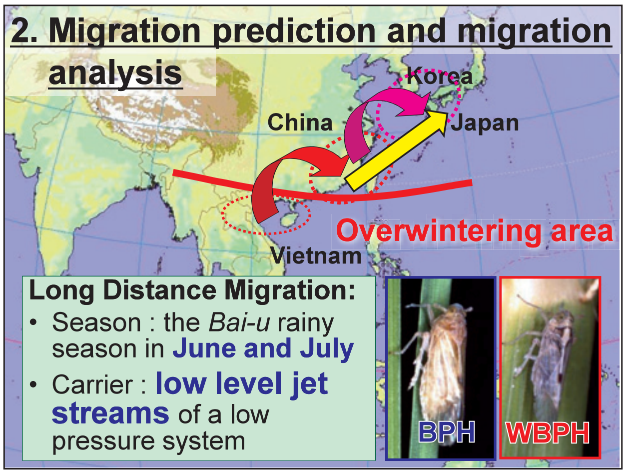
Production of insecticide in China
Tons(ai.)
0
1000
2000
3000
4000
MIPC
Buprofezin
Imidacloprid
Insecticide resistance has been developed
1993
1995
1997
1999
2001
2003
2005
Data from J.Q. Wang

9



Outbreaks of SBPH
Insecticide resistance
Viral diseases (RSV and RBSDV)
Korea
Japan
China
Overseas migration of resistant and viruliferous insects
Thailand
Vietnam
Cambodia
Outbreaks of WBPH
Insecticide resistance
Viral disease (SRBSDV)
Outbreaks of BPH
Insecticide resistance
Viral diseases (RRSV and RGSV)
Current problems by the rice planthoppers in East-Asia and Indochina Peninsula

10



2. Migration prediction and migration analysis
Korea
China
Japan
Overwintering area
Vietnam
Long Distance Migration:
• Season : the Bai-u rainy season in June and July
• Carrier : low level jet streams of a low pressure system
BPH
WBPH

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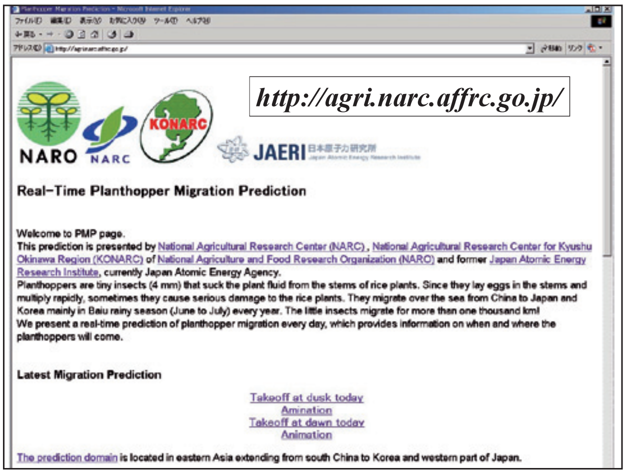

http://agri.narc.affrc.go.jp/
NARO
NARC
KONARC
JAERI
Real-Time Planthopper Migration Prediction
Welcome to PMP page.
This prediction is presented by National Agricultural Research Center (NARC), National Agricultural Research Center for Kyushu Okinawa Region (KONARC) of National Agriculture and Food Research Organization (NARO) and former Japan Atomic Energy Research Institute, currently Japan Atomic Energy Agency.
Planthoppers are tiny insects (4 mm) that suck the plant fluid from the stems of rice plants. Since they lay eggs in the stems and multiply rapidly, sometimes they cause serious damage to the rice plants. They migrate over the sea from China to Japan and Korea mainly in Baiu rainy season (June to July) every year. The little insects migrate for more than one thousand km!
We present a real-time prediction of planthopper migration every day, which provides information on when and where the planthoppers will come.
Latest Migration Prediction
Takeoff at dusk today
Amination
Takeoff at dawn today
Animation
The prediction domain is located in eastern Asia extending from south China to Korea and western part of Japan.

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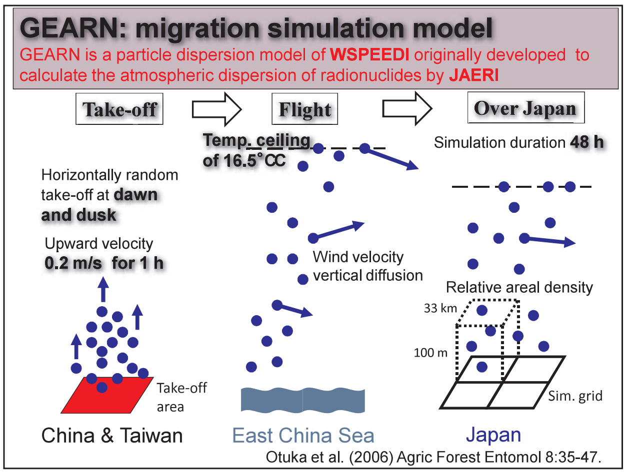

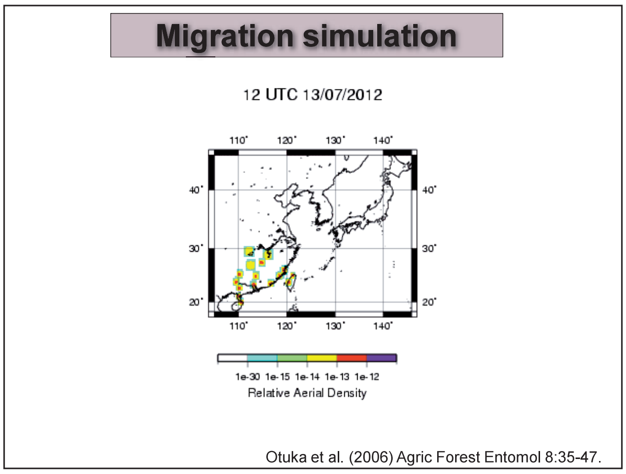

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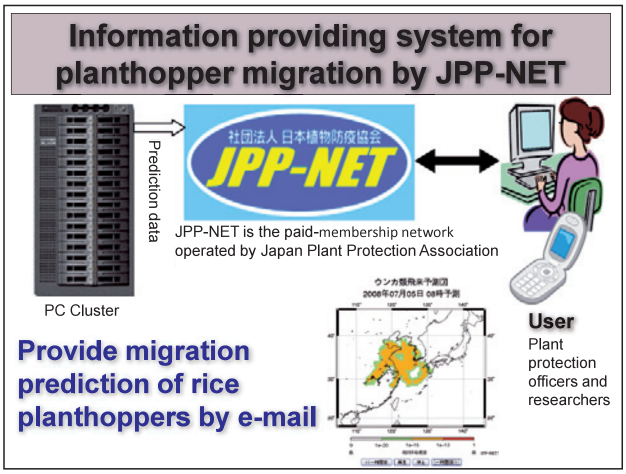

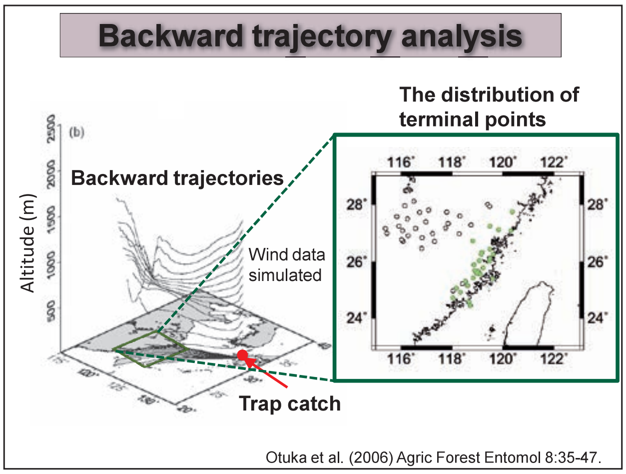

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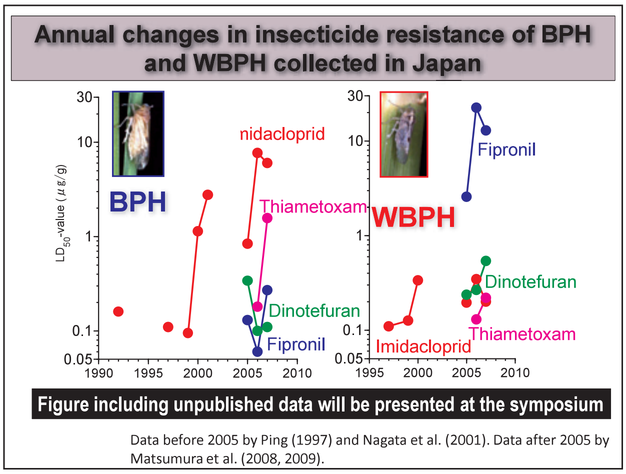

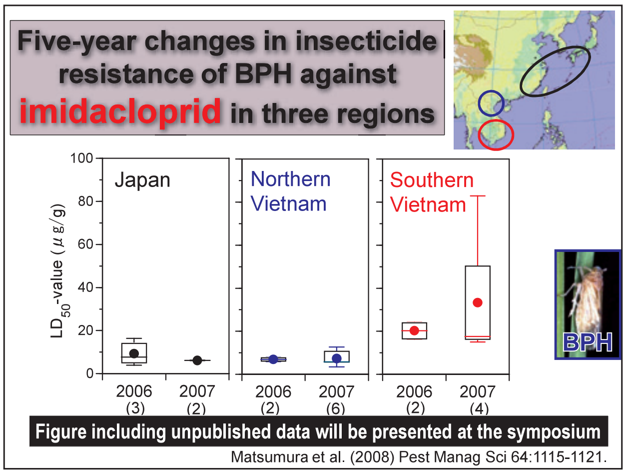

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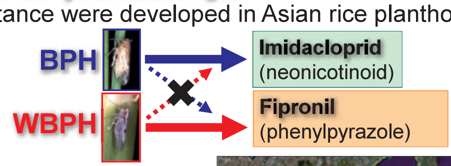
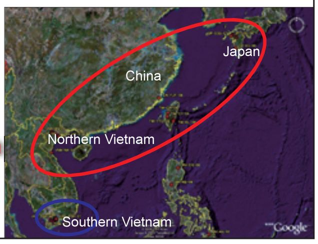
Summary

1. **Species-specific changes** in insecticide resistance were developed in Asian rice planthoppers.



2. Insecticide resistance of **Southern Vietnam** against imidacloprid is **higher** than **northern Vietnam and east Asian ones**, and is **increasing** from 2006-2010.



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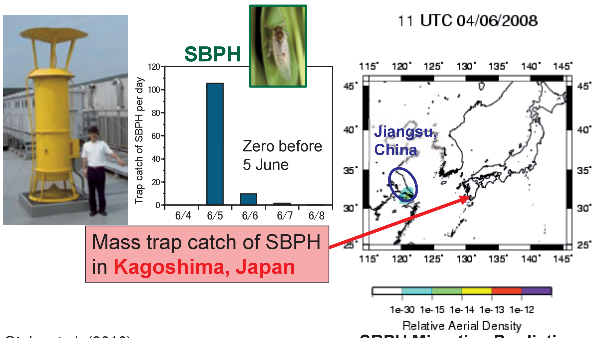
Overseas migration of SBPH from Jiangsu, China to western Japan on 5 June, 2008



Otuka et al. (2010)
Appl Entomol Zool 45:259-266.

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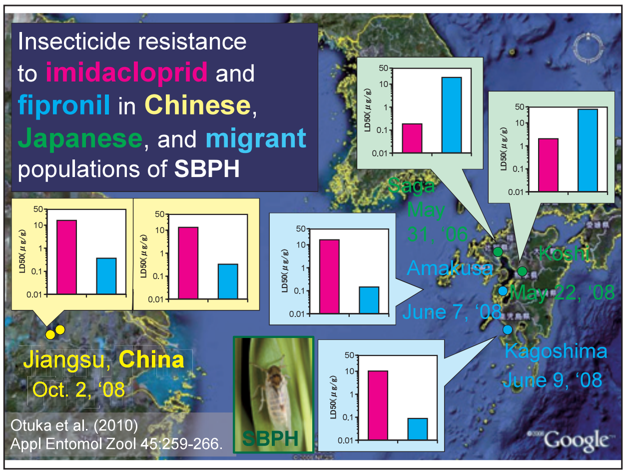

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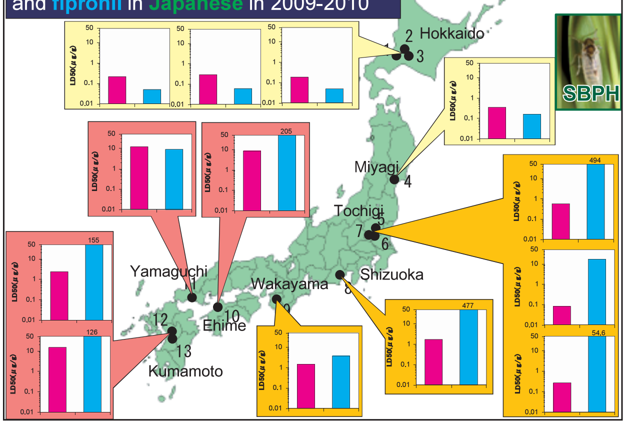
Insecticide resistance to **imidacloprid** and **fipronil** in **Japanese** in 2009-2010

Sanada-Morimura et al. (2011)
Appl Entomol Zool 46:65-73.



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Summary

1. SBPH developed **area-specific insecticide resistance** in China and Japan (resistant to **imidacloprid** in China and **fipronil** in Japan)
2. **Overseas migration** occurred from China to Japan in June 2008.
3. After the migration, some Japanese populations became **resistant to both imidacloprid and fipronil**, suggesting that **intercrossing** between the immigrant and domestic populations cause a change in their insecticide resistance.
4. **Overseas migration might drastically affect the status of insecticide resistance** in populations over long distances, such as in different countries.

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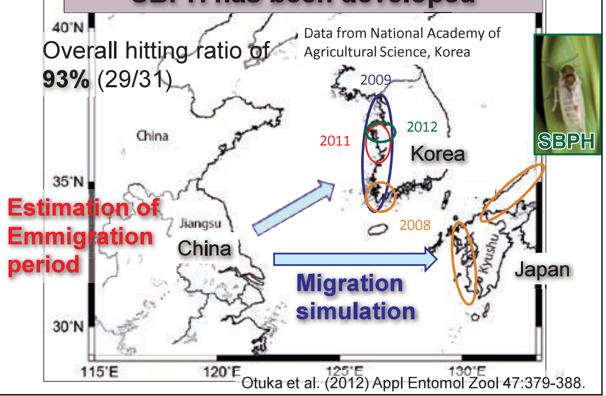
Migration prediction method of SBPH has been developed



Otuka et al. (2012) Appl Entomol Zool 47:379-388.

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Ho Van CHIEN (Vietnam)
Shou-Horng HUANG(Taiwan)

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Chairman Dr. Kazunobu Toriyama: I would now like to introduce our next speaker, Dr. Masaya Matsumura. His topic is "Migration Prediction and Insecticide Resistance Monitoring for Rice Planthoppers." He has been working on this subject for nearly 16 years, I believe. Last year, he received an award from the Japanese Society of Applied Entomology and Zoology, so we can expect a very interesting presentation from him. The floor is yours, Dr. Matsumura.

Dr. Masaya Matsumura: Thank you, Dr. Toriyama. I am very happy to have this opportunity to discuss my work. My topic today breaks down into three parts. First, I will briefly introduce the insects known as rice planthoppers. Next, I will talk about their migration patterns. And finally, I will describe the results of insecticide resistance monitoring.

There are three major species of rice planthoppers in Asia: the brown planthopper (BPH), the whitebacked planthopper (WBPH), and the small brown planthopper (SBPH). The ecologies of these three planthoppers are very different.

The first two species, BPH and WBPH, overwinter in tropical areas such as Vietnam, the Philippines, and Indonesia. Because their host plant is rice, they can only overwinter where rice is cultivated all year round. As you know, Japan and most areas of China do not plant rice in the winter, so these two species cannot overwinter in those locations. After overwintering in and around northern Vietnam, they migrate to China and Japan every year with the warmer weather.

The third species, SBPH, can overwinter in temperate zones on wheat and gramineous weeds. Previously, SBPH displayed no long-distance migration pattern (unlike BPH), but recently overseas migration of SBPH has occurred from eastern China to Japan and Korea.

The damage caused by BPH is usually called "hopperburn." This picture shows hopperburn damage that occurred in Japan in 2005. An infestation of WBPH occurred in Japan in 2009 on forage rice—especially the Indica rice variety. In addition, all three planthoppers transmit species-specific viral diseases. BPH transmits RRSV and RGSV, usually in tropical areas like the Mekong Delta. WBPH transmits a new virus, SRBSDV, which was first reported in 2008 and now occurs in northern Vietnam and China; it was also reported in Japan in 2010. SBPH transmits the viruses RBSDV and RSV, which have proven to be a problem in East Asia generally, and particularly in eastern China, Japan, and Korea.

What has caused the recent outbreaks of these planthoppers? This figure shows the cropping area of hybrid rice varieties in northern Vietnam. Hybrid rice cultivation began to increase in the late 1990s and continues to rise. That country had previously grown a variety of inbred rice that is resistant to insect pests, but the resistant variety doesn't taste very good and does not offer a particularly high yield, so Vietnam switched to Chinese hybrid rice and Chinese inbred rice. The problem is that most of the Chinese varieties are highly susceptible to BPH and WBPH, and so the change in varieties brought with it an increase in the population density of those two planthoppers.

What happened next? This figure shows the change in insecticide production in China. The red line represents Imidacloprid, which was developed in the mid-1990s and whose production volume has been steadily increasing. Imidacloprid is now a major insecticide used to control BPH and WPBH. This is true in both China and Vietnam. Recently, however, the resistance of rice planthoppers to these chemicals has been growing, and this is now a real problem in Asia.

In fact, all three species now present significant insecticide resistance. And they transmit viruses. As a result, Japan is currently dealing with the overseas migration of planthoppers that possess insecticide resistance and carry viral diseases. That's why we are working so hard to predict the migration patterns of these planthoppers, which can fly all the way from China to Japan, a distance of more than 1,400 km. In usual circumstances, they are only able to travel some 100 km through their own efforts, but they migrate from China to Japan on the wings of the wind. To combat these interlopers, we have developed a migration simulation model that tells us when they will arrive and from where.

I now come to the second part of my talk: predicting migration patterns. These two planthoppers migrate to Japan in June and July during *bai-u* (the rainy season). Low-level jet streams travel west to east, and the insects ride this wind across the open water. We can estimate the wind movement. In collaboration with the Japan Atomic Energy Research Institute (JAERI), we have developed a website, called Planthopper Migration Prediction, that offers information in real time. We use the GEARN migration simulation model. It is a particle dispersion model of WSPEEDI originally developed by JAERI to calculate the atmospheric dispersion of radionuclides. Many Japanese now know about WSPEEDI, as it was used in the wake of the Fukushima accident. And the same model can be used to estimate planthopper migration. Very simply, the model is as follows. Planthoppers take off from the source area. We enter this information into the computer and we estimate their migration. We input several parameters for the insects. Planthoppers usually fly horizontally, taking off only at dawn and at dusk, and their speed is about 0.2m/s. The upper air temperature is usually lower, and in general planthoppers cannot fly at low temperatures, so we input a temperature ceiling here. We then simulate the number of particles in Japan, and the result looks like this. Using this model, then, we can estimate when the planthoppers will come.

This is JPP-NET, which provides information on planthopper migration in Japan. It is a paid-member network operated by the Japan Plant Protection Association, and its users are generally prefectural plant protection officers and researchers. They can use email or their mobile phones to learn when the planthoppers will come. We can also estimate the source area. If we catch insects here, we can run a back-trajectory analysis to calculate the origin of those insects.

And finally, I would like to address the insecticide resistance monitoring of migratory planthoppers. This figure shows the annual change in the insecticide resistance of BPH and WBPH collected in Japan from 1996 to 2011. Please look at the red and blue lines. The red line is Imidacloprid. The blue line is Fipronil. This value represents lethal dose 50, which means that 50% of insects die at that dosage. If that number increases, it means that insecticide resistance has increased. You can see specific differences between insecticide resistances. BPH has developed resistance only against Imidacloprid, while WBPH has developed resistance only against Fipronil.

From 2006 to 2010 we monitored the insecticide resistance of BPH at three locations: East Asia, including Japan and China; northern Vietnam; and southern Vietnam. You can see very similar changes in insecticide resistance levels between East Asia and northern Vietnam, which means that by monitoring northern Vietnam we can know the insecticide resistance level of migrants to Japan. In southern Vietnam, on the other hand, the level of resistance has increased dramatically. As Dr. Fujii told us this morning, they go through three to four crop cycles a year in the Mekong Delta, so they experience a greater number of planthopper generations per year than in northern Vietnam. That is one reason why there has been a very rapid development of insecticide resistance in the Mekong Delta.

In the case of SBPH, overseas migration from China to Japan occurred in 2008, and insecticide resistance changed as a result. Previously, SBPH in China developed insecticide resistance only against Imidacloprid, while in Japan SBPH was only resistant to Fipronil. And immediately after overseas migration, we found that the insecticide resistance of the new arrivals was very similar to what it had been in China. However, SBPH are able to overwinter in Japan, and while they do so they mate with each other. And the result of that, as we found in the Kyushu area of western Japan, is a population of SBPH that is resistant to both insecticides. Such post-migration populations of Japanese SBPH, resistant to both Imidacloprid and Fipronil, suggest that intercrossing between the immigrant and domestic populations causes a change in insecticide resistance, which means that overseas migration could drastically affect the entire balance of insecticide resistance in Japan.

We are now engaged in collaborative research involving China, Japan, and Korea, because in addition to the 2008 migration of SBPH to Japan, there were also migrations to Korea in 2009, 2011, and 2012. In light of that development, the three countries are now working together on a migration projection model for SBPH.

Thank you.

Chairman: Thank you very much for that clear, informative presentation. Questions and comments will come later. But right now, please give him a big hand. Thank you very much.