Simulation of the Long Range Migration of Brown Planthopper, *Nilaparvata lugens* (Stål), by Using Boundary Layer Atmospheric Model and the Geographic Information System

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Abstract - Brown planthopper (*Nilaparvata Lugens*) is a migrant pest which can migrate from tropical area into subtropical and temperate area every year and caused a lot of damage in rice production. To understand the migration process of this pest, the Boundary Layer Atmospheric (BLAYER) model and Geographic Information System (GIS) were used to analyze the migration waves from June to July in 1997, 1998 and 1999 in South Korea. The simulation results showed: 1) Each migration wave had different mass distribution and immigration area at different time; 2) The vertical air current value distributed in BPH taking-off and landing area was about several centimeters per second, which is lower than BPH flight ability. 3) The trajectory route showed that BPH had different migration routes emigrated from different source areas according to the weather system. The main source of BPH immigrated in South Korea was from the East part of Guangdong Province and South East part of Fujian Province, People's Republic of China. 4) Comparing with the different migration heights (733 m, 1,348 m and 1,963 m above ground level), BPH mass distributed more northwestward in low height than in high height. 5) BPH mass movement also gave another evidence to identify the light trap data in late July.

Key Words - Brown planthopper, Boundary layer atmospheric model, Geographic information system, Migration, *Nilaparvata lugens*

Introduction

The brown planthopper (BPH), *Nilaparvata lugens* (Stål), is one of the most important rice pests both in tropical and temperate area in the South and East Asia. After the so called "Green Revolution", the introduction of the high yield, low height rice variety and the large amount use of fertilizer and pesticide, it has become the key pest in rice production (Li *et al.*, 1997). BPH can not overwinter in subtropical and temperate regions north of 22° N where the average temperature in winter is lower than 10 °C (Chen *et al.*, 1982; Lai, 1982), but every year, lots of BPH immigrants were caught by different traps in most part of China, Korea and Japan.

Researches on the BPH migration was greatly improved in East Asian countries. Kisimoto (1971, 1976, 1979) analyzed BPH migration related to the synoptic weather system, and found that immigrated BPH in Japan was closely related to the occurrence of the low level jet stream (LLJET) during the Baiu season from June to July. Cheng *et al.* (1979) found BPH step-by-step movement in east China area according to a national collaborative research project in early 1980's. Sogawa (1991, 1994, 1995) analyzed the windborne displacements of BPH related to the seasonal weather patterns in Kyushu

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district as well as in east China and South Korea. Uhm *et al.* (1988) and Uhm and Lee (1991) also classified the four different weather systems which caused the BPH immigration in South Korea from 1981 to 1987. Riely *et al.* (1991) observed BPH return flight in autumn in China by using radar observations. Li *et al.* (1997) analyzed main migration waves in different BPH occurrence years, and found that the stationary front was the most important weather system caused the BPH migration in China. All of these results showed the close relation between the BPH migration and weather patterns.

Recently some models were used in simulating the BPH migration in East Asia. They are becoming the important method to analyze the pest migration in different areas. Watanabe *et al.* (1990) and Watanabe and Seino (1991) used historical daily upper-air and surface weather data and charts, set up a model called LLJET to analyze the BPH movement in East Asia. By using this model, Sogawa *et al.* (1992, 1994) analyzed the immigrant trajectory routes both in Kyushu, Japan and in Zhejiang, China. Turner *et al.* (1999) set up the Boundary Layer Atmospheric Model (BLAYER), which concerned about the topography, meteorological and pest factors to forecast the BPH immigration in South Korea. This model can predict the BPH migration in the coming 48 hours by using the predictive meteorology data from the Korean Meteorology Administration (KMA).

With the quick advancement of computer technology, the Geographic Information System (GIS) has been increasingly widely used as an effective tool to solve the special problems in insect ecology. It has been used in forecasting pest outbreaks, analyzing the tendency of insect diffusion and migration, and evaluating pest management (Johnston, 1998).

Previous researches on BPH migration focused on using the historical meteorology data to analyze the trajectory route, the possible pest source area and the immigrated regions. In this paper, we used GIS spatial tools to analyze the simulation results of BLAYER model to get relatively complete and direct evidence about BPH migration in East Asia. We analyzed BPH migration processes such as the mass distribution in different periods and heights, vertical air current value related to BPH taking-off and landing, the trajectory routes, the possible pest source, and BPH migration in late July.

Materials and Methods

The tools

There are two tools used in simulating and analyzing data. One is Boundary Layer Atmospheric model (BLAYER) and the other is the Geographic Information System (GIS) software: ARC/INFO® (ESRI, 1990) and ArcView® (ESRI, 1996)

BLAYER model is a numerical model which simulate atmospheric flows within the lower part of the troposphere (Turner, 1998). Its specialty is simulating boundary layer flows over sloping terrain. The atmospheric component of the model is governed by an elastic, hydrostatic set of equations. The equations are expressed in a non-orthogonal, terrain-following, spherical set of co-ordinates. Additionally, a non-orthogonal, terrain-following, spherical of the atmospheric domain in order to resolve the strong vertical gradients in prognostic variables, such as temperature, that exist near surface.

Prognostic (i.e., predictive) equations are of the form

$$\partial A/\partial t + V \cdot \nabla A = \partial(K\partial A/\partial Z) + F$$

where A is the prognostic variable of interest, it could be temperature, moisture, winds, turbulent energy or insects, and F is some forcing term such as a source or pressure gradient. For a specific example for an insect (or any other passive tracer) concentration, the equation becomes

$$\partial\chi/\partial t + V \cdot \nabla\chi = \partial(\mathrm{K}\chi\partial\chi/\partial z)/\partial z + s + \nabla \cdot (Kd\nabla\chi)$$

where the terms are in order from left to right, the local time rate of change, advection, vertical diffusion, source/sink, and horizontal diffusion. Unfortunately the system of equation is not closed, so assumptions about some of the unknowns have to be made. Namely, particular forms for the coefficients of diffusion are assumed. The equations are solved by a combination of finite different and finite element techniques.

Data incorporated within GIS are generally encoded and stored as discrete "layers" representing thematically related features. GIS functions through deductive queries, which are useful in studying spatial relationship applied to land use, resources allocation, natural and human systems operations, valuation, decision-making, and conflict resolution (Johnston, 1998). Here, two of the main GIS software were used in this paper, ARC/INFO(r) and ArcView® (Environmental Systems Research Institute, Inc., (ESRI)).

Used data

Meteorological data: Korean Meteorological Administration (KMA) regional forecast model output data were used to input into BLAYER model. The data were gridded 850 hpa height fields for different periods from June to July in 1997, 1998 and 1999.

Trap catch data: The BPH daily light trap catch data were selected from 152 locations in South Korea from June to July in 1997, 1998 and 1999. Data source was from Division of Entomology, National Institute of Agricultural Science & Technology, Rural Development Administration.

BPH source data: BPH main damage and emigration periods and areas in early rice season in People's Republic of China were selected from Li *et al.* (1997). Also, National Agro-technical Extension and Service Center, P.R. China provided the data of macropterous BPH in rice filed in Guangdong and Guangxi provinces. Data periods were from June to mid July in 1997 and 1998.

Boundary data: The digital world map (boundary map) was come from ArcWorld™ 1 : 3 M (ESRI, 1992), which is the GIS database for ARC/INFO® and AcrView® users. It can create thematic maps of the world at the country level.

Simulations and GIS analysis

BLAYER model was used to predict the BPH migration from June to July in 1997, 1998 and 1999. Certain assumptions of BPH behaviors were made in order to simulate their movement. These were (a) the planthoppers fly continuously and their takeoff occurs at 9:00am in the morning (Turbulent wind gusts are thought to provide a takeoff mechanism for the planthopper. The initial development of the daytime convective boundary layer occurs around 9:00am and is often associated with the onset of turbulent wind gusts.), (b) the migrants fly continuously for periods no longer than 48 hours, (c) they have no forward flight speed of their own, and (d) they fly at altitudes above 500 m.

It was configured for the BPH simulations in the following way, the time step was five minutes and a uniform horizontal grid spacing of 0.5 degrees was used. This latter measure was to make the output suitable for incorporation into a Geographic Information System (GIS) that will form the basis of the Internet surveillance system. The domain used for the BLAYER simulations is a 91×71 horizontal grid that extends from 100° E to 145° E, and from 10° N to 45° N alone with the model topography. There are 24 nodes in the vertical with a model top at about 2200 m. Upper boundary conditions are set by time-varying 850hpa geopotential height fields. The process of running the model can be seen in Turner (1998).

After getting the simulation results, GIS tools were used to display and analyze the migration process. As we know GIS is a spatial analysis tool which can solve the problems related to the spatial distributions, and the location is the key point which connected with different coverages. The process of GIS analysis includes: 1) Transfer data forms into GIS used forms; 2) Create the coverage and connect the attributes in GIS softwares (ARC/INFO® and ArcView®); 3) Show and export maps in the ArcView®.

Results

BLAYER simulation results

The simulation of BLAYER model included the BPH mass distribution and the wind field in different periods and height (Turner *et al.*, 1999). The

Table 1. Peak number of light trap catch in different observational station from June to July in 1997 and 1998 in South Korea

1997		1998	
Date	Light trap number	Date	Light trap number
June 22	1	June 18	1
June 26	6	June 24	17
July 16	30	June 28	45
		July 15	70

migration process of BPH includes three parts: taking-off, moving in the upper air and landing. From BPH daily light trap catch data in 1997 and 1998, we selected seven migration waves which could give us an idea of BPH migration process (Table 1) in East Asia.

Taking-off and landing

We set BPH taking-off in 9:00am (Beijing Time Zone) as the assumptions of the model. Simulation results showed that the distribution of upward air current matched BPH source area very well, but the downward vertical air current was not strongly related to BPH landing in the main migration waves. The value of vertical air current is several centimeters per second, which is quite lower than BPH own flight ability (Riley *et al.*, 1991). Compared with the light trap catch data, catches were higher in the matched area than unmatched one, such as the waves in June 26 and July 16 in 1997 and June 24 and July 15 in 1998. So the downward air current still helped BPH landing though the air current strength was lower than its flight ability. These results supported that BPH has more positive ability to choose the suitable environment to take-off and land rather than only wait for the air current passively.

Movement in the upper air

From the BLAYER simulation, we selected three levels: 733 m, 1,348 m and 1,963 m to demonstrate BPH mass distribution in different heights. Simulation results showed that at low height, BPH mass distributed more north and east than high levels. This kind of distribution can be explained by the theory of plant boundary layer (PBL) - wind vertical distribution in PBL (Stull, 1989). Comparing with real light trap catch data with the mass distribution in different heights, there was no distinctive difference among these three levels. Concerned with the elevation in East Asia, the migration in 1,348 m was recommended.

The model predicted BPH mass movement every 2 hours. We assumed that BPH could fly with wind up to 48 hours. From the simulation, we could predict the process of the BPH mass movement, their direction, their speed and number, and understand how the mass moved in the upper air and where they distributed in different time periods. In the main immigration waves in early season, the simulation prediction of planthopper immigration matched the real catch data very well. Comparing the predicted BPH number with BPH light trap catch data, in the early immigration waves, for example the immigration wave in June 8, 1997 (Fig. 1) and June 13, 1998 (Fig. 2), the simulation predicted an influx immigrated in South Korea, but there was no BPH catch made in the light trap. It was because that there was no BPH emigrated from the source areas at that moment. However, in many stations, white backed planthopper was caught in the light traps (84 in June 8, 1997 and 10 in June 13, 1998), and the simulation prediction of WBPH immigration was corresponded in earlier days (WBPH, Fig. 1). In the fewest light trap catch day (caught one BPH and WBPH in June 24, 1997 and in June 16, 1998), no immigration was predicted. However, larger discrepancy occurred between model prediction and trap catch in 1999 (Fig. 2). Further study is needed for improving the light trap catch efficiency and the model itself.

The trajectory of each migration wave

In the long rang migration season (from mid June

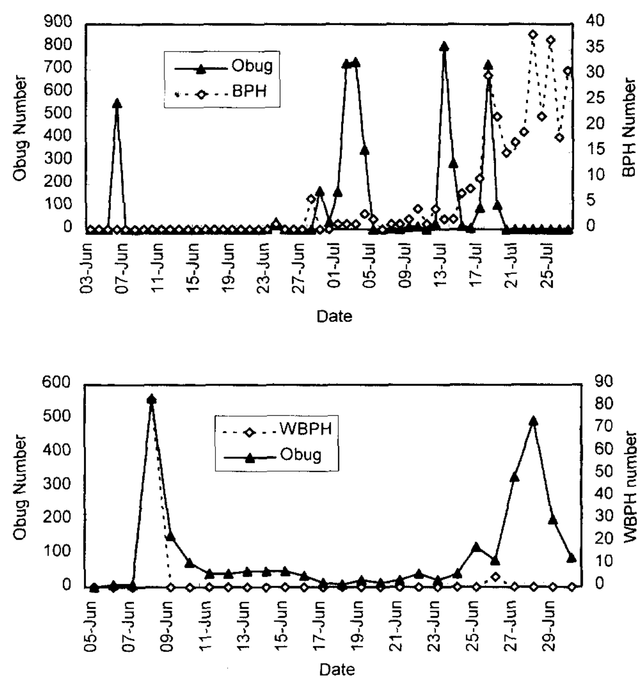

Fig. 1. Comparison of predicted pest number (Obug number) with BPH and WBPH light trap catches in 1997.

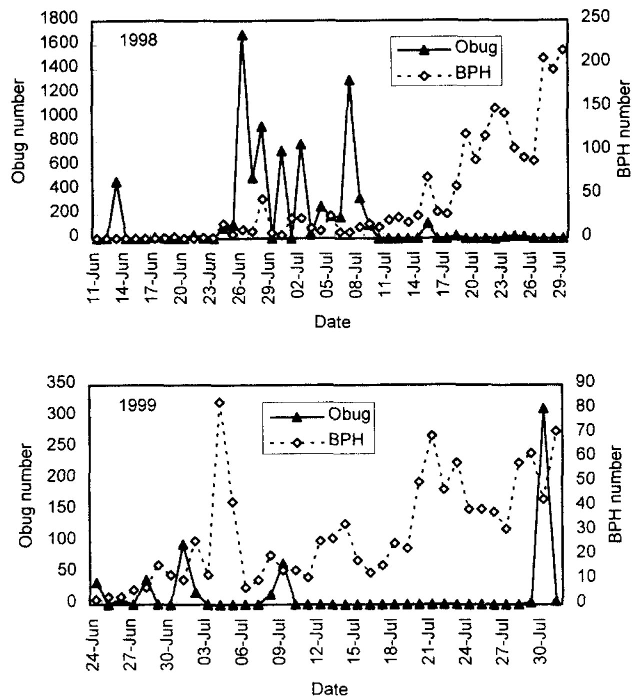

Fig. 2. Comparison of predicted pest number (Obug number) and BPH light trap catches in 1998 and 1999.

to July), BPH source is mainly from the early rice production area located in Yunnan, Guangdong, Guangxi and Zhejiang province in P.R. China (Li *et al.*, 1997). The possible source of BPH, their location, main damage period, and emigration time were shown in Table 2. The trajectory of the migrants was shown in Fig. 3. Each immigration wave had different migration routes depending on prevailing weather systems. The BPH from the west part of BPH source mainly immigrated inside China because the migration distance is longer than from the east part China to immigrate in South Korea. From the migration waves in 1997 and 1998, only East part of Guangdong province and South East part of Fujian province were the possible source of BPH immigrated in South Korea and Japan.

Migration process in late July

Usually, the increase of the light trap catch number has been used as the important method to identify BPH immigration from June to July in South Korea. However, in late July, the second generation of immigrated BPH increases very fast. Therefore, differentiating the BPH caught in light traps between immigrants from oversea and from local paddy fields has been the problem in analyzing BPH migration in late July. Our simulation modeling study could provide a clue to differentiate the local population with the immigrants. BPH mass movement in July 28 in 1997 (BPH catches: 216) mainly occurred in the South-West China, and the migrants could not arrive South Korea at that time. But after 48 hours a lot of BPH was caught in the light traps in many locations in South Korea. The simulation

Table 2. BPH main damaged and emigration periods in main early rice production areas in China*

Province	County name	Main damaged period	Emigration period
Yunnan	Funing	Late June to early July	Early to Mid July
	Yuling	Early to Mid June, Early to Mid July	Mid June to Late July
	Hepu	Early to Mid June, Early to Mid July	Mid June to Late July
Guangxi	Laibing	Early to Mid June, Early to Mid July	Mid June to Late July
	Lingchuan	Late June to early July	Mid to late July
	Hexian	Mid to late June, Mid July	Early to Late July
	Haikang	Early to Mid June, Early to Mid July	Mid to late June, Mid to late July
	Zhaoqing	Early to Mid June, Early to Mid July	Mid June to Late July
Guangdong	Xinhui	Early to Mid June, Early to Mid July	Mid June to Late July
	Meixian	Early to Mid June, Early to Mid July	Late June to Late July
	Shantou	Mid to Late June, Late July	Late June to Early July, late July
	Longyan	Mid to Late June	Early to mid July
Fujian	Tongan	Mid to Late June, Mid July	Early to late July
	Jianou	Late June to early July	Early to Mid July

*: Data source: The brown planthopper and its population management (Li *et al.*, 1997), p. 103-105

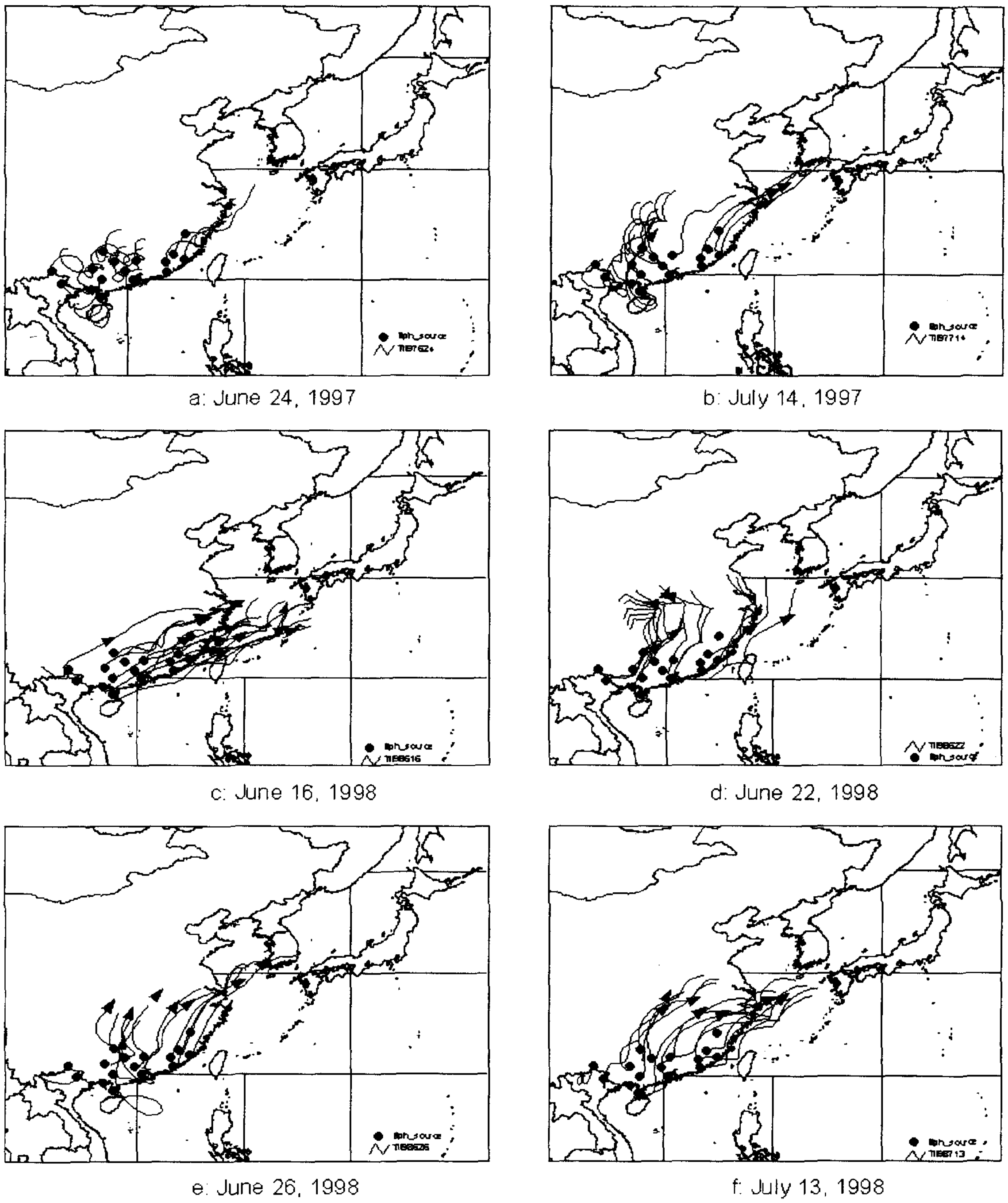

Fig. 3. Trajectory route of BPH migration waves at 1,348 m AGL from June to July in 1997 and 1998. (a) at June 24, 1997; (b) at July 14, 1997; (c) at June 16, 1998; (d) at June 22, 1998; (e) at June 26, 1998; (f) at July 13, 1998.

gave a good reason to prove that those BPH came from the local rice field instead of the immigrants. Migration wave in July 25, 1998 (BPH catches: 108) also showed this kind of the results. The air current carried the BPH from source area to south part of China, Taiwan and China East Sea and could not reach the light-trap area in South Korea.

Discussion

The BPH migration process, the relation between

BPH taking-off & landing and the virtual air current, the mass movement in different time and heights, and their trajectory routes were discussed in this paper by using Boundary Layer Atmospheric Model (BLAYER) and Geographic Information System (GIS) in 1997, 1998 and 1999. The real light trap catch data in South Korea has proved that the BLAYER model did a good simulation in forecasting BPH immigration in these years.

Here, we only focused on the simulation of BPH migration, and gave special assumptions to indicate the BPH take-off time and the flight duration in the model. Because the migration of the pests is closely related to the weather conditions, the BLAYER model can simulate not only BPH but also other migration pests, such as rice leaf folder, armyworm and the aphids. But different migration pests have their own habits, such as flight ability, take-off time and other matters (Chen *et al.*, 1980; Deng *et al.*, 1981; Riley *et al.*, 1987, 1991; Zhai *et al.*, 1997). It is possible to simulate the migration of those pests by using BLAYER model after change some assumptions.

From the simulation of BPH trajectories, we could find out that different BPH sources had different migration routes. Most of them migrated to the middle or east part of China, and some of them migrated to South Korea and Japan. So the BLAYER model could also be used in simulating the pest migration in China and Japan. To get a good simulation result, the model itself should be tested in the countries other than South Korea and need the modification.

Pest migration is an international problem which needs the international collaboration, including the exchange of the data, information and research results. With the improvement of the internet and other computer technology, the simulation of the pest migration will become more useful for international Integrated Pest Management (IPM).

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