THE POTENTIAL GEOGRAPHICAL DISTRIBUTION OF BACTROCERA DORSALIS (DIPTERA: TEPHRIDIDAE) IN CHINA BASED ON EMERGENCE RATE MODEL AND ARCGIS

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Abstract: The oriental fruit fly, Bactrocera dorsalis (Handel) (Dipteral: Tephrididae), is the important insect pest of fruits and vegetables in tropical and subtropical areas. It is necessary to know the potential geographical distribution of this pest in order to monitor and control it effectively. Pupal development takes place in the soil and is regulated by two key factors; soil temperature and moisture. These factors are primary determinants of fruit fly distribution. In this study, the potential geographical distribution of B. dorsalis from Jan. to Dec. in China was predicted based on the soil temperature and moisture data of Chinese meteorologic stations, the ER (Emergence rate) model constructed from empirical biological data, and analysis with ArcGIS. The ER data were obtained by observing the emergence of 7560 cultured pupae using a crossover design of 7 soil temperature grades and 6 soil moisture grades. The ER model ($Z = -0.0036X2 - 0.0001Y2 + 0.1681X + 0.0123Y - 1.5170$) was established with stepwise regression method where emergence rate (Z) is a function of soil temperature (X) and soil moisture (Y). According to reported geographical distributions in the world, four categories were used to describe different levels of suitability for B. dorsalis in China, including negligible (0≤ER≤0.01), low (0.01<ER≤0.2), moderate (0.2<ER≤0.45) and high (0.45<ER≤1). The potential geographical distribution and suitable levels for every month in China were obtained and showed that main parts of the distribution were south of ±35°N, and most regions in China had high suitability levels from May to September. Further analysis showed the desireability of strengthening monitoring in the north parts of China from Apr. to Oct. and to institute whole year monitoring in Guangdong, Guangxi, Yunnan, and Hainan provinces.

Keywords: Bactrocera dorsalis, potential geographical distribution, emergence rate, plant quarantine, ArcGIS

1. INTRODUCTION

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephrididae), originates from Taiwan and Ryukyu Islands and is a serious quarantine pest of fruits with a wide host area in tropical and subtropical countries (Huang Suqing et al., 2005). *Bactrocera dorsalis* has reportedly spread abroad to about 20 countries in North America, Oceania and Asia by IIE (International Institute of Entomology) as well as Europe and the Mediterranean Plant Protection Organization (IIE, 1994). In addition, *B.dorsalis'* host is continually expanding; 150 host species in 1960 (Christenson et al., 1960), 250 species in 2003 (Liang Guanghong et al., 2003) and in 2005. Presently, this fruit fly infects more than 300 species of fruits and vegetables from 46 families in southern provinces of China like Fujian, Hainan, Guangdong, Guangxi, Hunan, Guizhou, Yunnan, and Sichuan (Huang Suqing et al., 2005; Huang Kehui et al., 2005).

The oriental fruit fly can have three to eleven generations yearly in China, but mainly has four to eight generations, and its growth periods were 19d under 24℃, and 32.5d-35d under 33℃ in Yunnan province. The emergence rate of oriental fruit fly was between 80% and 90% in these areas. However, overwintering is variable and many generations are staggered resulting in different insect states occurring at the same time and place (Liang Guanghong et al., 2003; Liang Guangqin et al., 1993; Zhang Qingyuan et al., 1998; Zhou Yousheng et al., 1996; Jiang Xiaolong et al., 2001).

Knowledge of the geographical distribution of insect pests is necessary to properly monitor and manage them. Consequently, suitability analysis methods have gained attention in recent years. Suitability analyses are estimated from simple ecological estimates, climographic analysis (Cook et al., 1921, 1931), similarity distance of agricultural climate (Wei Shuqiu, 1984), Geographical Information System (Wu Yufen, 2005), Ecological Niche Models (Wang Yunsheng et al., 2007), CLIMEX (Sutherst et al., 1991, 2005; Song Hongmin et al., 2004; Stephens et al., 2007 ; Hou Bohua et al., 2005; Chen Lin et al., 2006), GARP (Zhou Guoliang et al., 2007), DIVA-GIS (Ge Quanqing et al., 2006 ; Hernandez, 2006), MAXENT (Elith et al., 2006; Wang Yunsheng et al., 2007) and so on. Moreover, software based on ecological niches including BIOMAPPER, BRT, GAM, GLM. The characteristic of these methods was more accurate and more simply than ever because many suitability analysis methods are based on exact software and comprehensive influence factors of corresponding pest.

Several methods have been used to predict the potential geographical distribution of oriental fruit fly. The first used fuzzy mathematics (Zhang Runjie et al., 2005) and showed that the potential geographical distribution of *B. dorsalis* in China occurred in regions south of 25°N including the Sichuan basin and part of Guizhou province The region between 25°N and the Changjiang River was less suitable, and other regions of China were unsuitable (Fan Jinan et al., 1998). The second method used CLIMEX and showed that the most suitable areas are in South China including Guangdong, Hong Kong, Hainan and Guangxi Zhuang Automomous Region, moderately suitable areas includes Yunnan, Sichuan, Southwest China and some parts of Fujian province, the suitability drops in some parts of Hunan, Hubei, Jiangxi and Zhejiang provinces. Unsuitable areas included the northern part of the Yangzi River (Hou Bohua et al., 2005). Stephens et al (2007) reported the current and future potential geographical distribution using CLIMEX, but the prediction did not align well with real distribution, especially in ShangHai (Zhou Guoliang, 2006). The third method was based on the fly's fatal temperature, accumulated effective temperature and bioclimate analogous distance. Its showed that the viability areas were 31.64% in China, the Northern distribution threshold was nearly (30±2)°N (Wu Yufen, 2005).The fourth method used GARP ecological niche modeling to predict potential ecological distribution of *B. dorsalis* in China. The results showed host fruit plants have been cultivated at high densities in both suitable and sub-suitable areas, and the major potential geographical distribution of *B. dorsalis* was concentrated south of Changjiang River (97.4°E-121.9°E, 18.2°N-33.0°N) (Zhou Guoliang, 2007).

Among factors affecting the potential geographical distribution of insect pests, temperature is considered the most pivotal (Ren Lu et al., 2007). As a serious insect pest, a lot of researches are focus on biological characteristics of *B. dorsalis*. Pupal development takes place in the soil and is regulated by two key factors; soil temperature and moisture. These factors are primary determinants of fruit fly distribution.The adult *B. dorsalis* emerges between

10.08℃-33.3℃ (Wu Jiajiao et al., 2003), Vergas reported that the threshold temperature for pupae of *B. dorsalis* was 9.3℃ (Vergas et al., 1996); Hsu reported 11.1℃ (Hsu et al., 1973); and Wu Jiajiao reported 10.08℃ (Wu Jiajiao et al., 2003). The emergence rate of *B. dorsalis* was highest when relative soil moisture was between 30%-80% (Yuan Shengyong et al., 2004; Lin Jintian et al., 2005). The aforementioned research used atmospheric temperature and soil moisture estimated from rainfall instead of direct measures of soil temperature and moisture which may misestimate the distribution of *B. dorsalis*. Furthermore, soil temperature and moisture vary over 12 months, so this variability should be addressed.

In the present study, the potential geographical distribution of *B. dorsalis* from January to December in China was predicted based on soil temperature and moisture data from Chinese observation stations, the ER (Emergence rate) model which is based on biological observations and statistical analyisis, and analysis using ArcGIS. In addition, four typical monitoring periods of *B. dorsalis* in China are detailed according to the prediction of potential geographical distribution and suitability levels.

2. MATERIALS AND METHODS

The two parts of this study include establishing the ER (emergence rate) model of *B. dorsalis* and analyzing the potential geographical distribution and suitability levels using the ER model and displaying distribution patterns using soil temperature and soil moisture of past years in China on an ArcGIS platform.

The *B. dorsalis* samples collected from Huangpu in Guangdong province were selected for the emergence experiment. Eggs of *B. dorsalis* were obtained from adults that had been reared for four generations on artificial diet. Mature larvae (6 days after egg hatch) were placed in moist sand (75% water) at 29℃ for pupation. All 7560 pupas were gathered after 24h under and held at 25℃.

The emergence rate (ER) data was collected by placing pupae in a plastic box (high 7cm, diameter 12.5cm) containing medium soil (Guangdong, DaHan) in an Artificial Climate box (Germany Binder Kbwf240). Data was analyzed using SPSS13.0 (http://www.seekbio.com/soft/1492.html) and ArcGIS 9.0 (Environmental Systems Research Institute. ESRI). Soil temperature and moisture (2001-2003) were obtained from China Meteorological Administration.

The ER model, based on soil temperature and relative water content was obtained from a crossover design experiment conducted from March 2007 to

August 2007 at the plant quarantine lab of Guangdong Entry-Exit Inspection and Quarantine Bureau. The design specified 7 soil temperature grades; 9℃, 14℃, 19℃, 24℃, 29℃, 34℃ and 39℃. Six relative water content grades included 0%, 20%, 40%, 60%, 80%, and 100%. Experiments consisted of 46 treatments and 3 replications during about 25 days and every box had 60 pupaes. All pupaes were placed 2cm under the soil and held in artificial climate boxes. Water was added as needed (Wu Qianhong et al., 1991).The ER of *B. dorsalis* was got and. the ER model was derived by stepwise regression (SPSS 13.0)

Geographic distribution and suitability was calculated for each month of the year for all of China and displayed as maps in ArcGIS. Soil temperature and moisture data were limited, but at least 10 days per month was obtained. Since values were obtained from different locations in different months, the full data set is presented in Table.3. The suitability of *B. dorsalis* was analyzed on the basis of these data and ER model results. The ER of *B. dorsalis* for every location in China was obtained. For each location, suitability was categorized into 4 levels; negligible (where the *B. dorsalis* is unable to occur and survive) ($0 \le ER \le 0.01$), low ($0.01 < ER \le 0.2$), moderate ($0.2 < ER \le 0.45$) and high ($0.45 < ER \le 1$). Suitability maps were plotted for each month using the inverse distance weight (IDW) raster interpolation.

3. RESULTS

3.1 ER model

Stepwise regression analysis results:

Stepwise regression ordered the independent variables according to their explanatory power. X^2 improved r^2 the most followed by X, Y and Y^2 *(Table.1, Table.2)*. Analysis showed that XY did not contribute to the explanatory power of the model, so it was dropped.

Table 1 Regression model summaries

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.2014(a)	0.0406	0.0328	0.3888
2	0.7843(b)	0.6151	0.6088	0.2473
3	0.8080(c)	0.6529	0.6443	0.2358
4	0.8471(d)	0.7175	0.7082	0.2136

Table.2 Analysis of variance of regression

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	0.7928	1.0000	0.7928	5.2442	0.0237(a)
	Residual	18.7447	124.0000	0.1512		
	Total	19.5375	125.0000			
2	Regression	12.0169	2.0000	6.0085	98.2699	0.0000(b)
	Residual	7.5205	123.0000	0.0611		
	Total	19.5375	125.0000			
3	Regression	12.7555	3.0000	4.2518	76.4859	0.0000(c)
	Residual	6.7820	122.0000	0.0556		
	Total	19.5375	125.0000			
4	Regression	14.0185	4.0000	3.5046	76.8360	0.0000(d)
	Residual	5.5190	121.0000	0.0456		
	Total	19.5375	125.0000			

a Predictors: (Constant), xx / b Predictors: (Constant), xx, x / c Predictors: (Constant), xx, x, y / d Predictors: (Constant), xx, x, y, yy

Table .1 shows regression model summary, four constants are available including XX, X, Y and YY. *Table.2* shows two constants are very significant because of $F=98.2699>F_{0.05}$ including XX and X, three constants are significant $F=76.4859>F_{0.05}$, four constants are significant $F=76.8360>F_{0.05}$.

The model was available because of $R^2=0.718$, $F=76.836>F_{0.05}$ and $P<0.01$. The regression analysis of the ER showed that P was significant on 0.01 level.

The model chosen for emergence rate determination was

Z = – 0.0036X2 – 0.0001Y2 + 0.1681X + 0.0123Y – 1.5170

Where:

Z is the ER (emergence rate) of *B. dorsalis*

X is the soil temperature

Y is the soil moisture

3.2 Potential geographical distribution of B. dorsalis in China:

Meteorological locations analysis in China: From the Table.3.

As the basis of this model, *B. dorsalis* suitability was analyzed for 12 months in China combining with the soil data from 2001 to 2003.Since different locations were used by the China Meteorological Service to determine soil temperature and moisture, percents of suitable locations were analyzed. From January to April, moderate and low levels were declining and high levels were increasing, which was the reverse trend from Nov. to Dec. From May to Oct., levels remained stable. It was obviously that two suitable high points were May and Sep., high level was the topmost in whole year, both locations and suitable locations were comprehensive from May to Oct.. There was a turning point in Jul., high suitability levels declined, and other levels increased. This is in accord with the *B. dorsalis* biology because soil temperature and moisture is beyond its tolerance.

Table.3 Meteorological locations analysis (Percents of Suitable locations (%) = Suitable locations / locations Percents Of five grades (%) = Numbers of suitable locations/ Suitable locations)

Month	Locations analyzed	Suitable locations	Percents of Suitable locations (%)	Suitability levels	Frequency within suitable locations	Percents within each level (%)
1	43	7	16.28	high	2	28.57
				moderate	1	14.29
				low	4	57.14
2	78	9	11.54	high	2	22.22
				moderate	6	66.67
				low	1	11.11
3	105	40	38.10	high	12	30.00
				moderate	10	25.00
				low	18	45.00
4	103	84	81.55	high	42	50.00
				moderate	31	36.90
				low	11	13.10
5	103	102	99.03	high	100	97.09
				moderate	1	0.97
				low	1	0.97
6	103	103	100	high	99	96.12
				moderate	3	2.91
				low	1	0.97
7	103	97	94.17	high	63	64.95
				moderate	33	34.02
				low	1	1.03
8	93	93	100	high	88	94.62
				moderate	5	5.38
				low	0	0.00
9	103	102	99.03	high	93	91.18
				moderate	9	8.82
				low	0	0.00
10	102	69	67.65	high	33	49.25
				moderate	17	25.37
				low	19	28.36
11	100	21	21.00	high	6	28.57
				moderate	5	23.81
				low	10	47.62
12	57	8	14.04	high	2	25.00
				moderate	1	12.50
				low	5	62.50

Four months (Feb., Mar., Jul. and Oct) had visible change. Each map indicates the geographic distribution of each suitability level.

The February map showed that the suitable areas were concentrated on the south of China including Yunnan, Sichuan, Guizhou, Guangdong and

Hainan. High level suitable areas were the south of Yunnan and southwest of Guangxi.

The Mar. map suitabilities are similar to reported local observations except for the southeast of Shandong including Laiyang (moderate level, 36.58°N), Weifang (moderate level, 36.45°N) and lvxian (high level, 35.35°N), which foreshadoows *B. dorsalis* spreading from the south to the north year by year in China because from its last reported latitude of 33°N (Zhou Guoliang et al., 2007) （Fig.1） .

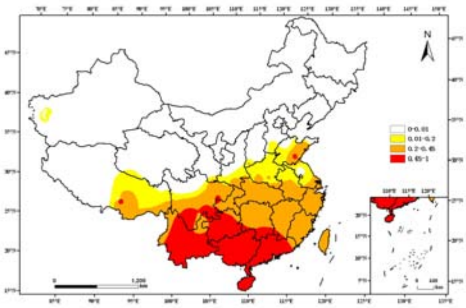

Fig.1: Mar. The potential geographical distribution of *B. dorsalis* and four levels including negligible (0≤ER≤0.01), low (0.01<ER≤0.2), moderate (0.2<ER≤0.45) and high (0.45<ER≤1)

The July map showed that the north of Jiangxi and the west of Hubei were low level suitable areas due to soil temperature and moisture being very high, a limitation showed by the ER. Likewise, the map showed the major areas of moderate level suitability in the south of China.

From the map of Oct. about suitable information of *B. dorsalis*, the results showed the north of China including Heilongjiang and Jilin were negligible. Suitable areas were reduced from the north to the south of China. But the east of Xinjiang including Shache (38.26°N) which was ought to be regarded was high level suitability. Maqu (34°N) from Gansu province was negligible because its soil temperature was very low. （Fig.2）

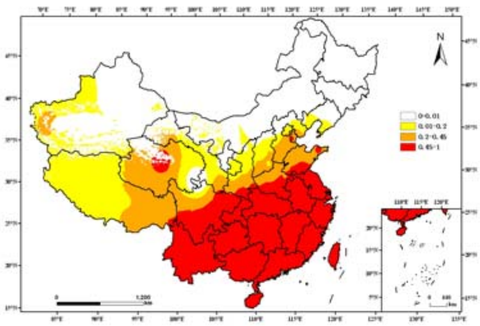

Fig.2: Oct. The potential geographical distribution of *B. dorsalis* and four levels including negligible (0≤ER≤0.01), low (0.01<ER≤0.2), moderate (0.2<ER≤0.45) and high (0.45<ER≤1)

3.3 Conclusions

This study confirms other research as well as observations of *B. dorsalis* distribution throughout China. Major suitable locations occur south of ±35°N with little occurrence north of 35°N.

The distribution expanded and contracted over the year with the wider distribution occurring in the summer months. Environmental conditions in high level locations correlated with optimal development conditions predicted by the emergence rate model. The results indicated that soil temperature affected the potential geographical distribution of *B. dorsalis* in China and suitable areas changed with the season.

In winter months the suitable areas for *B. dorsalis* in China were concentrated in south China, such as Yunnan, Guangxi and Guangdong. In March, *B. dorsalis* started to spread from south to north. At the beginning of April, the suitability of *B. dorsalis* was high in south China, where 81.55% of the locations were suitable. In that area suitability was rated high (50%) and moderate (36.9%), indicating that pest management actions against *B. dorsalis* shoud commence at this time. From May to December, major portions of China contained suitability areas, but it was obvious from the map that suitability in south China declined in July from high to moderate because soil temperatures exceeded the emergence threshold temperature of *B. dorsalis*, and high rainfall frequency in this period suppressed emergence.

4. DISCUSSION

4.1 The potential geographical distribution analysis of B. dorsalis in China

Yunnan suitability analysis: Yunnan was one of the important suitable areas during winter months and provided the source population of *B. dorsalis* for the coming year with adult populations peaking in July. This was also reported by Jiang Xiaolong and Chen Peng (Jiang Xiaolong et al., 2001; Chen Peng et al., 2007). The results indicated that Menzi(a county of Yunnan) didn't occur seasonally, which was different with Liuku(a county of Yunnan) in province, the south of Yunnan especially Menzi was suitable for occurring of *B. dorsalis* in whole year (Chen Peng et al., 2007).Hei Longjiang suitability analysis: Hei Longjiang areas have high suitability from May to September, however, these results are misleading since *B.*

dorsalis cannot survive the winter in this area.ShangHai suitability analysis: *B. dorsalis* emergence may happen at the beginning of April, but was highest from May to October. This correlates with the report of Zhou Guoliang who found progressively earlier emergence over several years. The fruit fly was found firstly in August in 2001, in June in 2002, in June in 2003 and in May in 2004 and 2005 (Zhou Guoliang, 2006).Qinghai, Tibet and Xinjiang areas suitability analysis: Suitability was high from May to September, but the results could not be substantiated because of the lack of host plants and a difficult winter.

4.2 Monitoring and trapping periods

This study indicated four monitoring and trapping periods for fruit fly emergence in China. Two months are not suitable and monitoring should be suspending at these times. The first period was from April 1 to October 31, and monitoring areas include Liaoning, Jilin, Heilongjiang, Inner Mongolia, Qinghai, Beijing, Tianjin, Hebei, Henan, Shandong, Shanxi, Shaanxi, Gansu and Ningxia. The second period, from March 1 to October 31 included Xinjiang, Zhejiang and Tibet. The third period was from March 1 to November 31 and included Sichuan, Chongqing, Guizhou, Jiangxi, Hubei, Hunan, Anhui, Jiangsu, Shanghai, Fujian and Taiwan. Monitoring should take place throughout the year in Guangdong, Guangxi, Yunnan, Hainan.

In summary, we reported that two important natural factors (soil temperature and moisture) determined the potential geographical distribution of *B. dorsalis* over 12 months in China, and that the ER model can be used to predict where and when these conditions are suitable for F emergence. This model may also apply to other countries. The ER model will be improved with future research.

4.3 Management countermeasures

Quarantine measures should be strengthened domestically as well as at the borders (inspection and quarantine). The critical tasks of border inspection and quarantine are port inspection and quarantine from May to September, especially from imports from these continents: America (America, Chile), Oceania (Australia, New Zealand, Nauru), Asia (Bangladesh, Bhutan, Hindustan, Kisan, Japan, Laos, Malaysia, Burma, Nepal, Oman, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, United Arab Emirates, Viet Nam), because many areas of China are suitable for fruit fly during this time. In addtion, domestic inspection and quarantine should address the transport of fruits and vegetables from south China to areas in the north, such as

Guangdong, Guangxi, Hunan, Guizhou, Fujian, Hainan, Yunnan, Szechwan, Hongkong, Macao, Taiwan and so on. Quarantine measures ought to be reinforced to prevent fruit and vegetable infestations.

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