Front. Agric. China 2007, 1(1): 76–80
DOI 10.1007/s11703-007-0014-y

RESEARCH ARTICLE

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Population dynamics of oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) in Xishuangbanna, Yunnan Province, China

Abstract Annual monitoring of the population dynamics of the oriental fruit fly *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in Xishuangbanna, southern Yunnan, was conducted by using methyl eugenol-baited traps in 1997, 2000, and 2003, and factors including temperature, rainfall, and host species with respect to the population fluctuation were analyzed systematically. The results showed that the fruit fly was present all year round in Xishuangbanna. Its population remained at a lower level from November to February, and increased from March until it reached a peak in June or July, depending on the rainfall that year. Afterward, the fly population declined remarkably until October. Temperature, rainfall, and host fruits were major factors comprehensively influencing the population fluctuation. The monthly mean temperature was in a range of temperatures suitable for development and reproduction of the fly. But the monthly mean minimum temperature from December to February was lower than the suitable temperature range, which was suggested a possible reason for the lower populations in winter months. Rainfall was another essential factor influencing the population fluctuations. The population was depressed when the monthly rainfall amount was lower than 50 mm, but increased when rainfall ranged from 100 mm to 200 mm. When the monthly rainfall amount was higher than 250 mm, the fruit fly population was reduced remarkably. The heavy rain in July and August explained the decreasing population. Mango, orange, pear, longan, and peach were found to be the main host species of the fly in Xishuangbanna. Among them, mango and longan were most preferred by the fly. Therefore, the planted areas, fruiting period, and production exerted essential effects on the fly population fluctuations, which were regarded as another major factor influencing the fly population in that area. Briefly, temperature, monthly rainfall, and the host species, through the way of their functions, the influence strength, as well as the period that they occurred comprehensively impacted the population fluctuations of the fruit fly in Xishuangbanna.

Keywords *Bactrocera dorsalis* Hendel, population dynamics, Xishuangbanna

Translated from *Chinese Journal of Applied Ecology*, 2005, 16(7): 1330–1334 [译自：应用生态学报]

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1 Introduction

The oriental fruit fly, *Bactrocera dorsalis* Hendel (Diptera: Tephritidae), is one of the most destructive pest insects of tropical and subtropical fruits and vegetables. It is highly polyphagous and able to infest more than 250 host plants of 40 families including many types of commercial fruits (Smith, 1989; Vargas et al., 1984; Vargas et al., 1990). The fruit fly has been listed as an important quarantine pest in most countries for a wide host range, high fecundity and severe damage it causes to agricultural products (Alyokhin et al., 2001; Bateman, 1972; Fletcher, 1989). This fly, first recorded in Taiwan province, China, expanded to most countries or regions around Asia and Pacific regions over 90 years (Haramoto et al., 1970; Christenson et al., 1976). *B. dorsalis* can complete 3–5 generations per year in most tropical areas, but may reach even 10 generations per year under optimum conditions. The generations are considerably overlapped in all the fly distribution. A female can lay 3–30 eggs in each oviposition (Fletcher, 1989) and more than 1 000 eggs during her lifespan (Zhou et al., 1996). The eggs are laid under the skin of the ripened or ripening fruits and the larvae feed on the fruit pulp, which causes severe damage to the fruits. Mature larvae detached from the fruits, fall on the ground, where they pupate in the soil (Arai, 1975; Arai, 1976). New emerged adults fly to host plants to obtain nutrition. After they achieve sexual maturation, they start a new cycle of damage to fruits (Zhang et al., 1999).

In China, *B. dorsalis* is mostly distributed in the southern and southwestern provinces or autonomous regions. Yunnan is viewed as one of the major provinces where this pest insect causes severe damage (Sheng et al., 1997; Zhu et al., 2000; Zhou et al., 1996). Yunnan has diverse climates including tropics, subtropics, temperate, etc. *B. dorsalis* manifests different infestations and occurrence patterns depending on the local climatic conditions. Xishuangbanna, located in southern Yunnan, is well known for its tropical damp monsoon climate and diverse tropical fruits and vegetables. As a result, the fruit fly infestations may occur throughout the year in Xishuangbanna (Zhu et al., 2000). Previous studies showed that the fly completed five generations per year and caused serious damages to local fruits and vegetables in Xishuangbanna. The aim of this study is to reveal the population dynamics pattern and to get a good understanding of causes and mechanisms of the population fluctuations of the fly in this area. The results will also provide scientific data for establishing practical management strategy of the fly under these particular geographical and climatic conditions (Dai et al., 1999).

2 Materials and methods

Field surveys of *B. dorsalis* adult population were carried out in four orchards and one vegetable garden in Xishuangbanna in 1997, 2000, and 2003. The cultivated patterns were almost similar in all the surveyed orchards, and the main fruit species included mango, orange, pear, longan, and peach. Three Steiner traps, more than 50 m apart, were placed on fruit trees at a height of 2 m above the ground at each site. A pheromone lure was suspended inside each trap near the center. The lure consisted of a small cotton ball soaked with 2 mL of methyl eugenol (Changzhou Biochemical Co. Ltd., Changzhou, China) and few drops of malathion, which was replaced at one month intervals throughout the year. Male flies were attracted by the lures and were quickly killed by the insecticide when they touched the cotton ball. *B. dorsalis* in each trap were identified and counted at 10-day intervals in 1997 and half-month intervals in 2000 and 2003.

Meteorological data used in this study were obtained from the Yunnan Meteorological Bureau. The data of the areas and yields of host plants of *B. dorsalis* used in this study were provided by the Xishuangbanna Agriculture Bureau. Statistical analysis of data was conducted with the software SPSS ver. 11.0.

3 Results

3.1 Annual fluctuation of the fly

Monthly mean capture rates of *B. dorsalis* males per trap in 1997, 2000, and 2003 are shown in Fig. 1. The temporal patterns of male adult captures in Xishuangbanna were identical in all the three study years. Low captures from November to February indicated the small population size or reduction of adult activity during winter. In 2000, the mean adult captures were 37 in November, 34 in December, 18 in January, and 29 in February. No differences in adult captures were detected in the three study years (F (2, 12) = 2.96, P = 0.2). The monthly mean captures of *B. dorsalis* from November through January were 16 in 1997, 29.5 in 2000, and 37.5 in 2003, respectively. High captures were recorded in March and April. The mean captures were 166 in 1997, 215.5 in 2000, and 245 in 2003. It showed the beginning of mass activities of *B. dorsalis* adult populations. The captures increased abruptly during May and June or July depending on the study year. The monthly mean captures were 829.3 in 1997, 910.2 in 2000, and 711.2 in 2003. The captures in peak month were 25 times as high as that from November through February, indicating the main occurrence period when *B. dorsalis* caused serious damage. The population peak period varied with years. The highest captures of *B. dorsalis* adults were in June in both 1997 and 2003, but in July in 2000. Apparently, the peak of the fly populations was closely related to locally heavy rainfall, which is discussed in details subsequently. The captures decreased dramatically from population peak month through October. The captures declined from 483 to 118 in 1997, 635 to 359 in 2000, and 1 017 to 493 in 2003 from August to October. The declining trends of the population were similar in the study years.

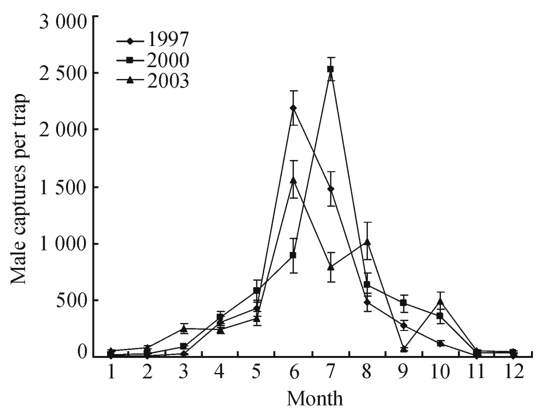

Fig. 1 Number of *B. dorsalia* male adults caught through Steiner trap in Xishuangbanna, Yunnan, in 1997, 2000, and 2003

3.2 Relationship between population fluctuation and climatic factors

Temperature, humidity, rainfall, sunlight, etc. were the main climatic factors causing fluctuations in *B. dorsalis* population. They interacted on each other and exerted synthetically effect on the population fluctuations of the fly except for its sole influence. A correlation analysis was carried out between the monthly captures and six monthly climatic factors. Positive correlations were found between monthly captures and the six monthly climatic factors: monthly rainfall amount, monthly rain days, monthly relative humidity, monthly mean temperature, monthly mean maximum temperature, and monthly mean minimum temperature. Negative correlation was found between the monthly captures and monthly sunlight hours (Table 1). A significantly positive correlation was found between the monthly captures and three climatic factors: monthly rainfall amounts, monthly mean temperature, and monthly mean maximum temperature ($P < 0.05$), suggesting that all the three factors were essential factors impacting the fly population fluctuations.

Table 1 Correlation relationship between population dynamic and climate factors in Xishuangbanna

Climate factor	Correlative coefficient and significance					
	1997		2000		2003	
	r	*p*	*r*	*p*	*r*	*P*
Rainfall / mm	0.697	0.012*	0.734	0.007*	0.780	0.003*
Sunlight / h	–0.352	0.262	–0.356	0.256	0.363	0.246
Raining Days	0.517	0.085	0.514	0.087	0.529	0.077
RHD / %	0.177	0.582	0.221	0.490	0.213	0.506
Monthly Mean Temp / °C	0.617	0.033*	0.617	0.033*	0.636	0.026*
Monthly Max. Temp / °C	0.369	0.238	0.348	0.268	0.381	0.222
Monthly Min. Temp / °C	0.686	0.014*	0.668	0.018*	0.686	0.014*

*: $P < 0.05$

3.2.1 Population fluctuation related to temperatures

Overall the air temperature in Xishuangbanna is favorable for *B. dorsalis*. Suitable temperature for development and reproduction of *B. dorsalis* ranges from 15°C to 34°C, while optimum temperature ranges from 18°C to 30°C (Fletcher, 1987; He et al., 2002; Jiang et al., 2001; Vargas, 1996; Wang, 1996; Wu et al., 2000). A large number of adults and larvae die at temperatures higher than 34°C or lower than 15°C. When the temperature falls below 18°C, the eggs, larvae, and pupae will prolong their development, and the emergence ratio of adults will decrease greatly (Fletcher, 1987; He et al., 2002; Jiang et al., 2001). In Xishuangbanna, the monthly mean temperature ranged from 16°C to 26°C, the monthly mean maximum temperature from 25°C to 31°C, and the monthly mean minimum temperature from 11°C to 22°C, based on the climatic data obtained from 1960 to 1990. Overall these temperatures fell into the suitable temperature ranges of the fly in the Xishuangbanna area, which explained why *B. dorsalis* could occur throughout the year in this district.

Figure 2 shows that the monthly mean temperatures from November, December, January, and February were 19.3°C, 16.3°C, 15.7°C, and 17.8°C, respectively, which fell into the suitable temperature range for the fly. At the same time, the monthly mean minimum temperatures were 15.7°C, 12.4°C, and 10.8°C, and 10.7°C for the same time period, and they appeared to be lower than the suitable temperature range for the fly. Furthermore, daily mean temperature lower than 10°C was recorded for 7 days, and lower than 5°C for 2 days from November to February. 2.7°C was recorded as the daily minimum temperature in winter. Though these temperatures were unsuitable for the fly, daily maximum temperature was mostly beyond 25°C. The variable temperature increased cold tolerance of the fly within a short period of time, which probably explained that the fly population increased from November through next February, but at a relatively low level.

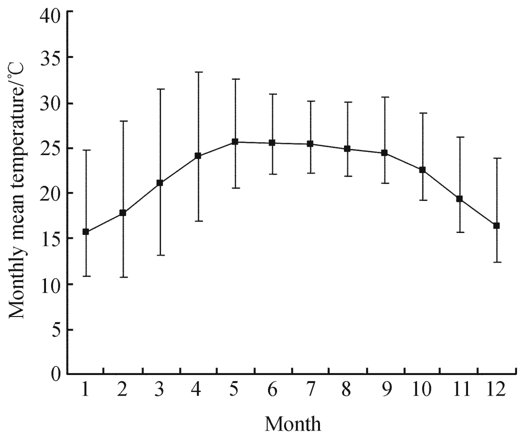

Fig. 2 Monthly mean temperature from 1960 to 1990 in Xishuangbanna

Monthly mean temperatures in March and April were 21.1°C and 24.1°C, which were in the optimum temperature range for the fruit fly, but the monthly mean minimum temperatures were below the suitable temperature range. The air temperature condition of the two months was helpful for the fly to increase its population again.

The monthly mean temperature, monthly mean maximum temperature, and monthly mean minimum temperature fell into the optimum temperature range of the fly from May to October, when adult population increased and reached a peak in June or July. The variations of air temperatures were consistent with population fluctuations, indicating positive relations between the air temperature and the fly population increase from May to October. Interestingly, though the monthly mean temperature from August to October also fell in the optimum range of the fly, adult population declined markedly. The phenomenon implied that other environmental factors also profoundly dominated the population fluctuations at this period.

3.2.2 Population fluctuation related to rainfall

The data of monthly rainfall amount in 1997, 2000, and 2003 are shown in Table 2. The rainfall in the wet season of May to October explained for 85% of the annual precipitation and 15% in the dry season, which was from November through April in Xishuangbanna. Heavy rainfall appeared in July and August, accounting for 20% of the annual precipitation.

Table 2 Monthly rainfall (mm) in Xishuangbanna of Yunnan Province in 1997, 2000, and 2003

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1997	9.3	14.9	19.9	28.3	62.8	99.0	365.4	212.8	167.1	98.5	9.3	14.9
2000	19.2	11.2	20.1	50.7	133.1	146.4	216.3	285.8	137.0	99.2	19.2	11.2
2003	20.8	13.3	19.3	46.5	136.5	144.2	280.1	217.7	141.8	96.1	20.8	13.3

In field conditions, the effects of rainfall on *B. dorsalis* population involved two aspects. The precipitations and rainfall frequency influence soil humidity, which affects pupation and eclosion of *B. dorsalis* pupae. Appropriate rainfall can increase soil and air humidity and help decrease mortalities of both mature larvae and new adults, and this favors copulations, ovipositions, and production of *B. dorsalis* adults. On the other hand, superabundant precipitations result in too high soil humidity, which negatively impacts the pupating and the emergence of the fly.

Table 1 shows the positive correlation between monthly rainfall and captures. Monthly mean rainfall was below 50 mm in the dry season of November to April, when overall the adult population was lower. When rainfall exceeded 100 mm from May to October, the adult population was higher. Further analysis shows that when the rainfall was 100–200 mm it benefited population increase in June and July; however the population declined when there was more than 250 mm rainfall.

Maximum monthly rainfall remarkably differed in the three study years. In August 2000, when the maximum rainfall was more than 250 mm, the adult population decreased abruptly. The same population fluctuation pattern was also seen in both 1997 and 2003, when the maximum rainfall was more than 250 mm in July. Days which had rainfall more than 25 mm were called heavy rain days. In 2000, the number of the monthly heavy rain days was 2.3 and this was mostly in August; whereas in 1997 and 2003, the number of the monthly heavy rain days was in July. As the monthly mean temperature fell in the suitable temperature range for the fly during July and August, it was reasonable that rainfall amount in the two months was likely to be one of the crucial factors resulting in population declines of *B. dorsalis* in Xishuangbanna.

3.2.3 Population fluctuation related to the host plants

Xishuangbanna is one of the important tropical fruit bases in Yunnan. The host plant species of *B. dorsalis* include mango, pear, plum, peach, guava, lichee, orange, longan, Chinese date, loquat, rambutan, grape, areca, watermelon, capsicum, tomato, etc. These host plant species provide very rich food resources for the fruit fly. They fruit alternately and make a continuous spectrum of host plants for *B. dorsalis* throughout the year. Among these host plants, mango, orange, longan, pear, and peach are regarded as the preferred host fruit species of *B. dorsalis*. Their planted area, harvest and fruiting period (Table 3) essentially influence the fly population fluctuations.

Table 3 Harvest and phenology of the five major host fruits of *B. dorsalis* in Xishuangbanna

Host species	Fruiting period / month	Harvest / $\times 10^3$ kg
Mango	7–8	1170
Orange	10	711
Longan	7–8	385
Pear	7–11	166
Peach	5–7	150

Table 3 and Fig. 1 demonstrate that population fluctuations of *B. dorsalis* were closely associated with the host fruit species cultivated locally. The capture peak of the fly adults was mostly consistent with the fruiting period of these hosts, indicating that they had important impacts on population growth of the fly. Based on harvest and field survey, mango was most preferred by the fly. Analysis showed that *B. dorsalis* could infest alternately different host plant species. From May through July or August, the fruits of mango, longan, peach, and pear ripened in succession. A large number of ripe fruits dropped on the ground, which provided enough food and reproduction material for *B. dorsalis*. The monthly captures during this period were obviously higher and reached a peak. When the fruiting periods ended gradually after August, *B. dorsalis* moved to infest other host plant species such as guava, orange, and lichee. After November, air temperature dropped and host fruits diminished. As a result, the number of *B. dorsalis* population declined accordingly.

4 Discussion

The present study revealed that population fluctuations of the fruit fly were almost identical during the three study years. Adult population of the fly remained at a very low level from November through February and got higher in the rest of the months. Peak of the population was recorded in June or July depending on the year.

The study shows that temperature, rainfall, and host plant species are the main environmental factors impacting population fluctuations of *B. dorsalis*. The temperature exerted influence on fly growth, reproduction, feeding activity, etc. Overall the temperature condition in Xishuangbanna was suitable for development and reproduction of the fruit fly, which explained why the fly was present throughout the year. The results further showed that the lower air temperatures from November through February may depress the population growth, and the air temperatures in the whole summer are in the optimum range for *B. dorsalis*, which becomes favorable for population increase of the fruit fly.

The influence of rainfall on *B. dorsalis* population involves two aspects. Rainfall less than 50 mm or more than 200 mm may suppress population growth. When the monthly rainfall gets higher than 250 mm, the fruit fly population would decline remarkably. It has explained why population declines in July or August. On the other hand, monthly rainfall from 50 mm to 200 mm is favorable for population increase of *B. dorsalis*. Rainfall influences indirectly *B. dorsalis* population dynamics through soil water content (He et al., 2002; Jiang et al., 2001). The degree of influence of rainfall with respect to soil differs from soil types. Besides, air temperature could affect the evaporation of soil water. In Xishuangbanna, both mango and longan are the most important host fruits (Narayanan and Chawla, 1962; Sheng et al., 1997), deciding population growth of the fruit fly. Peach, pear, orange, etc. are also important host plant species with respect to *B. dorsalis* population growth (Li and Ye, 2000). Fruiting periods of these host plants alternately provide a successive food resource for *B. dorsalis*.

Briefly, monthly mean temperatures, monthly rainfall, and the host plant species, through the way of their functions, the influence degree, as well as the period that they occur, comprehensively impact the population fluctuations of the fruit fly in Xishuangbanna areas.

Acknowledgements The study was conducted under the auspices of the National Key Project for Basic Research on Ecosystem Changes in Longitudinal Range-Gorge Region and Transboundary Eco-security of Southwest China (No. 2003CB415100). We also received financial support from the National Natural Science Foundation of China (Grant No. 30260023).

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