第 21 卷第 11 期
2001 年 11 月

生 态 学 报
ACTA ECOLOGICA SINICA

Vol. 21, No. 11
Nov., 2001

华北地区昆虫秋季迁飞的雷达观测

吴孔明[1]，程登发[1]，徐 广[1]，翟保平[2]，郭予元[1]

(1. 中国农业科学院植物保护研究所，北京 100094；2. 南京农业大学植物保护系，南京 210095)

摘要：1999 年 9～10 月利用昆虫雷达对华北地区昆虫秋季回迁的观测表明，秋季迁飞主要发生于 19:00～05:00 时，飞行高度一般在 300～2000m。迁飞方向与风向一致，多为从东北向西南方向迁飞。运行速度和飞行高度成正相关，迁飞个体的平均运行速度由 392m 高度的 4.8m/s 增加到 2000m 处的 27.8m/s。空中灯光诱捕表明，甜菜夜蛾和棉铃虫为优势迁飞种类。

关键词：昆虫迁飞；雷达观测；华北

Radar observation of autumn migration of insects in Northern China

WU Kong-Ming[1], CHENG Deng-Fa[1], XU Guang[1], ZHAI Bao-Ping[2], GUO Yu-Yuan[1]

(1. *Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing* 100094 *China*; 2. *Department of Entomology, Nanjing Agricultural University, Nanjing* 210095 *China*). ***Acta Ecologica Sinica*, 2001, 21(11): 1833～1838.**

Abstract: Flight and migration are important activities in the life cycles of many insect pests. Most insects can move several kilometers in one night even without wind assistance. If the insects climb to altitudes above the planetary boundary layer to gain wind assistance, they can indeed travel long distances during one or more nights. The capability of some insects to take long distance migration makes them potentially access to their favorable habitats for feeding and breeding, which become a major factor that insect pests bring the disastrous damage to the crop production. Over the last three decades, insect radar, as an important insect-detecting device, has been widely used in migration research in several countries, particularly in Britain, Australia and America, and has made many important contributions to the understanding of insect migration. In China, radar observations of insect migration were conducted from 1985 to 1990 in Jilin Academy of Agricultural Sciences and NRI (co-operation with Nanjing Agricultural University) in northeastern and southeastern China, respectively, and provided much valuable information on the migration flights of the oriental armyworm (*Mythimna separata*) and planthoppers (*Nilaparvata lugens*). In order to promote development of radar entomology in China, a scanning insect radar was established in Institute of Plant Protection, Chinese Academy of Agricultural Sciences (CAAS) in 1999. Here reported was a preliminary observation result on autumn migration of insects in northern China.

The CAAS entomological radar is equipped with a marine radar (RA722UA) manufactured in Japan by Anritsu Corporation and an antenna system of Chinese meteorological radar, with a microcomputer, image-processing LSI, and a custom-LSI for processing and storing the echo signal, displaying the radar image with high brightness, and for providing various high-level functions. It possesses a peak power of 10 kW and an operating frequency of 9.4GHz (X band, 3.2cm wavelength). The radar antenna consists of a double feed, 1.5m diameter parabola. The picture of the radar observiations is recorded by a computer and a special camera which can take multiple-exposure photographs.

基金项目：国家重点基础研究发展规划资助项目(G2000016208)

收稿日期：2000-08-16；**修订日期**：2001-01-10

作者简介：吴孔明(1964)，男，河南省固始县人，博士，研究员。主要从事昆虫生态学研究。

The radar observation was carried out during the autumn of 1999 in west suburban area of Beijing (116°20′E,39°47′N). The daily observations was made from 16:00 of the day to 09:00 of the next day. The meteorological data during the observations were recorded by a conventional equipment. One of the major problems of radar entomology is that of species identification of radar target. This problem was largely avoided in the present study by making aerial sampling. A 300 W common light trap was set up during the period of radar observation on the top of a building of 20 m height in observation site. The species and numbers of insects caught in the trap were identified and counted each day. The female moths were dissected to check their ovarian development and mating status. The aerial densities and ground speed of airborne insects were estimated by the algorithm described by Drake. The main results were as follows:

There were only very few insects flying during the day. Aerial densities usually increased gradually from 19:00 and peaked (more than 8.0 per million cubic meters) at about 21:00, then dropped little by little after 22:00. Large-scale southwestward migration were detected, and the average ground speeds of airborne insects below 400m agl were 4.8m/s, but 10.8m/s at altitude above 800m agl. A record of 27.8m/s was found at 2000m agl. Their flight azimuth was consistent with the wind directions.

Light-trap catches indicated that the migrating insects in this season were mainly noctuid moths, *Spodotera exigua* (Hübner) and *Helicoverpa armigera* (Hubner), accounted for 37.5% and 28.6% of total catches, respectively. Most of the catches were *H. armigera* by the 20th of September, but *S. exigua* dominated the aerial population since then. Based on the dissection data, 83.7% of *H. armigera* catches had no mating experience, and the rest (16.3%) had mated once, with 77.6% of total catches showing undeveloped ovary, and the 12.2% being sexual mature individuals. These two species cannot overwinter in remote northern and northeastern China, so these catches well indicated their migratory characteristics and capacity.

Among the trap catches, *Loxostage sticticalis* L. (5.5%) and *Agrotis ypsilon* (Rottemberg) (0.9%) were also found to be conspicuous migrants in China, whose return migration route from northeastern China remains a mystery up to now. These catches provided a circumstantial evidence for their southward migration, but their source region should still be determined by trajectory analysis. Some beneficial insects in the catches, such as *Chrysopa septempuctata* Wesmael (7.6%), *Propylaea japonica* (Thunberg) (3.3%), *Harmonia axyridis* (Pallas) (1.9%), *Chrysopa sinica* Tjeder (1.4%), *Coccinell septempunctata* L. (0.4%), showed clearly the phenomena of accompanying migration by natural enemies with their prey.

Helicoverpa armigera (Hübner) and *Spodoptera exigua* (Hübner) are the important insect pests in agriculture in China. Their damage area can be extended into northeastern China such as Liaoning and Jilin Provinces etc., by a long distance facultative migration with East Asia monsoon in spring and summer. The present observation indicated that they could cover a distance of 150～680 km during one night. Therefore, it was possible that two species the radar observed came from northeastern China, to where they were taking the movement with the aid of East Asia monsoon.

Key words: insect migration; radar observation; northern China

文章编号: 1000-0933(2001)11-1833-06 **中图分类号**: Q969 **文献标识码**: A

迁飞是昆虫从时间和空间上躲避不良环境的手段，也是导致大范围暴发成灾的主要原因之一。我国重要的农业害虫棉铃虫、褐稻虱和粘虫等都为迁飞性害虫。因此，研究昆虫迁飞行为对阐明农业害虫的灾变机制，发展区域性预警技术有重要价值。由于迁飞性害虫在行为上的特殊性（飞行高度远在人的目力之外），如果没有专门设备就无法对其迁飞过程进行直接监测，更不可能做出定量分析。昆虫雷达的出现为研究昆虫的迁飞过程提供了一种革命性的工具[1]。20 世纪 60 年代后期开始，英国、澳大利亚和美国开始利用

雷达技术研究昆虫迁飞，使昆虫迁飞研究由迁飞规律的定性分析发展到起飞-运转-降落过程的定量描述[2]。国内则在 20 世纪 80 年代初由吉林农业科学院组建了我国第一部昆虫雷达并观测了粘虫、草地螟在我国东北的迁飞[8-11]，南京农业大学也在 20 世纪 80 年代末与英国自然资源研究所合作利用雷达观测了水稻害虫在华东地区的迁飞[12-14]。国内以前对昆虫迁飞的雷达观测主要是在迁入区和迁出区，华北地区则属东亚迁飞场中秋季回迁的过境区，明确其过境飞行中的行为及空中虫群的构成无疑有助于深化对迁飞过程的认识。为此，1999 年秋季对华北昆虫的回迁进行了观测研究，结果报道如下。

1　材料与方法

1.1　昆虫雷达

昆虫雷达为日本产航海雷达，但天线改装为国产 711 型气象雷达天线，以适应对飞行昆虫的观测。雷达峰值功率 10Kw，波长 3.2cm，发射频率 9410 兆赫。天线扫描和信号采集由计算机控制，其回波信号同时显示在雷达平面显示器(PPI)和计算机监视器上并定时存储为数字化文件供分析用。全套系统安装在载重汽车上，并配备一部发电机供野外作业使用。

1.2　观测地点和时间

观测地点为位于北京西郊的中国农业科学院植物保护研究所农场(地理位置 116°20′E，39°57′N；海拔高度 44.40m)，地势平坦，80m 以内无障碍物。于 1999 年 9 月 5 日至 10 月 28 日共计进行 22 次雷达观测，其中 9 月 13 日至 16 日观测时间为 16:00 至次日 9:00，其它观测多集中于 19:00 至 22:00。记录雷达观测期间的地面风向、风速、气温等气象资料。

1.3　地面取样

在距观测地点 100m 的楼顶(距地面高度 20m)设置一 300W 灯光诱捕器，灯光向上照射诱捕空中昆虫。诱捕时间为 19:00～7:00。每日检查诱捕的昆虫种类和数量，并解剖诱捕的棉铃虫雌蛾，检查卵巢发育进度和交配情况。

1.4　数据分析

空中虫群密度和运行速度按 Drake 的算法计算[15]。

2　结果与分析

2.1　雷达观测

利用昆虫雷达昼夜连续观测表明，8:00 ～ 17:00 空中虫量极少，一般于 19:00 后 PPI 上昆虫回波数量明显增加，至 21:00 时达到高峰，此后回波数量渐降，至 5:00 后回波数量显著减少(图 1)。天气晴朗夜晚，回波数量多，分布范围广(图 2)，9 月 13～14 日和 19～28 日 20:00～21:00 空中虫群密度均在 8 头/10^6m^3 以上。其飞行高度一般在 300m 以下，在 2000m 高度也有少量个体。阴雨天回波数量少且主要分布于 1200m 以下。9 月 16 日 20:00～21:00 在阵雨期间观测，空中虫群密度平均仅为 0.7 头/10^6m^3。观测期间主要为东北风，利用多次曝光法获得的回波移动轨迹显示，昆虫的迁飞方向和风向相同，即从东北向西南方向迁飞(图 3)。运行速度和飞行高度呈正相关。9 月中旬晴朗夜晚的观测结果表明，飞行高度 100m 以下和 786m 以上的个体的平均运行速度分别为 4.8m/s 和 10.8m/s(表 1)。

2.2　昆虫种类

9 月 10 日至 10 月 28 日雷达观测期间，空中共计诱捕中、大型昆虫 578 头，其中甜菜夜蛾 217 头(雌蛾 32 头)，棉铃虫 165 头(雌蛾 75 头)，分别占 37.5% 和 28.6 %。其它种类主要为大草蛉、草地螟、旋幽夜蛾、黄地老虎和龟纹瓢虫，总计占 25.8%（表 2)。从时间动态上，9 月 20 日以前以棉铃虫为主，9 月下旬以甜菜夜蛾为主。自 10 月初始，空中迁飞昆虫数量急剧下降(图 4)。对诱捕的棉铃虫雌蛾生殖系统的解剖表明，83.7%的雌蛾没有交配，16.3%的雌蛾交配 1 次。卵巢发育 1 级个体占 77.6 %，3 级以上个体仅占 12.2%，具有典型的迁飞昆虫生理特征。

3　讨论

3.1　棉铃虫和甜菜夜蛾是近年来华北和东北地区的重要害虫，其在华北北部以北地区不能越冬，每年春、夏季随季风迁入[16-18]，对棉铃虫种群适合度的研究已表明，第 3 代棉铃虫 8 月中下旬在华北北部以北地区

表 1 空中迁飞昆虫的密度和运行速度

Table 1 The aerial density and ground speed of flying insects

高度 (m) Hight	空中虫群平均密度 (头/10^3m^3) Mean aerial density of flying insects per 10^3m^3	运行速度 (m/s) Ground speed
<<392	0.3	4.8±0.2
392～785	1.7	7.0±2.1
785～1177	1.8	10.8±8.0
1178～1569	2.0	16.2±11.1
1570～1961	1.9	21.1±1.4
1962～2472	0.6	27.8±10.7

1999-09-24, 20:00～20:30, 仰角 Angle 58°, 距离档 Range 1.5

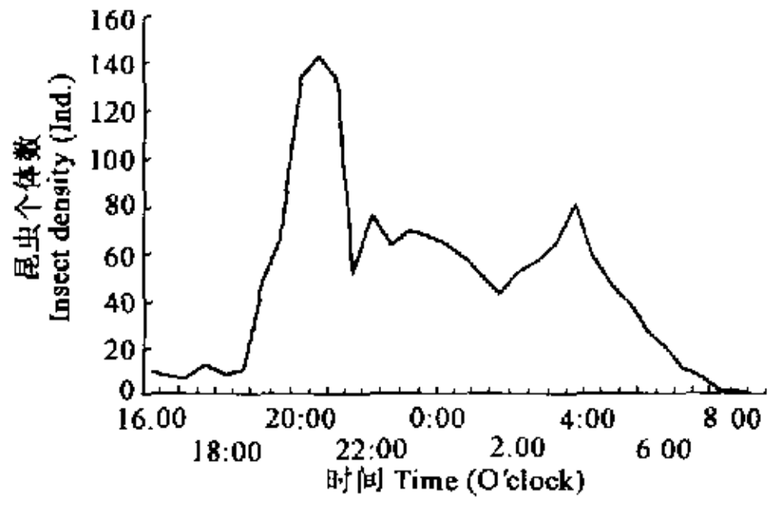

图 1 空中迁飞昆虫数目的日变化规律(雷达观测, 1999 年 9 月 14～15 日, 仰角 58°)

Fig. 1 Hourly distribution of insect targets from radar observation (14～15 September 1999, angle 58°)

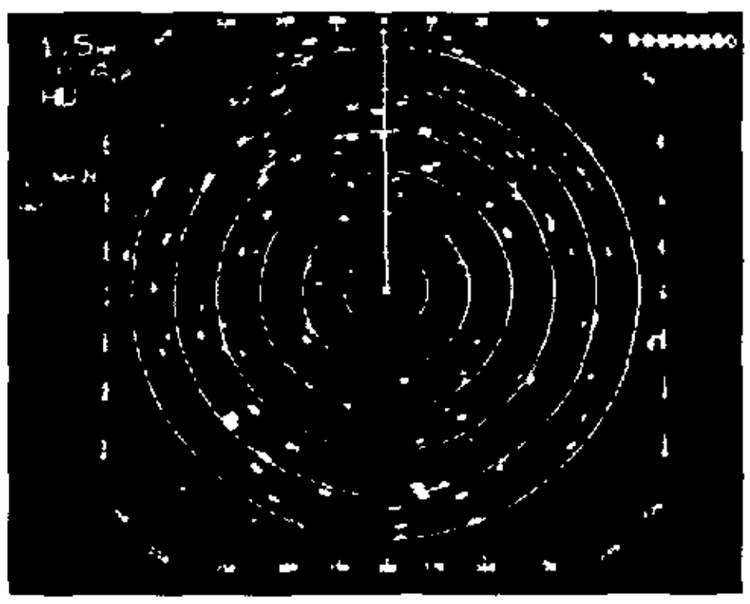

图 2 昆虫回波图象(仰角 58°, 距离档 0.75, 1999 年 9 月 28 日 21:00)

Fig. 2 Insect echoes on the PPI (angle 58°, range 0.75, 21:00, 28th Sep. 1999)

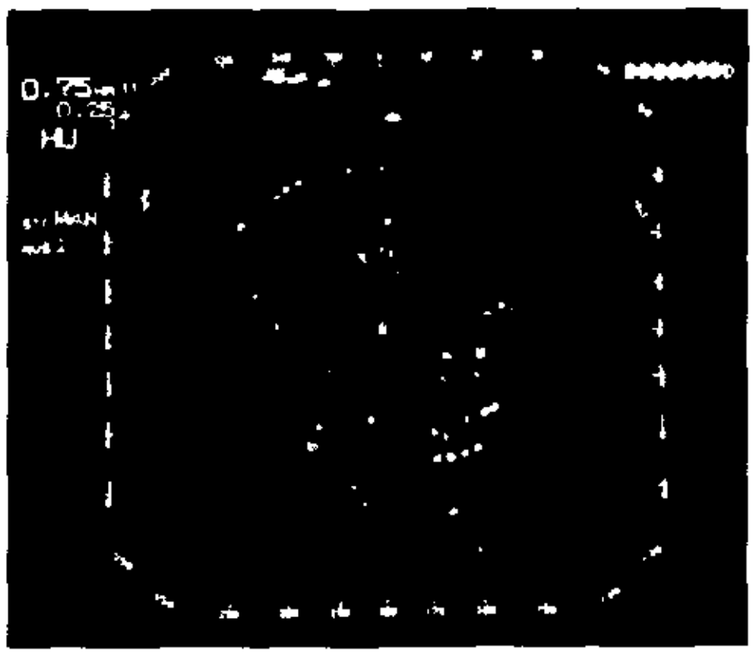

图 3 空中迁飞个体的运行轨迹(仰角 58°, 距离档 0.75, 6 rpm, 1999 年 9 月 20 日 19:30)

Fig. 3 Tracks of flying insects (angle 58°, range 0.75, 19:30, 20th Sep. 1999)

不能形成滞育蛹, 成虫羽化后东北各地已失去适宜产卵的寄主植物, 远距离迁飞成为棉铃虫繁延种群的唯一手段[3]。本项研究表明, 甜菜夜蛾和棉铃虫等昆虫秋季夜间迁飞时间约 9h 左右, 以运行速度 4.8～21.1m/s 计算, 每夜可迁飞 150～680Km, 因此, 试验中观测的棉铃虫和甜菜夜蛾等昆虫应为随东北气流从华北以北地区向南迁飞的个体。

3.2 在诱捕的其他蛾类中, 草地螟和小地老虎也是典型的迁飞性害虫, 但由于我国东北地区自然地理特征的 Pied piper 效应, 使其从东北的回迁至今仍是一个谜。入秋之后, 位于蒙古高压东部和阿留申低压西部之间过渡地带的我国东北地区处于夏季风和冬季风的转换期, 随着夏季风的迅速南撤, 取而代之的是西北风或西风。除了某些天气系统过境引起的短暂的东北风外, 东北虫源极少有机会迁返华北及其以南地区, 以致在我国 20 世纪 60 年代到 70 年代的历次粘虫标放试验中, 从未成功回收到远距离回迁的东北标记蛾。1982 年 8 月 29 日凌晨 3:00, 曾在黄海北部海面(38°38'N, 121°58'E)观测到草地螟蛾群的大规模越海迁飞, 1h 内捕到草地螟蛾 6504 头[20]。但从风场分析可知, 当时低压中心位于海参崴附近, 从 8 月 28 日 20:00 到 29 日 20:00, 35°N 以北从地面到 850hPa 等压面全为西北风, 故这批草地螟蛾群不可能来自东北, 而且

蛾群随风所至之处也是其葬身之地，因草地螟的分布南界为 37°N。本研究期间所捕到的草地螟蛾源自何处，尚待进一步的轨迹分析才能确定。

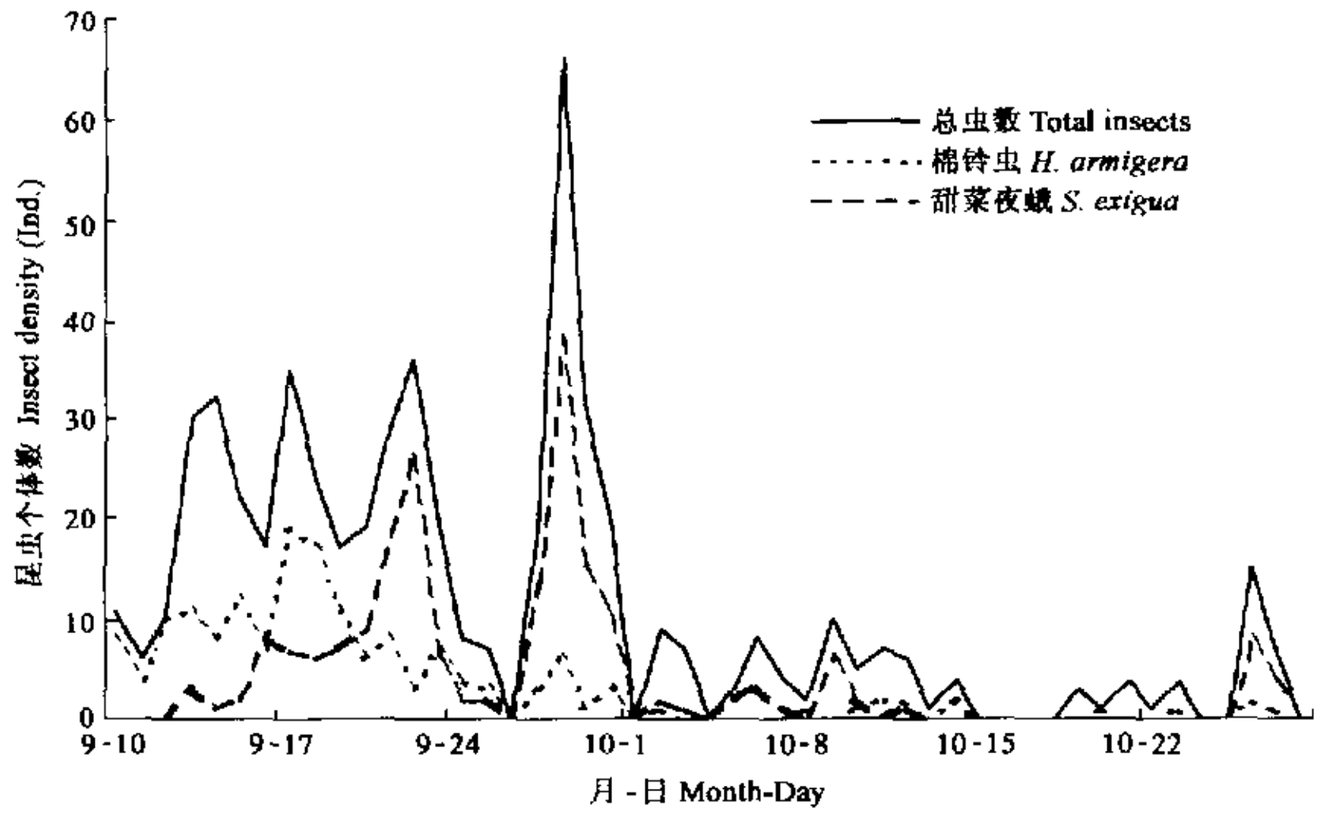

图 4　雷达观测期间空中诱捕棉铃虫和甜菜夜蛾的数量动态

Fig. 4　Population dynamics of cotton bollworm and beet armyworm captured by light trap during days of radar observations

表 1　雷达观测期间空中灯光诱捕的昆虫种类和比例

Table 1　Composition of catches from a zenith-pointing light trap on a building (20 m agl) **during the observations**

昆虫种类　Species	数量 (No.)	比例(%) Ratio	昆虫种类　Species	数量 (No.)	比例(%) Ratio
甜菜夜蛾 *Spodoptera exigua* (Hubner)	217	37.5	小地老虎 *Agrotis ypsilon* (Rottemberg)	5	0.9
棉铃虫 *Helicoverpa armigera* (Hübner)	165	28.6	豆荚螟 *Maruca testulalis* Geyer	3	0.5
大草蛉 *Chrysopa septempuctata* Wesmael	44	7.6	黄翅缀叶野螟 *Botyodes diniasalis* Walker	3	0.5
草地螟 *Loxostege sticticalis* L.	32	5.5	桃蚌螟 *Dichocrocis punctiferalis* Guenée	3	0.5
牛轴草切根虫 *Scotogramma trifolii* (Rottemberg)	29	5.0	大青叶蝉 *Tettgella viridis* (L.)	2	0.1
黄地老虎 *Agrotis segetum* (Schiffermüller)	25	1.3	七星瓢虫 *Coccinella septempunctata* L.	2	0.1
龟纹瓢虫 *Propylaea japonica* (Thunberg)	19	3.3	单梦尼夜蛾 *Orthosia gracilis* (Denis et Schiffermüller)	1	0.2
异色瓢虫 *Harmonia axyridis* (Pallas)	11	1.9	豆荚野螟 *Maruca testulalis* Geyer	1	0.2
中华草蛉 *Chrysopa sinica* Tjeder	8	1.4	梨剌蛾 *Narosoideus flavidorsalis* (Staudinger)	1	0.2
瘤连纹夜蛾 *Maducunoghia confusa* Stephens	5	0.9	烟青虫 *Helicoverpa assulta* Guenée	1	0.2
瓜绢野螟 *Diaphania indica* (Saunders)	1	0.2			

3.3　天敌伴迁现象已有诸多报道[21]，如黑肩绿盲蝽和小宽蝽[13,22~24]、蚜茧蜂[17,18]、草蛉和瓢虫类[1,22,23]等。本研究期间所诱捕的其他种类中，几种天敌昆虫也是我国北方最常见的种类。它们随气流与其猎物一起回迁，表现出不同营养层之间的协同进化。

参考文献

[1]　翟保平. 追踪天使　　雷达昆虫学 30 年. 昆虫学报，1999，**42**：315~326.

[2]　Schaefer GW. Radar observations of insect flight. In: Rainey R C ed. *Insect Flight*. Oxford: Blackwell Scientific,

1976, 157～197.

[3] Greenbank D O, Schaefer G W, Rainey R C. Spruce budworm (Lepidoptera: Tortricidae) moth flight and dispersal: new understanding from canopy observations, radar, and aircraft. *Mem. Ent. Soc. Canada*, 1980, **110**: 49.

[4] Reynolds DR, Riley JR. Flight behaviour and migration of insect pests: radar studies in developing countries. *NRI Bulletin, Chatham Maritime: NRI*, 197, **71**:114.

[5] Drake VA & Farrow RA. The influence of atmospheric structure and motions on insect migration. *Ann. Rev. Ent.*, 1988, **33**: 183～210.

[6] Wolf W W, Westbrook J K, Raulston J, *et al*. Recent airborne radar observations of migrant pests in the United States. *Phil. Trans. R. Soc. Lond.*, 1990, **B 328**: 619～630.

[7] Beerwinkle KR, Lopez J D, Witz JA, *et al*. Seasonal radar and meteorological observations associated with nocturnal insect flight at altitudes to 900 meters. *Environ. Ent.*, 1994, **23**(3): 676～683.

[8] Chen RL, Bao XZ, Drake VA, *et al*. Radar observations of the spring migration into northeastern China of the oriental armyworm moth, *Mythimna separata*, and other insects. *Ecol. Ent.*, 1989, **14**: 149～162.

[9] 陈瑞鹿. 雷达在粘虫迁飞研究中的应用. 见:林昌善主编,粘虫生理生态学. 北京:北京大学出版社, 1990. 293～335.

[10] 陈瑞鹿,暴祥致,王素云,等. 草地螟迁飞的雷达观测. 植物保护学报, 1992, **19**: 171～174.

[11] Chen R L, Sun Y J, Wang S Y, *et al*. Migration of the oriental armyworm *Mythimna separata* in East Asia in relation to weather and climate I. Northeastern China. In: Drake V A, Gatehouse A G eds. *Insect Migration: Tracking Resources through Space and Time*. Cambridge: Cambridge Univ. Press, 1995, 93～104.

[12] Riley J R, Cheng X N, Zhang X X, *et al*. The long-distance migration of *Nilaparvata lugens* (Stål) (Delphacidae) in China: radar observations of mass return flight in autumn. *Ecol. Ent.*, 1991, **16**: 471～489.

[13] Riley J R, Reynolds D R, Smith A D, *et al*. Observations on the autumn migration of *Nilaparvata lugens* (Homoptera: Delphacidae) and other pests in east central China. *Bull. ent. Res.*, 1994, **84**: 389～402.

[14] Riley JR, Reynolds DR, Smith AD, *et al*. Observation of the autumn migration of the rice leaf roller *Cnaphalocrocis medinalis* (Lepidoptera: Pyralidae) and other moths in eastern china. *Bull. ent. Res.*, 1995, **85**:397～414.

[15] Drake V A. Quantitative observation and analysis procedures for a manually operated entomological radar. CSIRO Div. *Ent. Tech. Paper*, 1981, **19**: 41.

[16] 郭予元. 棉铃虫迁飞规律及其与寄主植物的互作关系研究进展. 昆虫学报, 1997, **40** (增): 1～6.

[17] 吴孔明,郭予元. 一代棉铃虫成虫在渤海海面的迁飞考察. 植物保护学报, 1998, **25**(4): 337～340.

[18] 苏建亚. 甜菜夜蛾的迁飞及在我国的发生. 昆虫知识, 1998, **35**(1): 55～57.

[19] 吴孔明,郭予元. 棉铃虫种群适合度研究. 昆虫学报, 1997, **40**(增): 7～12.

[20] 全国草地螟科研协作组. 草地螟发生、测报和防治的研究. 病虫测报, 1987, (增): 1～9.

[21] 翟保平. 也谈褐飞虱的再迁飞问题. 病虫测报, 1992, **12**(3): 36～40.

[22] 刘浩官, 刘振杰, 祝为华. 我国海上网捕褐稻虱的结果. 昆虫学报, 1983, **26**(1): 109～113.

[23] 朱明华. 黑肩绿盲蝽的迁飞观察. 昆虫知识, 1989, **26**(6): 350～353.

[24] Cook AG, Perfect TJ. The influence of immigration on population development of *Nilaparvata lugens* and *Sogatella furcifera* and its interaction with immigration by predators. *Crop Protection*, 1985, **4**(4): 423～433.

[25] Riley J R, Reynolds D R, Farrow R A. The migration of *Nilaparvata lugens* (Stål) (Delphacidae) and other *Hemiptera* associated with rice during the dry season in the Philippines: a study using radar, visual observations, aerial netting and ground trapping. *Bull. ent. Res.*, 1987, **77**: 145～169.

[26] Reynolds DR, Wilson MR. Aerial samples of micro-insects at night over central India. *J. Pl. Prot. Tropics*, 1989, **6**(2): 89～101.

[27] Mochida O, Takada H. Possible migration of aphid parasites (Hymenoptera: Aphidiidae) across the East China Sea. *Appl. Ent. Zool.*, 1978, **13**(2): 125～127.

[28] 罗瑞梧, 杨崇良, 尚佑芬, 等. 燕麦蚜茧蜂种群动态及其控蚜效能研究. 植物保护学报, 1994, **21**(2): 163～168.

[29] 李世良, 张凤海, 梁家荣, 等. 空中昆虫的航捕观察. 昆虫知识, 1986, **23**(2): 53～56.