

Seasonal Abundance of Economically Important Fruit Flies (Diptera: Tephritidae: Dacinae) in Bangladesh, in Relation to Abiotic Factors and Host Plants

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Abstract. Fruit fly monitoring traps baited with male lures (cue lure, methyl eugenol, zingerone) were maintained for two years (Nov 2016–Oct 2018) at ten sites (reduced to three on year two), in village-style subsistence agriculture environments, at the Atomic Energy Research Establishment campus, Savar, Dhaka, Bangladesh. A total of 15 species and 135,034 flies were collected, dominated by polyphagous fruit pest *Bactrocera dorsalis* (58.0% of all trapped flies), cucurbit pests *Zeugodacus cucurbitae* (23.6%) and *Z. tau* (13.5%), and non-pest *B. rubigina* (3.6%). Three other pest species, collected in much smaller numbers, were polyphagous fruit pests *B. zonata* and *B. correcta* and cucurbit pest *Dacus longicornis*. Data was used to document the seasonal abundance of the above-mentioned species, in relation to host fruit availability and abiotic factors. Seasonal abundance of *B. dorsalis*, with peaks during wet summer months, was positively correlated with rainfall ($r=0.70$), temperature ($r=0.66$) and host availability ($r=0.72$). Seasonal trends in captures of *B. zonata* and *B. rubigina* were similar to those of *B. dorsalis*. Captures of *Z. cucurbitae* peaked in March 2017, early in the rainy season, and May 2018, in the middle of the rainy summer season, with no clear correlation with rainfall, humidity, or host availability. Captures of the two other cucurbit pests were inversely related to rainfall, with abundance peaks during the dry winter months. Data on seasonal abundance of these species will be utilized in formulating an area-wide pest management strategy in the agro-ecological system under consideration.

Key words: *Bactrocera*, *Zeugodacus*, *Dacus*, *dorsalis*, *cucurbitae*, *tau*, *zonata*, male lures, trapping

Introduction

Fruit flies (Diptera: Tephritidae) are among the most serious insect pests on horticultural crops throughout the tropical and subtropical regions (Aluja et al. 1996, Armstrong and Jang 1997, Hasyim et al. 2008, Vargas et al. 2015). They lay eggs under the skin of fruits and fleshy

vegetables. As their larvae feed in the decaying fruit flesh, infested hosts quickly become rotten and inedible or drop to the ground prematurely, thus causing considerable yield losses, between 30 and 100% depending on the fruit species and season (Dhillon et al. 2005). Besides causing billions of dollars in direct losses

to a wide variety of fruit, vegetable, and flower crops, they limit the development of agriculture in many countries because of strict trade quarantines imposed to prevent their spread (Heather and Hallman 2008). All fruit flies in the tribe Dacini are frugivorous or florivorous, and about 10% of the 940 currently recognized species are pests of commercial fruits and vegetables (Fletcher 1987, White and Elson-Harris 1992, Vargas et al. 2015, Doorenweerd et al. 2018). Fruit flies in the genera *Bactrocera*, *Zeugodacus*, and *Dacus* are of particular concern throughout much of the Old-World tropics, where they constitute a significant threat to agricultural resources.

In Bangladesh, 13 pest and 16 non-pest species of dacine fruit flies have been recorded, the most destructive of which are the oriental fruit fly (*B. dorsalis* [Hendel]), melon fly (*Z. cucurbitae* [Coquillett]), pumpkin fruit fly (*Z. tau* [Walker]), peach fruit fly (*B. zonata* [Saunders]), and the recently discovered carambola fruit fly (*B. carambolae* Drew & Hancock) (Leblanc et al. 2013, 2014a, 2019). Most of these species have been detected repeatedly in survey traps in all the districts of Bangladesh, although *B. carambolae*, a recent introduction to Bangladesh as evidenced by the genetic profile of the invasive population (C. Doorenweerd, pers. comm.), is still restricted to the southeastern portion of the country (Leblanc et al. 2019). Field research on dacine fruit flies in Bangladesh has mainly focused on fruit fly diversity surveys (Leblanc et al. 2013, 2014b, 2019); surveying their damage (Kabir et al. 1991, Akhtaruzzaman et al. 1999a); developing field control for cucurbit-infesting pest species (Chowdhury et al. 1993; Akhtaruzzaman et al. 1999b; Khan et al. 2007a, b); and preliminary population cycle monitoring (Alim et al. 2012, Uddin et al. 2016).

Traditional control measures using chemical insecticides have many disad-

vantages, such as pesticide residues and the inability of the insecticides to penetrate infested fruits to kill larvae. Moreover, the public demand for insecticide-free fresh fruit has encouraged the use of environmentally friendly methods of pest control. Dacine fruit flies is a well-suited group to demonstrate how pests can be effectively controlled using minimal quantities of pesticide by integrating the use of male lures, female food-based attractants, crop sanitation, augmentative releases of parasitoids, and sterile insect releases into an area-wide control program, as was successfully implemented in Hawaii (Mau et al. 2007; Vargas et al. 2008, 2016). Before a fruit fly management program can be designed for a specific agro-ecosystem, it is necessary to generate baseline information on levels of fruit infestation and the seasonal incidence of the pest in relation to host availability and weather parameters. That information will help determine the appropriate methods of control and timing of action (Laskar and Chatterjee 2010). Monitoring fruit fly populations year-round is one of the first requirements for compiling basic information needed to formulate an effective area wide IPM program, towards sustainable agriculture in Bangladesh.

Continuous population monitoring was initiated in Dhaka in 2016, as a prelude to the development of a pilot area-wide suppression project for Bangladesh in collaboration with the FAO/IAEA Coordinated Research Project D41027, "Simultaneous Application of SIT and MAT to Enhance Pest *Bactrocera* Management." We are presenting here the results of two full years of male lure trapping for seven species of dacine fruit flies—cucurbit pests *Zeugodacus cucurbitae*, *Z. tau*, *Dacus longicornis* (Wiedemann); fruit pests *B. dorsalis*, *B. zonata*, *B. correcta* (Bezzi); and non-pest *B. rubigina*—in relation to abiotic factors (daily temperature and rainfall) and host

fruit availability, to help improve management of these fruit fly species.

Materials and Methods

The study was conducted over two full years (October 2016 to October 2018) at the Bangladesh Atomic Energy Research

Establishment (AERE) Campus (N 23.954 E 90.280), Savar, Dhaka, a 263.5-acre experimental area comprised of agricultural land, dendrarium, and concrete buildings (Fig. 1a). A diversity of fruit trees (mango, guava, banana, starfruit, citrus, sapodilla, etc.) and vegetables (including cucurbita-

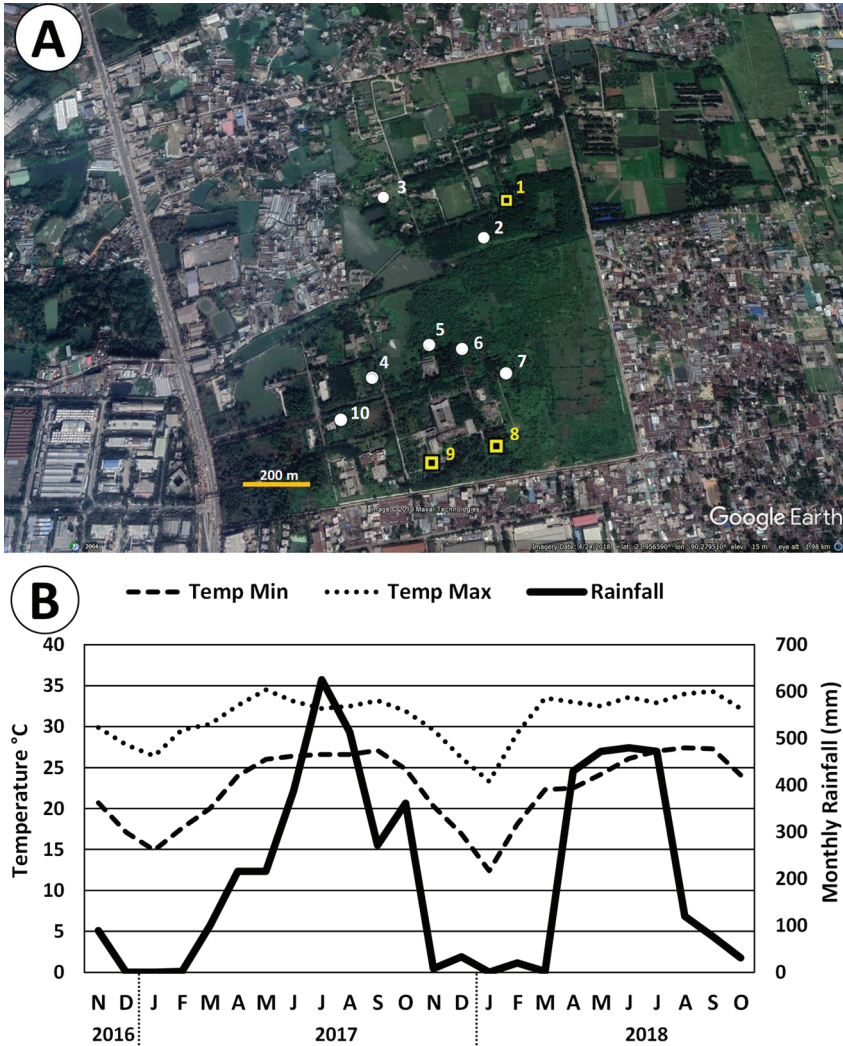


Figure 1. A: Fruit fly trapping sites maintained at the Atomic Energy Research Establishment compound in Bangladesh in 2016–2017 (sites 1 to 10) and 2017–2018 (sites 1, 8, 9). B: Mean monthly rainfall and minimum and maximum temperature recorded in Dhaka, Bangladesh, during the study period.

ceous and solanaceous hosts) are grown in village-style small gardens, rather than as commercial orchards and large gardens, which is typical of subsistence fruit and fleshy vegetable production across much of Bangladesh. The AERE campus was selected because of easy access, and all major cultivated fruit and vegetable crops grown in Bangladesh were represented and commonly infested with fruit flies.

Starting October 16, 2016, three traps baited with male lures (cue-lure, methyl eugenol, and zingerone) were maintained in trees, 1.8 m above the ground and about 10 m apart, at each of 10 sites throughout the AERE campus (Fig. 1a). The number of sites was reduced to three during the second year of monitoring (December 6, 2017 to October 31, 2018). Traps were built out of 120 ml polypropylene containers (Globe Scientific 5915 Polypropylene Specimen Container), with two 2-cm diameter circular lateral holes for fly entry, drilled just below the lid threading. For cue-lure and methyl eugenol traps, a commercially available lure plug containing 2 g of lure (Scentry Biologicals, Billings, Montana, USA) and a 10x15-mm strip containing 10% dichlorvos (2,2-dichlorovinyl dimethyl phosphate) (Vaportape® II, Hercon Environmental, Emingsville, Pennsylvania, USA) were suspended from the trap's ceiling with a hook made of tie wire. For zingerone-baited traps, the plug was replaced by a 15-mm long cotton dental wick dipped in zingerone (vanillylacetone) (Sigma-Aldrich, St. Louis, Missouri, USA) melted in a beaker over a hotplate and left to solidify in the wick. To protect captured flies from ant attack, Tangle-Trap adhesive (Tanglefoot Company, Grand Rapids, Michigan, USA) was smeared on the wire holding the traps. Plastic plates (15 cm diameter) were placed over traps to prevent trap flooding by frequent rain.

Trapped dead flies were collected

weekly and counted and identified at the fruit fly research laboratory of AERE's Insect Biotechnology Division, Institute of Food and Radiation Biology. Specimens requiring further species confirmation were sent, preserved in 95% ethanol, to taxonomist co-author LL (University of Idaho). Information on the monthly availability of host plants at the fruiting stage, recorded during year 1 of the study, was provided by Dr. Md. Zainul Abedin, a retired AERE scientist in charge of the station dendrarium. Daily temperature and rainfall data for Dhaka were provided by the Bangladesh Meteorological Department, Agargaon, Dhaka 1207, Bangladesh. Weekly trap capture data was recorded on a Microsoft Excel spreadsheet, and numbers of captured flies for each species were divided by the actual number of days past the previous trap servicing, to generate standardized flies-per-trap-per-day (FTD) data used for analysis. For each species, mean (and SE) monthly FTD was calculated using all weekly FTDs for all (3 or 10) traps. Likewise, mean daily rainfall and temperature were calculated based on the actual day intervals used to generate monthly FTD data. Fruit fly population fluctuations in relation to abiotic factors (rainfall, temperature) (Fig. 1b) and host fruit availability (number of fruiting host species available each month) were analyzed using the Pearson correlation coefficient (Table 1), based on FTD data for the three trapping sites continuously monitored over the two years.

Results and discussion

A total of 15 species and 135,034 flies were collected during the two years of trapping. The four dominant species were polyphagous fruit pest *B. dorsalis* (58.0% of all trapped flies), followed by cucurbit pests *Z. cucurbitae* (23.6%) and *Z. tau* (13.5%), and non-pest *B. rubigina* (3.6%). Three other pest species, collected in

Table 1. Correlation (Pearson) between monthly captures of seven species of fruit flies and mean monthly rainfall, temperature, and number of known hosts available at the fruiting stage for each fly species.

Year:	Rainfall			Temperature			Hosts
	1–2	1	2	1–2	1	2	1
Fly species							
<i>Bactrocera</i>							
<i>dorsalis</i>	0.70	0.89	0.47	0.66	0.63	0.72	0.72
<i>zonata</i>	0.46	0.06	0.72	0.22	0.39	0.23	0.37
<i>rubigina</i>	0.52	0.47	0.80	0.31	0.44	0.39	No data
<i>correcta</i>	–0.29	–0.59	–0.09	–0.27	–0.78	0.10	–0.57
<i>Zeugodacus</i>							
<i>cucurbitae</i>	0.11	–0.44	0.68	–0.22	–0.55	0.05	–0.30
<i>tau</i>	–0.39	–0.68	0.02	–0.64	–0.89	–0.48	–0.68
<i>Dacus</i>							
<i>longicornis</i>	–0.38	–0.37	–0.52	–0.32	–0.35	–0.35	0.19

much smaller numbers, were polyphagous fruit pests *B. zonata* (650 specimens) and *B. correcta* (89 specimens) and cucurbit pest *D. longicornis* (532 specimens). Other species collected in small numbers and not included on graphs were *B. nigrifacia* Zhang, Chi & Chen (203 specimens), *Z. diversus* (Coquillett) (176), *B. abbreviata* (Hardy) (62), *B. digressa* Radhakrishnan (46), *B. syzygii* White & Tsuruta (16), *B. nigrofemoralis* White & Tsuruta (11), *B. propinqua* (Hardy & Adachi) (5), and *B. tuberculata* (Bezzi) (3).

Seasonal host fruit availability, documented during the first year of trapping, showed that a diversity of host fruits and vegetables were commonly available at the fruiting stage throughout the year at AERE (Figs. 2–5). Although not quantified, fruits from cultivated trees were available in largest quantities during the in hot rainy season (May–August) and rather scarce during the cooler, drier season (November–February). Likewise, wild hosts were mainly observed fruiting during the hot summer months. Host fruit availability is well known to be the main

driver of seasonal abundance of fruit flies (Drew and Hooper 1983; Vargas et al. 1983a, b; Drew et al. 1984; Leblanc et al. 2014a).

Seasonal abundance was positively correlated with rainfall, temperature, and host availability for most of the fruit-infesting species, and especially for *B. dorsalis* (Figs. 2–3, Table 1). The very high captures of *B. dorsalis* in methyl eugenol traps at AERE and its consistent peaks of abundance during the wet season or summer months (Fig. 2a) were consistent with those documented in studies in Chapai Nawabganj, Bangladesh (Uddin et al. 2016), Hawaii (Vargas et al. 1983b, 1989, 1990; Leblanc et al. 2014a), Kunming, China (Ye and Liu 2005), and India (Gupta and Bhatia 2000). By May in Bangladesh, most of the gutti (non-grafted plant) varieties had matured, and fly populations started increasing. Between June and August, at the peak of the monsoon season, most of the mangoes and guavas, major hosts to oriental fruit fly, were ready to harvest, and flies were correspondingly most abundant. Past that

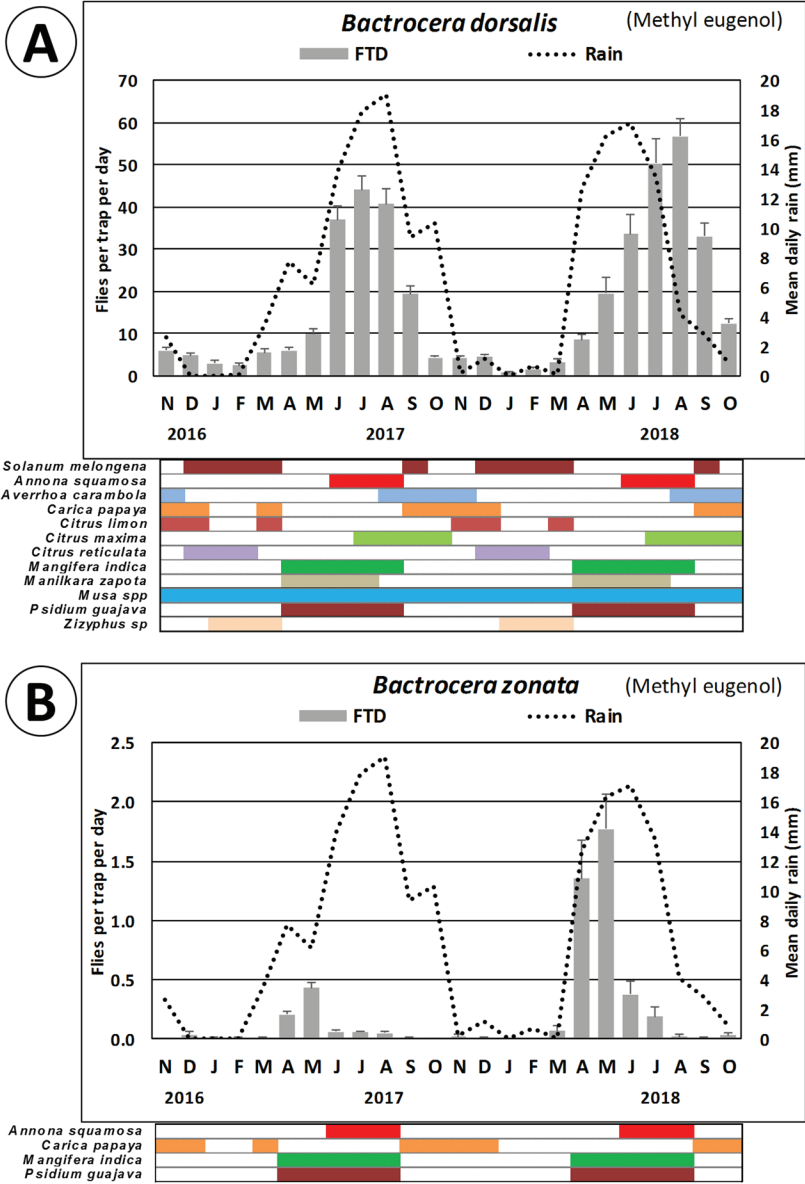


Figure 2. Distribution and mean monthly trap captures of *Bactrocera dorsalis* (A) and *B. zonata* (B), in relation with abiotic factors and host fruit availability.

peak, populations declined slowly and remained low until May the following year. Although trapped in much lower numbers, seasonal trends in captures of *B.*

zonata at AERE were similar to those of *B. dorsalis*, with slightly earlier peaks in the wet season (Fig. 2b) and strongly correlated with rain in year 2 (Table 1), again

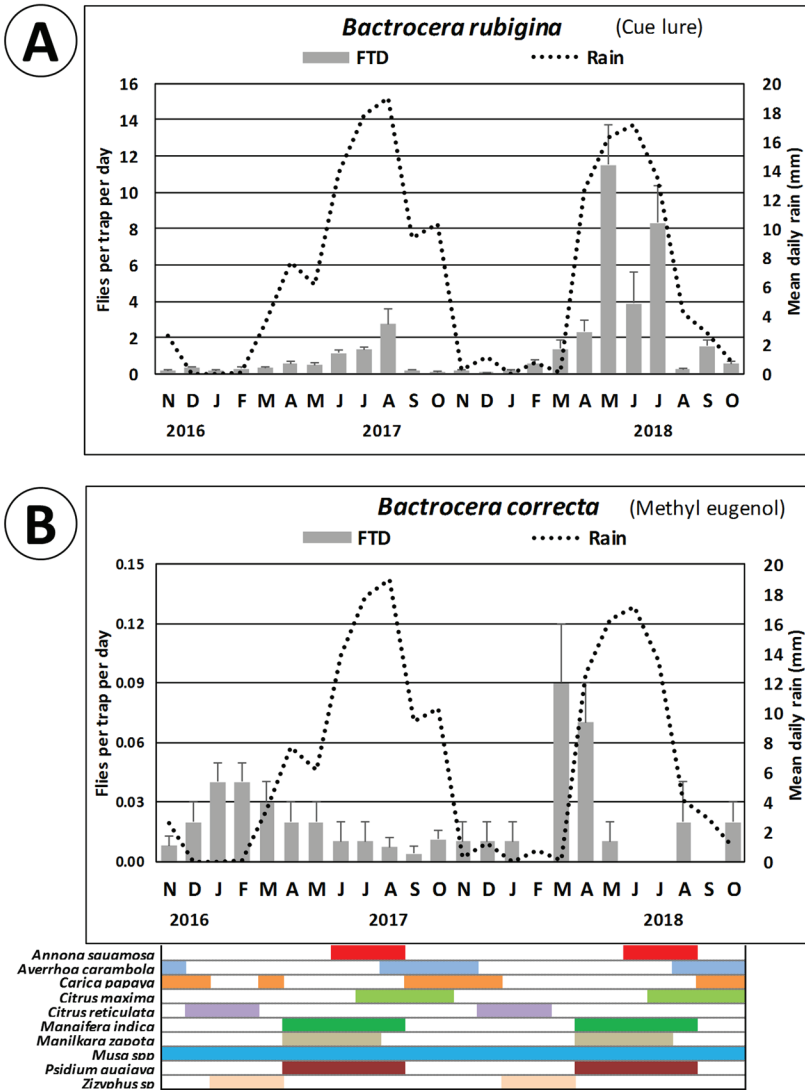


Figure 3. Distribution and mean monthly trap captures of *Bactrocera rubigina* (A) and *B. correcta* (B), in relation with abiotic factors.

within the main period of availability of two of its prime hosts: guava and mango. These are consistent with seasonal trends documented, under higher population levels, in Bangladesh (Hossain et al. 2017), India (Agarwal et al. 1999), Pakistan (Mahmood et al. 2002), and Egypt (Ali

et al. 2011, Draz et al. 2016). Seasonal peaks in abundance were also positively correlated with rainfall and temperature for *B. rubigina* (Fig. 3a), a non-pest first recorded in 2013 in Bangladesh (Leblanc et al. 2013). Despite being widespread and common in Bangladesh and throughout

tropical Asia, its main host plant, likely different from the less widespread *Litsea verticillata* host recorded in China (Liang et al. 1993), has yet to be determined. We suspect it may breed on flowers of Melastomataceae, as do two very closely related species (Leblanc et al. 2015). *Bactrocera correcta* is a much less common pest species in Bangladesh, reported for the first time in 2014 (Leblanc et al. 2014a), and associated with localized patches of cultivated host fruit such as mango, guava, and sapodilla (Kapoor 1993). Its numbers in traps were not high enough to infer on seasonal abundance (Fig. 3b) or interpret the apparently negative correlations to all factors (Table 1), but it likely peaks during the summer months in areas where it is more common.

With fruiting cucurbit hosts available throughout the year, captures of *Z. cucurbitae*, the second most abundant species at AERE, peaked in March 2017, early in the rainy season, and May 2018, in the middle of the rainy summer season (Fig. 4a). Both years, populations declined during the tail end of the rainy season. Because of the marked difference in abundance peak seasons, we could not detect a clear correlation with abiotic factors or host availability. Nonetheless, summer population peaks for melon fly were largely consistent with those reported in literature in Hawaii (Harris et al. 1986; Vargas et al. 1989, 1990; Leblanc et al. 2014a), West Bengal, India (Laskar and Chatterjee 2010), and Bangladesh (Alim et al. 2012).

Captures of the two other cucurbit-infesting species, *Z. tau* (Fig. 4b) and *D. longicornis* (Fig. 5), on the other hand, were inversely related to rainfall and temperature (Table 1), with abundance peaks during the dry and cooler winter months. Higher captures of *Z. tau* in December and its scarcity during rainy months at AERE contradict findings in Sumatra by Hasyim et al. (2008). Abundance of these spe-

cies at AERE may be driven by a locally dominant cucurbit host, possibly pumpkin (*Cucurbita maxima*) for *Z. tau* (Fig. 4b) and *Luffa* gourds for *D. longicornis* (Fig. 5). Systematic host fruit surveys will be required to confirm this hypothesis.

In Bangladesh, calendar pesticide sprays, routinely used on crops to control fruit fly infestations, have been implicated in the reduction of natural enemies and, in some cases, secondary pest outbreaks. In addition, many pesticides used on non-traditional specialty fruit crops are not registered for such specific use. Abuse and misuse of pesticides have renewed concerns regarding food safety and groundwater quality in many parts of the world. Because of the complexity of agroecosystems in Bangladesh and the pest complexes that can occur on each crop, area-wide pest management (AWPM) approaches to fruit fly suppression are proposed as an alternative to the current practices. AWPM is a long-term campaign against a pest population throughout a sizeable geographic area, with the objective of reducing it to a non-economic status (Lindquist 2000). For fruit flies, it integrates available pest control technologies—field sanitation, protein bait application techniques as sprays or in traps, male annihilation techniques using male lures, and sterile fly and parasitoid releases—into a comprehensive management package that can be economically viable, environmentally safe, and sustainable (Vargas et al. 2008, 2016).

Pest management programs using eco-friendly methods have been proposed for Bangladesh on many occasions. However, demonstration of SIT releases against blowfly conducted in Cox's Bazar in the early 2000s (Islam et al. 2017) identified several problems associated with the control technology available at that time. These included the high economic cost of large-area programs, insufficient informa-

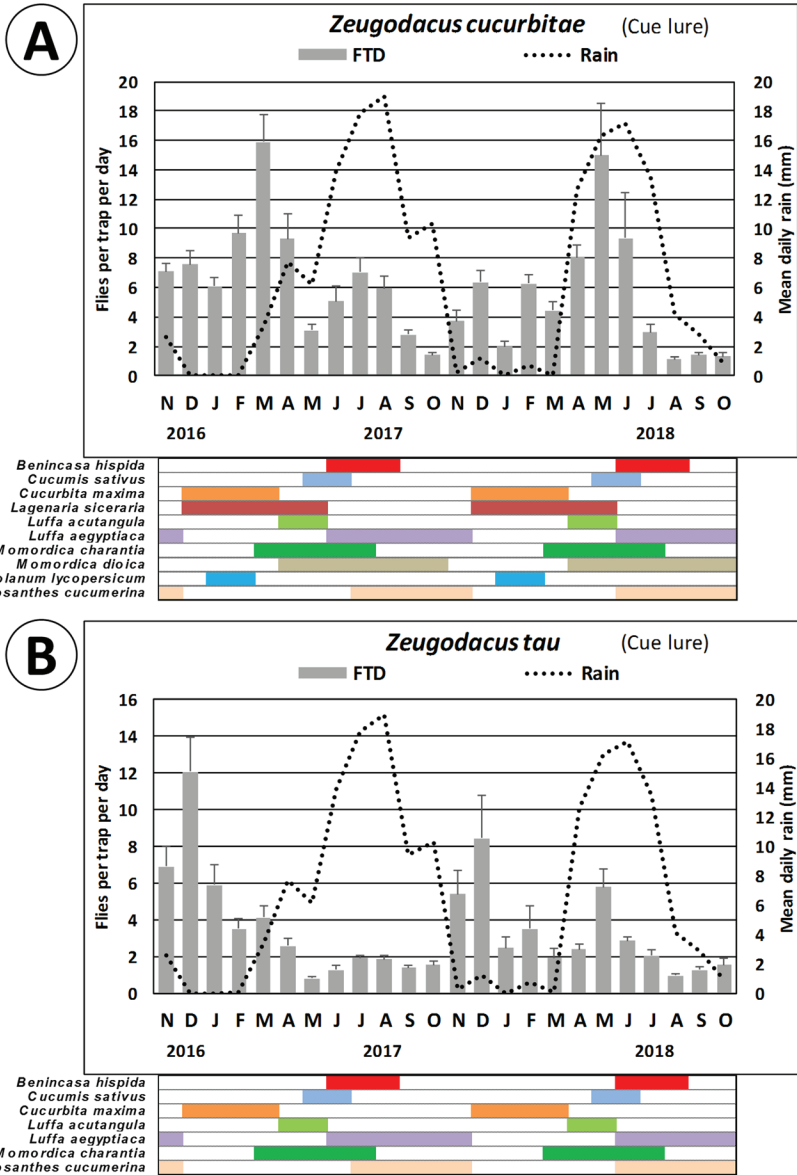


Figure 4. Distribution and mean monthly trap captures of *Zeugodacus cucurbitae* (A) and *Z. tau* (B), in relation with abiotic factors and host fruit availability.

tion on the effects upon non-target fauna, environmental concerns, quarantine issues, and the lack of a large-scale sterile fly-rearing facility. Successful fruit fly

AWPM for Bangladesh will require a continuous application of control measures over a large area, barriers to prevent immigration of flies from surrounding

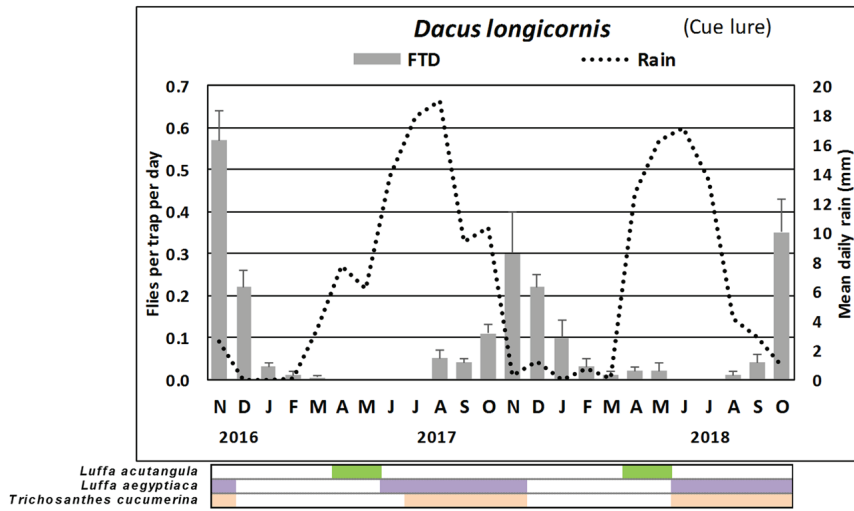


Figure 5. Distribution and mean monthly trap captures of *Dacus longicornis*, in relation with abiotic factors and host fruit availability.

areas (Cohen and Yuval 2000), strict crop sanitation, and effective grower education (Mau et al. 2017). It is best suited for large-scale commercial farmers who can invest labor and resources for pest control. Although scientists in Bangladesh have developed most of the technologies over the years to combat accidental fruit fly outbreaks, the technologies were never packaged and transferred to Bangladeshi farmers. The current pilot program, under care of AERE, is designed to demonstrate that area-wide control targeting multiple species can be achieved on the AERE compound. Mass rearing of melon fly and its parasitoid *Psytalia fletcheri* (Silvestri) (Hymenoptera: Braconidae) is being developed at AERE for sterile fly and augmentative parasitoid releases. These will be most effective if the overall population is first reduced, through male annihilation and crop sanitation, and releases are initiated during periods of lowest fly populations, which are determined by monitoring through trapping. Although trapping is a convenient tool to

monitor population cycles and the impact of control measures, regular sampling of fruit, starting before control is initiated, will be required to generate baseline data on levels of infestation and economic losses and document the actual impact of the area-wide control pilot exercise. Along with melon fly, oriental fruit fly should also be targeted in the exercise through male annihilation, female food attractants, crop sanitation, and fruit bagging. Over the long term, these technologies can be transferred, in collaboration with the Bangladesh Department of Agricultural Extension, to Bangladesh farmers and inhabitants, focusing on such relatively low-cost options as crop sanitation, male annihilation, and fruit bagging. It will promote the production of a greater diversity of higher-quality crops while reducing the use of organophosphate and carbamate insecticides, thus balancing the ecological, social, and economic aspects of farming in a move toward sustainability for local consumption and possible niche export markets.

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