Patterns in Appearance and Fruit Host Utilization of Fruit Flies (Diptera: Tephritidae) on the Kalaupapa Peninsula, Molokai, Hawaii

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Abstract. Distribution and population characteristics of tephritid flies, namely, solanaceous fruit fly, *Bactrocera latifrons* Hendel, oriental fruit fly, *B. dorsalis* (Hendel), melon fly, *B. cucurbitae* (Coquillet), and Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) were monitored with male lure traps on Kalaupapa peninsula on the island of Molokai. Likewise, fruits were inventoried and sampled to augment trap data and generate information on the spatial patterns of fruiting phenology and fruit utilization among fruit flies. In 1991–1992 and 1995, trap catches indicated that *B. dorsalis* and *B. cucurbitae* had similar seasonal population trends and were caught in highest density in residential and wild guava areas. However, the mean catch/trap/day for *B. dorsalis* (654 ± 493.73) was ca. 40-fold higher than *B. cucurbitae* (31.4 ± 15.28). Only 1 *C. capitata* was caught in a coffee tree, *Coffea arabica* L., in Kalaupapa Settlement on December 12, 1995. Although, *B. latifrons* was never caught in male lure traps baited with latilure, fly presence was detected in fruit collections. For the first time in Kalaupapa settlement, we report infestations of *B. latifrons* in sodom apple, *Solanum sodomeum* L., lei kikania, *S. aculeatissium* Jacq., cherry tomato, *Lycopersicum esculeatissium* Miller and coffee, *Coffea arabica* L. Fruit sampling proved to be a sensitive tool to survey for fruit flies, particularly, *B. latifrons*, as well as a reliable indicator to characterize fruit host sharing among the four fruit fly species. Niche biology and ecology of *B. latifrons* is discussed in relation to other tephritid fruit flies on the Kalaupapa peninsula.

Key words: *Bactrocera dorsalis, B. cucurbitae, B. latifrons,* distribution ecology, host utilization, habitat sharing

Introduction

The fruit fly complex in Hawaii consists of the oriental fruit fly, *Bactrocera dorsalis* (Hendel)(van Zwaluwenberg 1947),(Christenson and Foote 1960), the melon fly, *B. cucurbitae* Coquillet (Clark 1898), the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), (Back and Pemberton 1918)and the solanaceous fruit fly, *B. latifrons* Hendel (Vargas and Nishida 1985). These fruit flies have deterred crop production in Hawaii. Polyphagous in feeding habits, fruit fly larvae infest a wide variety of fruits and vegetables which results in spoilage of marketable produce. Moreover, stringent quarantine restrictions are levied on Hawaiian produce in order to safeguard accidental introductions of fruit flies into the continental U.S.

Fruit flies are resilient pests with typical ecological adaptiveness. They may differ in distribution patterns and host utilization preferences but most species can survive, with some degree of flexibility, in a wide range of habitats with varying environmental conditions (Harris and Lee 1982, Vargas 1994). Fruit flies can travel over short distances to feed and breed or they can disperse passively over long distances with the aid of wind currents into new sites where colonization occurs. At times, however, their movement or migration is hampered by the presence of physical or ecological barriers.

Hawaii is completely isolated in the Pacific Ocean. The irregular terrain and mountain ranges (of volcanic origin) that characterize each island provide isolation and unique habitats for fruit flies. We postulated that Kalaupapa peninsula in Molokai typifies such a habitat where populations of fruit flies, restricted and confined by physical barriers, are well entrenched and established. However, the ecology of fruit flies in Kalaupapa has neither been investigated nor any information published on their adaptive biology or ecology. This study investigated patterns in appearance, abundance and fruit host utilization of fruit flies in Kalaupapa in relation to physical geography, host fruiting phenology, weather, and climatic effects on the Kalaupapa peninsula from May 1991 to December 1992 and July to December 1995.

East Molokai, located near the center of the north coast of the island, includes the low coastal Kalauapapa peninsula which is 457–762 m. below the windward cliffs (Fig. 1). At the highest point, this peninsula (2,500 acres) is bounded by southwestern rim of the extinct Kauhako crater. From its rim, the land slopes down in all directions. The peninsula has a windward and leeward side with median rainfall of < 63–127 cm per year (Baker *et al.* 1968). There is great variation in rainfall in this small area because of the windward location and location at the base of the high cliff along the north coast of east Molokai. The natural vegetation (sparse grass and shrub cover) includes: lantana, *Lantana camara* L.; guava, *Psidium guajava* L.; ekoa, *Leucaena glauca* (L.) Benth.; cacti, *Ferocactus wislizenii* (Engelm.); kukui nut, *Aleurites moluccana* (L.) Willd.; eucalyptus, *Eucalyptus robusta* Sm.; and sandalwood, *Santalum ellipticum* Gaud. In abandoned widely dispersed residential sites false kamani, *Terminala cattapa* L. and Tamarind, *Tamarindus indica* L. exist. In the Kalaupapa settlement residential area, vegetable gardens and fruit trees are grown.

The overland entrance to Kalaupapa is via a mule trail (Fig. 1) along the pali coast from the upland side of East Molokai or by airline service to the airport on the windward tip of the peninsula. On the leeward side of the peninsula, is the Kalaupapa settlement where maintenance shops, dining hall, hospital (for Hansen Disease patients), residential, and administration facilities are located. The peninsula was formerly a Hansen Disease colony under the administration of the Hawaii Department of Health. Special permission from the Department of Health is required to enter the settlement. In December 22, 1980 the peninsula became a part of the Kalaupapa Historical Park which includes north shore valleys and cliffs.

Methods and Materials

Trapping. From May 1991 to December 1992, an intensive trap survey was conducted. Details about the trap sites and host plant distribution are shown in Fig 1. A total of 35 trap sites were used with 4 plastic traps per site of the cylindrical type used by Hafraoui *et al. (*1980). Each trap contained a cotton wick (1.3 x 3.8 cm). saturated with either 3–5 ml latilure, methyl eugenol, cue-lure, or trimedlure including 5% naled toxicant to catch *B. latifrons*, *B. dorsalis*, *B. cucurbitae*, and *C. capitata*, respectively. Four temporary trap sites were added in 1991–1992 in feral coffee to monitor medfly. From June to December 1995, using the 1991–1992 sites, medfly traps were located in the settlement and guava areas and four at new sites on the mule trail. The same male lures and dosages of lure per trap used in 1991–1992 were used in 1995 except no traps were used to catch the solanaceous fruit fly. Follow up studies were conducted from July to December 1995 to determine if medfly had migrated into Kalaupapa from the coffee orchards in Kualapuu and the effect of phenology changes on host fruit utilization by fruit flies. The traps were distributed as shown in Fig. 1.

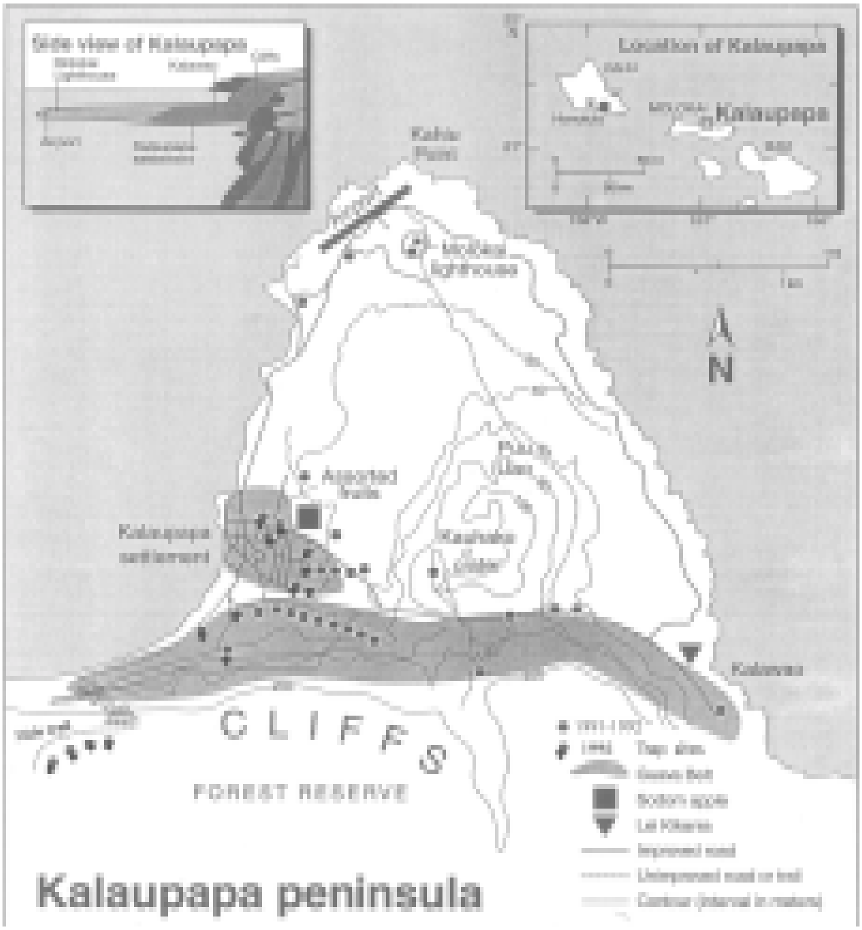

Figure 1. Map of Kalaupapa peninsula showing the location and distribution of tephritid fruit fly traps, and sites where fruits were collected.

The traps were serviced monthly to collect fly catches and replenish the lures and replace missing traps. The traps were located in residential, upland coffee, upland and lowland guava areas. These areas included various habitats and elevational gradients ranging from 15 to 137 m.

Fruit collecting. Fruit samples were collected monthly when available from all over the peninsula. The fruits collected were transported by airplane to Honolulu and set up in our laboratory. The fruit samples were counted, weighed and placed in fruit holding boxes containing sand. Ten percent of some of the fruit samples were held individually in plastic bags until emergence was completed. The sand in the holding boxes and the plastic bags were screened weekly for 3–4 weeks to remove pupae. The pupae were held in glass jars until emergence was completed and the numbers of adult flies and parasitoids recorded. The distribution of tree and vegetable fruits grown in Kalaupapa settlement were recorded to evaluate the autecology of the tephritid fruit flies.

Data analysis. Fruit flies were removed from traps monthly and counted. Trap catches were expressed as mean (± STDERR) number of flies per trap per day. Trap catch means were transformed using ln (x + 1) transformation. Variation among trap sites and months during our study was evaluated by General Linear Model(GLM) analysis of variance (SAS Institute 1993). Trap means were combined into two groups consisting of fruit fly species and yearly trap catch.

Results

Flies trapped. Trap captures are summarized in Fig. 2. In 1991–1992, trap captures of *B. dorsalis* and *B. cucurbitae* showed that the flies were concentrated in the Kalaupapa residential area and the guava belt below the cliff where rainfall was highest and the habitat was most stable. Trap catches at the airport and the light house were lowest among all the traps. Few hosts were present in the sites that were exposed to the trade winds. *B. dorsalis* was the most abundant and widely distributed fruit fly species in the Kalaupapa peninsula in 1991–1992. It was caught in every methyl eugenol trap (in large or small numbers). Peak abundance of *B. dorsalis* occurred in May 1991 followed by a decline to a low level in February 1992. In 1992, *B. dorsalis* reached a peak in March then declined from April to June. Smaller peaks occurred in July and October–November. Overall, the trap catches for *B. dorsalis* were significantly higher ($F = 424.16$; $P < 0.001$) than the trap catches for *B. cucurbitae.*

B. cucurbitae trap catches showed similar cyclic trends as those of *B. dorsalis* except that numbers trapped were very low. In March 1991 (Fig. 3) over 20.32 cm of rain fell contributing to the production of a good guava crop which had a positive influence on *B. dorsalis* population trends. No fruit flies were caught in the *C. capitata* or *B. latifrons* traps in 1991–1992. In 1995 during the months of June to September there was a drought (Fig. 3) which caused a decline in guava fruit production and fruit flies in Kalaupapa peninsula. In the fall of 1995, melon fly trap catches were higher than the oriental fruit fly. *B. cucurbitae* population trends were influenced by fruit and vegetable crops grown in the Kalaupapa settlement.

In the fall season of 1995, the 500 acre crop of coffee in Kualapuu, in central Molokai, came into production for the first time. On December 12, 1995, one *C. capitata* was caught in Kalaupapa settlement in a coffee tree. Thirty-seven *C. capitata* were caught in four traps at the top of the cliff over-looking Kalaupapa at the beginning of the mule trail.

Host fruits and fruit utilization on the peninsula. Table 1 shows a summary of the results of infested fruit collections made in Kalaupapa peninsula. For the first time in Kalaupapa Hawaii, *B. latifrons* was found infesting lei kikania, *Solanum aculeatissimum,* (Jacq.), sodom apple, *S. sodomeum* L. and cherry tomato, *Lycopersicon lycopersicum* cv *cerasitorme* (Dunal), (Hawaii Ent. Soc. Newsletter 1991). Ninety-three percent of the 339 *B. latifrons* reared from fruit came from sodom apple. Thus, *B. latifrons* alone utilized sodom apple except for two collections (with 5 *B. cucurbitae* and 11 *B. dorsalis*). *B. latifrons* and *B. cucurbitae* infested lei kikania in low numbers. *B. cucurbitae* alone infested bittermelon, *Momordica charantia* L. and *B. dorsalis* alone infested guava. Each of the flies utilized separate niches. *B. dorsalis, B. cucurbitae, and B. latifrons* infested cherry tomato thus sharing this larval resource. *B. dorsalis* was the primary user of coffee with *B. cucurbitae, and B. latifrons* infesting this fruit once, a new host record. *B. dorsalis* was the primary user of Haden mango, *Mangifera indica* L. Pepper,*S. nigrum* L. eggplant, *Solanum melongena* L. and squash, *Cucurbita pepo* L. preferred hosts of *B. latifrons* (Harris *et al*. unpublished data) were not infested. Fruit sampling proved to be a sensitive tool to survey for fruit flies, particularly, *B. latifrons,* as well as a reliable indicator to characterize fruit host sharing among the four fruit fly species.

Parasitoids reared. Forty two parasitoids were recovered from Kalaupapa fruits. Among

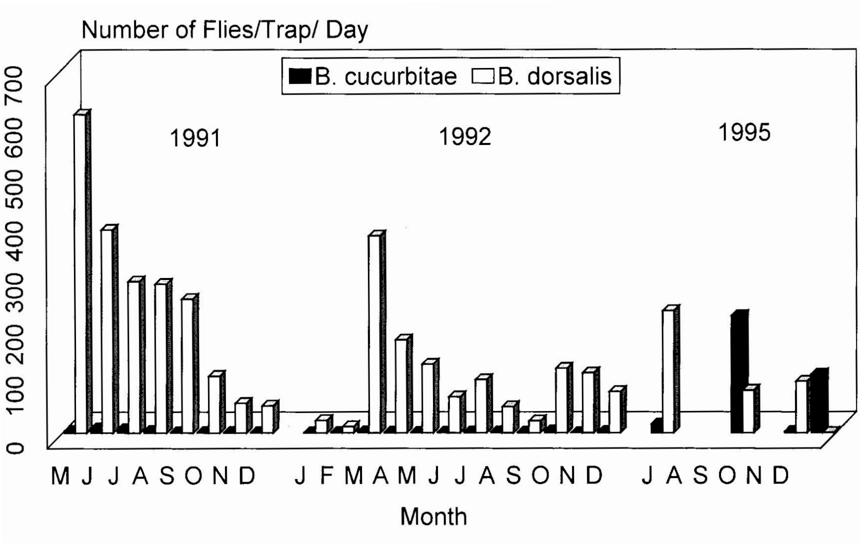

Figure 2. Population trends of *B. dorsalis* and *B. cucurbitae* as shown by male lure trap captures (May 1991–December 1992) and (June 1995 –January 1996).

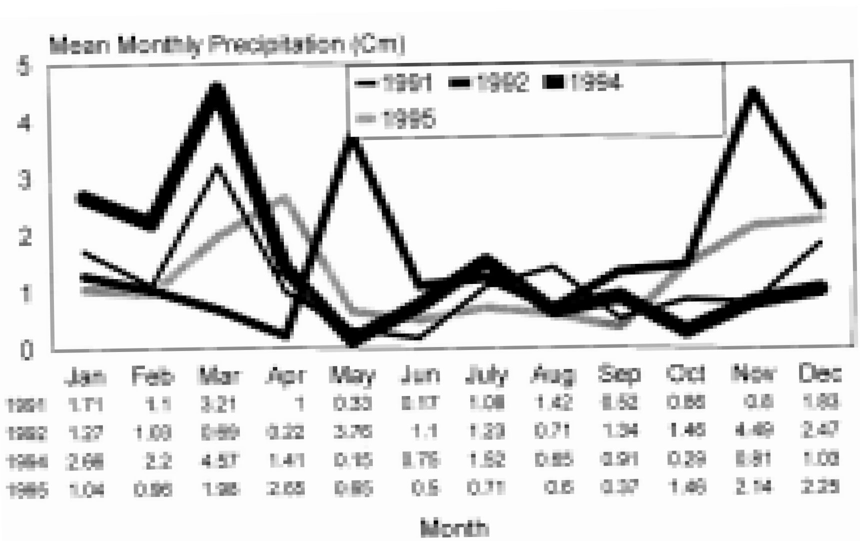

Figure 3. Monthly mean (cm) rainfall in Kalaupapa during 1991–1992 and 1994–1995.

these *F. (=Biosteres) africanus* (Sonan) (=*Opius oophilus* Fullaway) was the dominant species. *Diachasimorpha longicaudata* (Ashmead), was recovered in smaller numbers.

Overlap in host utilization. The data in Table 2 summarizes information on overlap in host utilization by three tephritid fruit fly species (*B. cucurbitae*, *B. dorsalis* and *B. latifrons*)

Table 1. Summary by fruit or vegetable variety, scientific name, number of fruits, fruit weight, number of pupae, number dead, number of parasitoids emerged, number of emerged flies of each of 4 fruit fly species and number/kg collected in Kalaupapa, Molokai.

						No. emerged				
Fruit or vegetable var.	**Fruit no.**	**Fruit wt. (kg)**	**No. pupae**	**No. dead**	**No. parasites**	***C. capitata***	***B. cucurbitae***	***B. dorsalis***	***B. latifrons***	**No./kg fruit[1]**
1991–1992										
Bittermelon *Momordica charantia* L.	65	1.79	69	21	1	0	48	0	0	26.81
Cherry tomatoes *Lycopersicum esculeatissium* Miller	250	4.11	107	40	0	0	32	33	2	7.8, 8.02, 0.49
Coffee *Coffea arabica* L.	1062	3.01	42	21	3	0	1	16	1	0.33, 5.93, 0.33
Eggplant *Solanum melongena* L.	19	3.28	0	0	0	0	0	0	0	0
False kamani *Terminalia catappa* L.	209	4.36	62	20	16	0	2	24	0	0.46, 5.5
Guava *Psidium guajava* L.	31	1.09	46	20	19	0	0	14	0	12.84
Japanese squash *Cucurbita pepo* L.	1	1.48	0	0	0	0	0	0	0	0
Lei kikania *S. aculeatissium* Jacq.	2575	23.16	10	1	0	0	18	0	9	0.33, 0.39

Pepper *S. nigrum* L.	11	1.2	2	2	2	0	0	0	0	0
Pumpkin *Cucurbita pepo* L.	2	0.59	0	0	0	0	0	0	0	0
Sodom apple *Solanum sodomeum* L.	7427	192.14	438	107	1	0	5	0	322	0.03, 1.68
Tangerine *Citrus nobilis* Lour. var. *deliciosa* (Ten) Swingle	2	2.09	0	0	0	0	0	0	0	0
1995										
Bittermelon	2	0.3	1	0	0	0	1	0	0	0
Cherry tomatoes	36	1.05	73	63	0	0	9	0	4	0.8, 3.81
Coffee	69	1.78	0	0	0	0	0	0	0	0
False kamani	109	1.94	0	0	43	0	0	75	0	38.66
Guava	10	0	0	0	0	0	0	0	0	0
Haden mango *Mangifera indica* L.	23	6.49	171	34	4	0	0	171	0	26.35
Mountain apple *Syzygium malaccense*	48	2.87	2	0	0	0	0	0	0	0
Sodom apple	130	2.28	80	58	5	0	0	11	1	4.82, 0.44

[1]By fruit fly species.

in the Kalaupapa peninsula. *B. cucurbitae* utilized seven, *B. dorsalis* six, and *B. latifrons* four species of host fruits. It is evident that overlap in host utilization is common. For example Sodom apple, Cherry tomato, and coffee were hosts shared by 3 species of fruit flies (*B. cucurbitae*, *B. dorsalis*, and *B. latifrons*) while guava, bittermelon, and mango was utilized by one species, respectively, *B. dorsalis,* or *B. cucurbitae*. Thus niche overlap in fruit fly utilization of five fruits (Sodom apple, lei Kikania, cherry tomato, false kamani, and coffee) is essential for fruit fly survival in the small peninsula.

Discussion

Our studies suggest that fruits grown in the Kalaupapa peninsula were low in numbers confined to a small area. Two settlement residents grew vegetables. All of the vegetable fruits infested were collected in one garden. All infested coffee was obtained from one residence. Fewer than 52 fruit trees were counted in Kalaupapa settlement consisting of citrus, mango, guava, mock orange, avocado, papaya, and banana. Feral guava was abundant in a belt below the topside cliff in the forest reserve. The large area located near the shoreline with grass and shrub cover was arid with few host plants. The tephritid fruit flies were adapted to the fruiting phenology of the host plants. Sodom apple and lei kikania were found on the peninsula < 8 Km apart in different climatic zones. *B. latifrons* showed more host specificity, by utilization of solanaceous fruits, more than the other fruit fly species. *B. dorsalis* and *B. cucurbitae* were less discriminating in host specificity utilizing more of the available ripe fruits. The abundance of *B. dorsalis, B. cucurbitae,* and *B. latifrons* was strongly correlated with host fruiting phenology. Of the 13 varieties of fruits collected, three were not infested. Of the 10 varieties of fruits infested, eight varieties shared larval resources with 2 or 3 of the fruit fly species. *B. dorsalis* was reared from coffee in the residential settlement area but not from upland coffee below the cliff in Kalaupapa. There is a resident population of *C. capitata* in the < 500 acre coffee plantation in Kaulapuu, Molokai which was not fruiting in 1991–1992. In December 1995, *C. capitata* populations increased to a high level and some moved (by assistance of the wind) from Kaulapuu coffee orchards to Kalaupapa. Whether or not they will become established in Kalaupapa remains to be seen. The rearing of *B. latifrons* from coffee and *B. cucurbitae* from false kamani is rare, but shows that the flies are capable of utilizing these fruits in times of host scarcity. The most abundant host was guava which produced the largest host fruit biomass in 1991–92. Yet we observed only a few ripe guavas that had fallen on the ground under guava trees. This was because the fruits were eaten by feral pigs and deer. In 1995, due to a drought in Kalaupapa, guava fruits dried up on many trees before they ripened. Because of the isolated small area of the peninsula created by cliffs, the flies could not move to more favorable habitats as they do in the coastal plain area of Honolulu, Oahu (Harris and Lee 1982), upland and lowland areas on Kauai (Harris et al 1993), and other areas in the islands (Vargas and Nishida 1985).

Vargas (1994) conducted a fruit fly survey on the island of Niihau Hawaii. He encountered a similar climate, and vegetation on Niihau that we found on Kalaupapa peninsula. Vargas captured *B. cucurbitae, B. dorsalis* and *C. capitata* in his male lure traps but no *B. latifrons.* He reared *B. dorsalis* and *C. capitata* from coffee and mango and only *B. cucurbitae* from Teasal gourd. No *B. latifrons* were recovered on Niihau even though *B. latifrons* is found on Kauai upwind of Niihau. The breeding populations of fruit flies in Kalaupapa and Niihau have similar behaviors and autecology but what is novel is the flies will infest available fruits whether they have infested them before or not.

Liquido *et al.* 1994 reported 40 collections of lei kikania recovered from upland central Molokai. From a total of 2,940 fruit samples, nine adult *B. latifrons* were recovered. In our study on the peninsula, we collected 2,575 lei kikania fruit samples. Nine *B. latifrons* and

Table 2. Overlap in host plant utilization by *B. cucurbita, B. dorsalis,* and *B. latifrons* in Kalaupapa, peninsula, Molokai. *C. capitata* was not found in any collected fruit.

	Host tephritid fruit fly species			Number of fly/species/ host species
Fruit	***B. cucurbitae***	***B. dorsalis***	***B. latifrons***	
1991–1992				
Bittermelon	X	-	-	1
Cherry tomato	X	X	X	3
Coffee	X	X	X	3
False kamani	X	X	-	2
Guava	-	X	-	1
Sodom apple	X	-	X	2
1995				
Bittermelon	X	-	-	1
Cherry tomato	X	-	X	2
False kamani	-	X	-	1
Lei kikania	X	-	X	2
Haden Mango	-	X	-	1
Sodom apple	-	X	X	2

eighteen *B. cucurbitae* were recovered. These data compare very well with a fruit collection we made in upland central Molokai. From 20 cucumbers and 145 tomato fruits 21 *B. latifrons* and 11 *B. cucurbitae*, respectively, were recovered. Our conclusion from these studies is that the utilization of more than one species of host plant is an advantage to a fly species because it can survive on alternative hosts when one becomes scarce. Tephritid flies routinely adapt to many different host plants and habitats that we do not see very often because we seldom investigate this phenomenon in the right places and at the right times.

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