Trapping Records of Fruit Fly Pest Species (Diptera: Tephritidae) on Oahu (Hawaiian Islands): Analysis of Spatial Population Trends

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Abstract. Fruit fly monitoring traps with male lures (cue-lure, methyl eugenol, trimedlure, latilure) and food lure (torula yeast and BioLure) were maintained on the island of Oahu for three years (2006–2008) at 40 sites, characterized as rural or residential, with or without agriculture or feral forest in proximity. The 1.7 million flies collected belonged to species already known to be established in Hawaii (*Bactrocera cucurbitae*, *B. dorsalis*, *B. latifrons*, and *Ceratitis capitata*); no new invasive species were trapped, though the remotely possible presence of sibling species nearly identical to *B. dorsalis* can't be ruled out. *B. cucurbitae* was predominant in leeward western Oahu and most abundant, in both rural and residential areas, wherever agriculture was practiced nearby. *B. dorsalis* was trapped in highest numbers in the windward northeastern portion of Oahu, and the presence of adjacent forest increased captures in both residential and rural environments. *C. capitata* was trapped in very large numbers at a coffee farm in Waialua and was rare at all other sites.

Key words: *Bactrocera*, *capitata*, *Ceratitis*, *cucurbitae*, *dorsalis*, food lures, *latifrons*, male lures, trapping

Introduction

Four species of exotic pest fruit flies (Tephritidae) have invaded Hawaii: the melon fly, *Bactrocera cucurbitae* (Coquillett) (first detected in 1895), Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (1907), Oriental fruit fly, *B. dorsalis* (Hendel) (1946), and Malaysian fruit fly, *B. latifrons* (Hendel) (1983). Together they cause extensive damage to crops in Hawaii and constitute a reservoir for potential introductions to the United States mainland and other Pacific Islands (Vargas et al. 2007). Hawaii is vulnerable to possible invasions of additional pest fruit fly species from the Asia-Pacific region, where 68 species of *Bactrocera* are known to infest commercial/edible fruits and vegetables (http://www.herbarium.hawaii.edu/fruitfly/index.php).

Networks of traps have been in place for decades to detect fruit fly incursions in California, Texas, and Florida (IPRFFP 2006). As described below, a trapping system has recently been established on Oahu, Hawaii, to confirm that the four established pest species are the only ones that occur on Oahu, and to implement a permanent early detection system for new invasive fruit fly species. Here we present the results of the Oahu tephritid fruit fly trapping survey conducted between 2006 and 2008. Using this data, we have compared fruit fly abundance in differ-

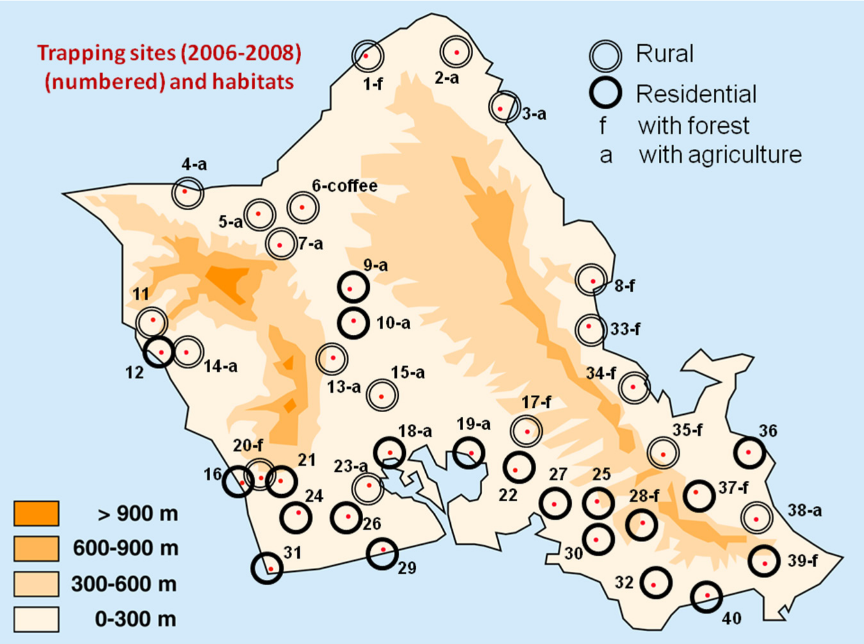


Figure 1. Map of trapping sites on Oahu (2006–2008), with habitat at each site.

ent habitats and optimal trap position to maximize fruit fly captures and increase the detection rate of exotic fruit- and vegetable-infesting flies.

Materials and Methods

Traps were maintained for three years (January 11, 2006 to November 25, 2008) at 40 sites on Oahu (Fig. 1) in a diversity of residential and rural environments at altitudes ranging from sea level to 510 meters, with rainfall varying from 530 to 2870 mm/yr (Giambelluca et al. 2011).

Sites were classified as residential or rural, with or without agriculture or forest within a 500-m radius, by ground examination at location and by plotting their GPS coordinates in Google Earth and characterizing the environment within a 500 m radius circle drawn around each site, using aerial photography dating from December 31, 2007. Sites were classified as residential if ≥ 40% of the area within the circle was made up of suburban-type residential environments. Sites were classified to include agriculture if ≥ 20% of the area within the circle was occupied by plots under cultivation. Sites that may be influenced by agricultural production were defined by the presence of large-scale commercial agriculture (papaya, cucurbit, pineapple, corn, or sugarcane farming), smaller-scale diversified agriculture (vegetable, fruit tree, or ornamental tree farms), and community gardens. Backyard small gardens and fruit trees within residential areas were not defined as agriculture. Sites were classified as containing forest if ≥ 20% of the area was occupied by uniform feral forest vegetation, which commonly included strawberry guava (*Psidium cattleianum* Sabine). One site, with traps bordering large-scale (> 60 ha) coffee farming, was treated separately from the other rural sites with agriculture, because of the large number of *C. capitata* collected. Gulch forest was also within the circle area of that site. Overall, there were 20 sites in rural environments (12 and 7 in proximity of agriculture and forest, respectively), and 20 sites in residential environments (3 each in proximity of agriculture and forest).

A total of six traps, including four bucket traps with male lures and two MultiLure traps with food attractant, were maintained at each site. Bucket traps were made of 1-liter white polyethylene containers (Highland Plastics, Mira Loma, CA), with four lateral 22-mm-diameter holes, 24 mm below the top to allow fly entry, and five small drainage holes at the bottom to prevent water accumulation. The trap was attached to a support tree with a 15-gage aluminum tie wire, inserted through a central hole in the lid fitted on the trap top, and bent into a hook inside the trap. For three of the traps, male lure plugs charged with 2 g of cue-lure (attracts *B. cucurbitae*), methyl eugenol (attracts *B. dorsalis*), or trimedlure (attracts *C. capitata*) (Scentry Biologicals, Billings, MT) were placed inside a plastic basket (AgriSense, Palo Alto, CA), suspended from the trap's ceiling through the wire hook. The fourth trap was charged with latilure, a two-component liquid attractant for *B. latifrons* (McQuate and Peck, 2001), composed of the chemicals alpha-ionol (Bedouldan Research, Danbury, CT), and cade oil (Penta, West Caldwell, NJ). Two dental cotton wicks (38 mm long x 10 mm diameter) were soaked, one in each chemical, and held in two separate baskets attached to the hook. One 25 x 90-mm strip containing 10% dichlorvos (Vaportape, Hercon Environmentals, Emingsville, PA) was also attached to each trap's hook to rapidly kill the flies entering all bucket traps traps.

A MultiLure trap (Better World manufacturing, Fresno, CA), consisting of a transparent cover that interlocks with an opaque yellow base, allowing insect entry through a bottom opening and serving as a vessel to hold liquid, was used to hold five torula yeast pellets (ERA International, Freeport, NY), diluted in 400 ml of a 10% aqueous solution of propylene glycol (Sierra Antifreeze, Old World Industries, Northbrook, IL). The other food lure used inside a MultiLure trap was the three-component BioLure (Leblanc et al. 2010).

At each site, the cue-lure, trimedlure, and BioLure traps were hung on one tree (≤ 2 m apart) and the methyl eugenol, latilure, and torula yeast traps were hung on a second nearby tree, at least 3 m distant from the first tree. The torula yeast and BioLure traps were continuously running and emptied, and the yeast solution was replaced every week. The male lure traps were covered with plastic bags that were removed once a week to expose the traps to attract and collect male flies for a 24-hour period. The lure plugs and pesticide strips were replaced with fresh ones every 6 weeks.

The collected flies were counted and examined by technicians to confirm that they belong to the already established species or to detect potential new invaders. They received basic training to detect the obviously different species, but not the species closely related to *B. dorsalis*. Results are reported for the male lure and the torula yeast traps, but not BioLure, because it collected far fewer specimens of the same species. The data, as number of flies per trap per day (male lures) or per week (torula yeast) were ln(x+1) transformed and analyzed for each species and lure separately using one-way ANOVA (SAS Institute, 2004). Captures in different environments were compared using the Tukey's honest significant difference test.

Results and Discussion

Over 1.7 million flies were counted and examined during the three years of trapping: 399,904 male *B. cucurbitae* in the cue-lure traps (5,506 samples), 1,133,800 male *B. dorsalis* in methyl eugenol (5,654 samples), 23,566 male *C. capitata* in trimedlure (5,173 samples), and 55,622 *B. cucurbitae*, 80,279 *B. dorsalis*, and 34,700 *C. capitata* in the torula yeast traps (5,441 samples). On the other hand, very few *B. latifrons* were collected: only 24 males and one female were found in latilure-baited traps and 18 males in torula yeast traps.

The technicians who collected and sorted through trap samples did not come across species other than the four already established. Their training was adequate to detect most of the potential invaders other than the *B. dorsalis* complex species. The senior author has examined under the microscope several thousand specimens of *B. dorsalis* collected in male lure and torula yeast traps and confirmed that they were consistent with the typical *B. dorsalis*, characterized by Drew and Hancock (1994). The length of aedeagi and ovipositors on dissected specimens from Oahu were also within the known size range of Asian populations of *B. dorsalis* (L.L., unpublished). He did not observe specimens of the morphologically distinct *B. carambolae* Drew and Hancock, *B. caryeae* (Kapoor), *B. kandiensis* Drew and Hancock or *B. occipitalis* (Bezzi), all economic species of the *B. dorsalis* complex attracted to methyl eugenol. However, several thousand is a very small proportion of the >1.1 million *B. dorsalis* trapped over the years, thus the possible presence in small numbers of sibling species cannot be ruled out with certainty. Although several species most closely related to *B. dorsalis* cannot be distinguished by means other than morphometrics, recent evidence, based on measurements and genetic studies over an extensive geographic range, suggests that *B. papayae* Drew and Hancock and *B. philippinensis* Drew and Hancock (Krosch et al. 2012, Schutze et al. 2012) and possibly *B. invadens* Drew, Tsuruta and White (SanJose et al. in prep.) are likely to be synonymous with *B. dorsalis*.

Melon fly was predominant in leeward western Oahu (Fig. 2) and was most abundant, in both rural and residential areas, at sites where agriculture was practiced nearby (Figs. 5a, b). Similarly on Kauai, *B. cucurbitae* was predominant on the dry leeward side and rare above 300 m elevation (Harris et al. 1986, Vargas et al. 1989). Wild bittermelon (*Momordica charantia* L.), a common weed found in localized clumps in disturbed areas and agricultural plots, including commercial sugarcane (Harris et al. 1986) and pineapple (Harris and Lee 1989) plantations, was found to be the most heavily infested host and the main factor determining *B. cucurbitae* distribution (Harris et al. 1986). Cultivated backyard vegetable gardens in residential areas had an important, but lesser, impact on *B. cucurbitae* distribution (Harris et al. 1986). It was also most abundant within agricultural areas (Vargas et al. 1989, 1990), and its numbers declined sharply with distance from potential breeding sites and increasing rainfall (Harris et al. 1986).

Oriental fruit fly was trapped in highest numbers in the windward northeastern portion of Oahu (Fig. 3) and in rural areas. The presence of adjacent forest increased captures in both residential and rural environments in methyl eugenol traps (Fig. 5c). Strawberry and feral common (*Psidium guajava* L.) guava are very common in forests, sustaining up to 95% of the *B. dorsalis* population on Oahu, while cultivated hosts are secondary in importance (Newell and Haramoto, 1968). The same pattern was also documented on Kauai, where *B. dorsalis* was most common in wet windward areas and invaded cultivated areas from the nearby thick guava belt and gulch forests (Vargas et al. 1983b, 1989, 1990).

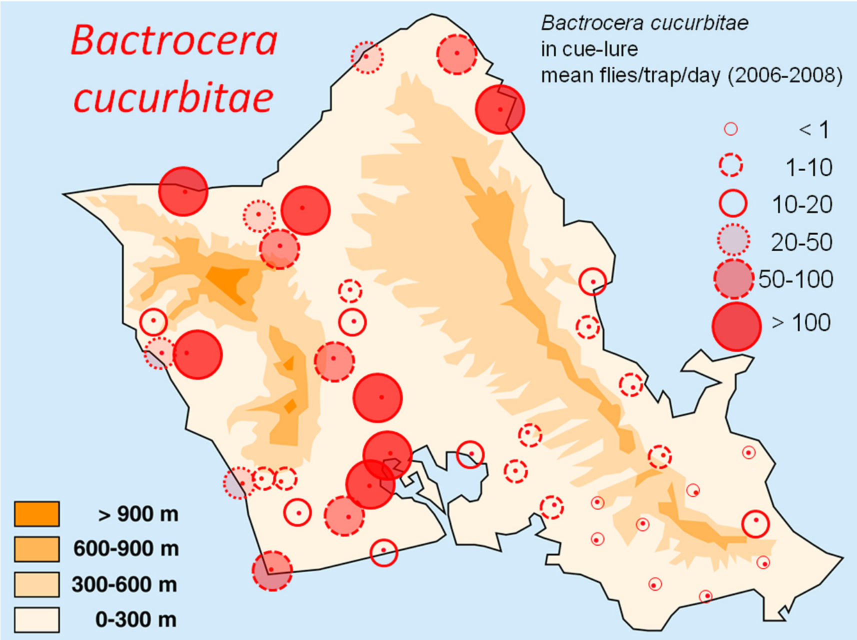


Figure 2. Mean captures per trap per day of *B. cucurbitae* in cue-lure traps (2006–2008) at each trapping site on Oahu.

Mediterranean fruit fly was trapped in very large numbers at the coffee farm in Waialua and rare at all other sites (Figs. 4, 5e and f). Medfly was displaced by *B. dorsalis* after its introduction in 1946, becoming an uncommon localized pest around coffee farms and at higher elevations by 1947 (Bess 1953, Haramoto and Bess 1970), but has since become, once again, locally extremely abundant with the recent development of large-scale coffee farms on Kauai (since 1987) and Oahu (since 1996). Outside of coffee farming locations, *C. capitata* was reported to be more common on leeward dry coastal and seashore areas and rare on the wet windward side on Oahu (Harris and Lee 1987) and Kauai (Vargas et al. 1983a), consistent with our trapping data (Fig. 4). Feral coffee in valleys was found to be a major factor in maintaining higher numbers in the Makaha-Waianae valleys of Oahu (sites 11, 12, and 14 on Fig. 1) (Nishida et al. 1985, Vargas and Nishida 1989, Harris and Lee 1986) and the leeward Waimea and Hanapepe valleys on Kauai (Vargas et al. 1983b). It is also locally common in suburban residential areas of leeward southern Oahu (Fig. 4), where mock orange (*Murraya paniculata* (L.) Jack), a common ornamental hedge component in suburban residential areas, is the main host of *C. capitata* (Harris and Lee 1987, Vargas and Nishida, 1989).

The coffee site also yielded the most *B. dorsalis* (Figs. 5c, d) and the second largest numbers of *B. cucurbitae* (Fig. 5a) among the different habitats. Wild bittermelon, a ubiquitous weed in commercial agriculture (Harris et al. 1986), is likely responsible for the high numbers of *B. cucurbitae*. The high captures of *B.*

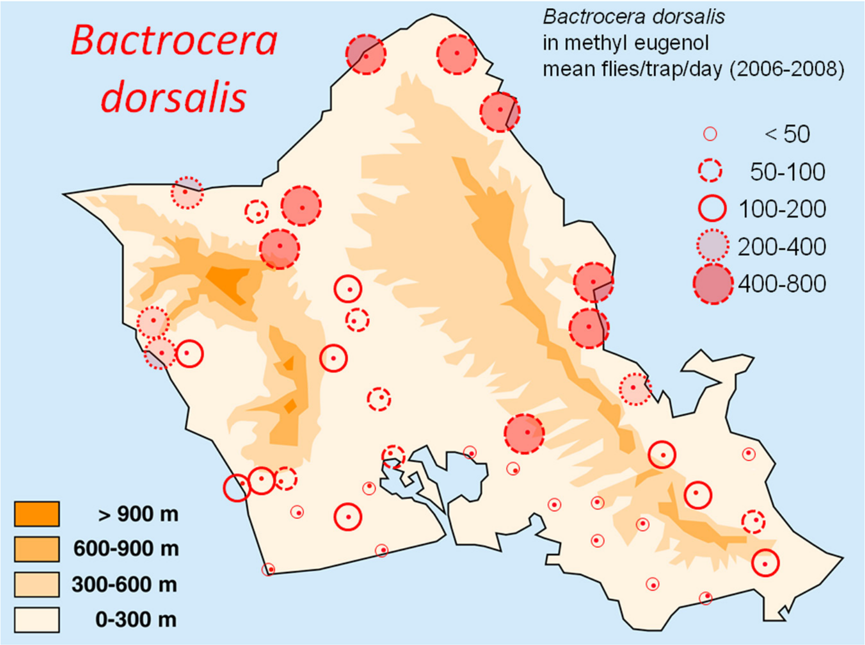


Figure 3. Mean captures per trap per day of *B. dorsalis* in methyl eugenol traps (2006–2008) at each trapping site on Oahu.

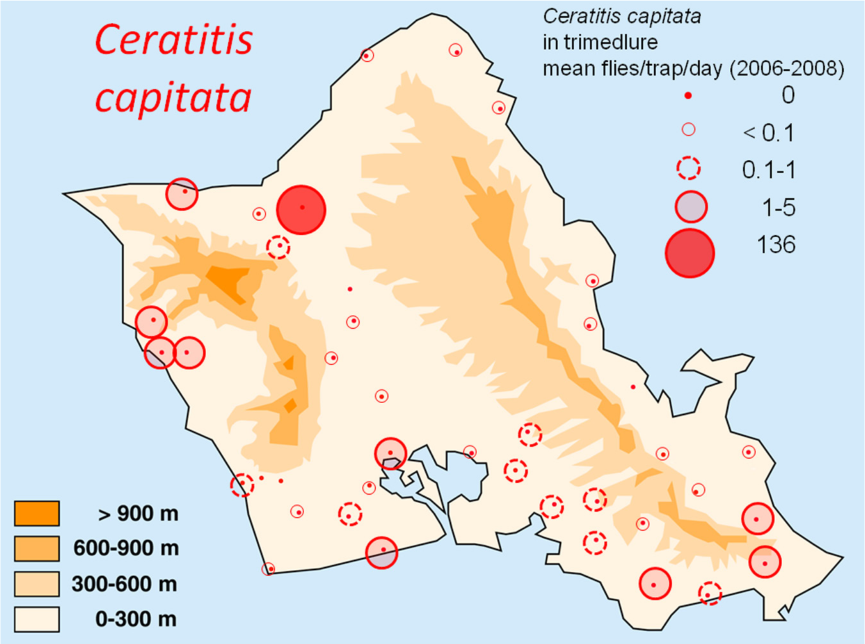
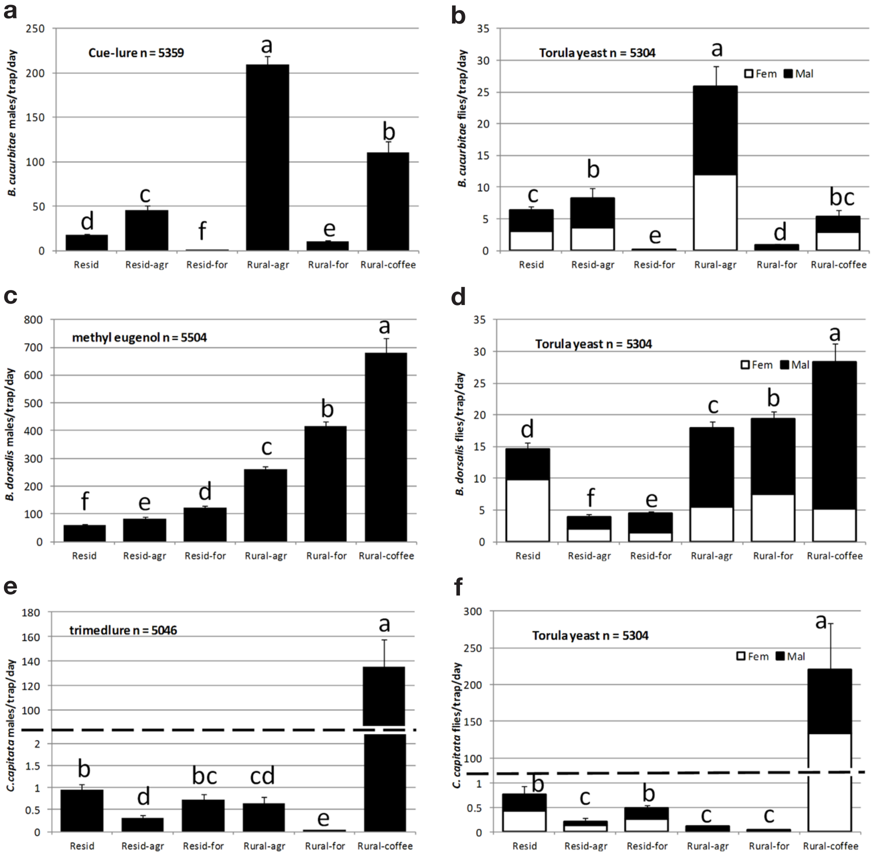


Figure 4. Mean captures per trap per day of *C. capitata* in trimedlure traps (2006–2008) at each trapping site on Oahu.



Figures 5a–f. Mean (± S.E.) captures in different habitats for *B. cucurbitae* in cue-lure and torula yeast (a, b), *B. dorsalis* in methyl eugenol and torula yeast (c, d) and *C. capitata* in trimedlure and torula yeast (e, f) traps. Units are flies per trap per day in male lure and per week in torula yeast traps.

Values with the same letter are not significantly different at the 0.05 level, Tukey's test, one-way ANOVA on ln(n+1) transformed data. $P < 0.001$ for all graphs. *B. cucurbitae*: cue-lure: $F = 837.17$; df = 5,5353; torula yeast: $F = 190.38$; df = 5,5298. *B. dorsalis*: methyl eugenol: $F = 400.26$; df = 5,5498; torula yeast: $F = 84.37$; df = 5,5298. *C. capitata*: trimedlure: $F = 977.49$; df = 5,5040; torula yeast: $F = 733.23$; df = 5,5298. Number of samples (cue-lure, methyl eugenol, torula yeast): residential: 1867, 1926, 1859; residential near agriculture: 553, 558, 517; residential near forest: 377, 419, 401; rural with agriculture: 1495, 1490, 1463; rural near forest: 917, 961, 915; coffee farm: 150, 150, 150.

dorsalis is likely due to the proximity of gulch forest, but also to breeding on coffee berries, a suitable host heavily infested by *B. dorsalis* at lower elevations, comparable to the Waialua Coffee farm (< 200m) (Bess 1953, Haramoto and Bess 1970, Vargas et al. 1983a, Harris and Lee 1986).

The protein traps collected far fewer *B. cucurbitae* and *B. dorsalis* in one week than male lures collected in one day, but almost consistently collected as many or more *C. capitata* than trimedlure. The high proportion of male *B. dorsalis* (Fig. 5d) captured in protein traps was likely due to the proximity of the methyl eugenol trap. Also, the use of propylene glycol in torula yeast traps is not recommended because it is known to reduce fruit fly captures (Leblanc et al. 2010), although in arid areas using propylene glycol may help to prevent complete desiccation and thus increase efficacy. Attraction to torula yeast is short-ranged compared to male lures, but nonetheless food lures allow the detection of pest species not attracted to male lures, such as *B. latifrons*, *B. cucumis* (French), and *B. depressa* (Shiraki).

In conclusion, the general island distribution patterns documented on Kauai, with *B. dorsalis* and *B. cucurbitae* most abundant on the windward and leeward sides of Kauai, respectively, and the higher numbers of *C. capitata* in leeward and suburban areas of Oahu, were confirmed to some degree in this study, although their abundance is more primarily determined by local land use patterns and their associated vegetation. The positioning of traps in proximity to agriculture and feral forest can help improve detection of exotic cucurbit and fruit-infesting species, respectively, but trapping needs to be most concentrated in high-risk areas, where invasive species are most likely to initially establish. The trapping network was reviewed and modified in early 2009, with the elimination of latilure and BioLure and the relocation of the trapping to 134 sites, concentrated around residential areas, commercial and small-scale farming, community gardens, and ports of entry.

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