Distant-Dependent Capture Probabilities of Mediterranean and Oriental Fruit Flies (Diptera: Tephritidae) in a Food-Based Trap in a Hawaiian Mango Orchard

Author: Shelly, Todd

Source: Florida Entomologist, 104(2) : 117-123

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.104.0207

Distant-dependent capture probabilities of Mediterranean and oriental fruit flies (Diptera: Tephritidae) in a food-based trap in a Hawaiian mango orchard

Todd Shelly[1,*]

Abstract

Certain species of true fruit flies (Diptera: Tephritidae) are worldwide pests of fruits and vegetables, and many countries operate trapping programs to detect and monitor invasions. Food-based traps are an important component of detection programs because they are general attractants that are neither sex- nor species-specific. Torula yeast borax solution is a food bait that is used widely, but little is known regarding its attractiveness in terms of distant-dependent capture rates in field settings. The goal of the present study, which was conducted in a Hawaiian mango (*Mangifera indica* L.; Anacardiaceae) orchard, was to measure capture probabilities of oriental fruit flies, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), and Mediterranean fruit flies, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), released at 5, 10, or 20 m from a centrally located trap baited with torula yeast borax solution. For both species, capture probabilities were relatively low and decreased with increasing release distance from the trap. Trap captures were female-biased strongly in *B. dorsalis*, while the sex ratio of captured *C. capitata* was more variable and differed among the release distances. Based on data pooled over the sexes, *B. dorsalis* was captured at significantly higher rates than *C. capitata* for release distances of 5 and 10 m, and a marginally significantly higher rate ($P = 0.053$) for the 20 m releases. These findings are compared with other release-recapture studies of tephritids that involved food baits, and the relative attractiveness of torula yeast borax solution and male lures are noted for *B. dorsalis* and *C. capitata*.

Key Words: *Ceratitis capitata*; *Bactrocera dorsalis*; food-based trapping; detection

Resumo

Ciertas especies de verdaderas moscas de la fruta (Diptera: Tephritidae) son plagas mundiales de frutas y verduras, y muchos países operan programas de captura para detectar y monitorear invasiones. Las trampas a base de alimentos son un componente importante de los programas de detección, por ser atrayentes generales que no son específicos del sexo ni de la especie. La solución de bórax de levadura Torula es un cebo alimenticio que se usa ampliamente, pero se sabe poco sobre su atractivo en términos de tasas de captura dependientes de la distancia en entornos de campo. El objetivo del presente estudio, que se realizó en un huerto de mango hawaiano (*Mangifera indica* L.; Anacardiaceae), fue medir las probabilidades de captura de moscas orientales de la fruta, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) y moscas del Mediterráneo *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), liberada a 5, 10 o 20 m de una trampa ubicada en el centro cebada con solución de bórax de levadura torula. Para ambas especies, las probabilidades de captura fueron relativamente bajas y disminuyeron al aumentar la distancia de liberación desde la trampa. Las capturas de trampas fueron fuertemente sesgadas por las hembras de *B. dorsalis*, mientras que la proporción de sexos de *C. capitata* capturada fue más variable y difirió entre las distancias de liberación. Según los datos agrupados por sexos, se capturó *B. dorsalis* a tasas significativamente más altas que *C. capitata* para distancias de liberación de 5 y 10 m, y una tasa marginalmente significativamente más alta ($P = 0.053$) para las liberaciones de 20 m. Estos hallazgos se comparan con otros estudios de liberación-recaptura de tefrítidos que involucraron cebos alimenticios, y se observa el atractivo relativo de la solución de bórax de levadura torula y los señuelos para machos para *B. dorsalis* y *C. capitata*.

Palabras Claves: *Ceratitis capitata*; *Bactrocera dorsalis*; trampas a base de alimentos; detección

A number of true fruit fly species (Diptera: Tephritidae) are important pests of fruits and vegetables and cause serious economic losses both domestically through direct damage of crops and internationally through trade restrictions on crops with perceived risks of infestation (White & Elson-Harris 1992). Given this threat, many fruit fly-free countries operate trapping programs to detect and monitor invasions (e.g., Gonzalez & Troncoso 2007; Jessup et al. 2007). Within limits imposed by budgetary constraints, the design of trapping systems for pest tephritids should maximize detection sensitivity, i.e., ensure a high probability of capturing invasive flies (Lance & Gates 1994). What constitutes an acceptable level of detection sensitivity for an invasive population is arbitrary and may vary among regions that differ in certain parameters, such as climate and host availability. Additionally, of course, intrinsic biological differences among tephritid species in longevity, reproductive potential, and dispersal also may influence the nature of the trapping system used as well as the determination of an acceptable capture probability.

---

[1] USDA-APHIS, 41-650 Ahiki Street, Waimanalo, Hawaii 96795, USA; E-mail: todd.e.shelly@usda.gov (T. E. S.)

*Corresponding author; E-mail: todd.e.shelly@usda.gov

While the operational threshold for adequate trapping system sensitivity may vary, several features of trapping systems are viewed generally as critical determinants of detection capability for fruit flies and invasive insects in general. These include the size of the area surveyed, the seasonal timing of trapping activity (in areas where trapping is not yr-round), density and spatial array of traps within the target area, and the attractiveness of the bait/trap combination (Lance 2014; Berec et al. 2015; FAO/IAEA 2018; Stringer et al. 2019). Unfortunately, the complexity and scale of interactions among trapping system, fly biology, and environmental parameters make it difficult to implement a comprehensive, experimental approach for evaluating the performance of fruit fly trapping systems.

One feature that has received considerable empirical study is the relationship between trap/bait combinations and capture probability of pest tephritids. Fruit fly detection programs rely heavily on male lures, which are natural or synthetic compounds attractive to males of certain pest tephritids (Tan et al. 2014). Mark-release-recapture studies have provided estimates of distance-dependent capture probabilities for traps baited with male lures for the Mediterranean fruit fly (medfly) *Ceratitis capitata* (Wiedemann) (male attractant, trimedlure), the oriental fruit fly *Bactrocera dorsalis* (Hendel) (methyl eugenol), and the melon fly *Zeugodacus cucurbitae* (Coquillett) (all Diptera: Tephritidae) (cue-lure) (Delrio & Zümreoğlu 1982; Wong et al. 1982; Cunningham & Couey 1986; Lance & Gates 1994; Enkerlin 1997 [cited in Manoukis et al. 2015]; Shelly et al. 2010; Shelly & Nishimoto 2011; Shelly et al. 2014; Manoukis et al. 2015; Manoukis & Gayle 2016).

In addition to male lures, fruit fly detection efforts also use food-based traps because male lures do not attract females, and males of many fruit fly species show no attraction to these sex-specific lures (Drew & Hooper 1981; Royer 2015). Thus, food-based traps are deployed as general (i.e., not sex- or species-specific) attractants in surveillance programs. However, compared to male lures, relatively few studies have measured distance-dependent capture probabilities for food-based traps. Working with melon fly in Hawaii, Shelly and Manoukis (2018) recorded capture rates < 4% for flies released between 10 to 50 m from a food trap. These probabilities are low relative to those obtained for males captured in cue-lure-baited traps (Shelly & Nishimoto 2011; Manoukis & Gayle 2016), supporting the perception that male lures, in general, are more powerful attractants than food baits.

The goal of the present study, which was conducted in a Hawaiian mango (*Mangifera indica* L.; Anacardiaceae) orchard, was to measure capture probabilities of medflies and oriental fruit flies released at different distances from a centrally located trap baited with torula yeast borax solution, a standard food bait (FAO/IAEA 2018). Capture rates were obtained for both males and females of both species. Quantifying these capture rates is necessary for making rigorous interspecific comparisons regarding the attractiveness of the standard food bait, intraspecific comparisons regarding the relative attractiveness of different types of food bait, and even intraspecific comparisons regarding the relative attractiveness of food baits and male lures. Accordingly, the results obtained here are compared with other release-recapture studies of tephritids that provided quantitative estimates of the effective sampling range of food baits. The present results also allow quantification, for both *B. dorsalis* and *C. capitata*, of the difference in attractiveness between the standard food bait and male lures.

Materials and Methods

The study involved 2 different experiments, the principal experiment and an ancillary one performed to gain a clearer interpretation of the results from the initial experiment. Protocol for the principal experiment is described first, and the slight modifications adopted for the ancillary experiment then are presented.

STUDY SITE

Field work was conducted in a small mango orchard (0.4 ha, 30 m elevation) at the University of Hawaii's Urban Garden, Pearl City, Oahu, Hawaii, USA, between 2 Mar and 29 May 2020, during which daily maximum and minimum air temperatures averaged 27.9 °C (range: 26.1–31.1 °C and 21.9 °C (range: 20.0–23.9 °C), respectively (National Weather Service, Honolulu International Airport, Honolulu, Hawaii, USA). The orchard contained 24 trees, most of which were 6 to 8 m in height, arranged in a 6 × 4 grid. Most trees bore either flowers or unripened green fruits, although a few scattered ripe fruits were present toward the end of the study.

INSECTS

Medfly pupae were obtained from a recently established laboratory colony started with 200 to 300 wild adults that emerged from coffee berries (*Coffea arabica* L.; Rubiaceae) collected in a commercial plantation on the island of Kauai, Hawaii, USA. Rearing procedures followed Shelly et al. (2020). Adults used in the releases were separated by sex within 1 to 2 d of eclosion, before reaching sexual maturity at to 5 d of age (Shelly, unpublished data), held in laboratory-constructed screen mesh cubical cages (30 cm per side; 250 to 300 flies per cage), and supplied unlimited food (a 3:1 [v:v] mixture of sugar:yeast hydrolysate) and water. One d prior to release, flies were transferred to screen-covered, 0.8 L plastic cups (Karat, Chino, California, USA; 100 same-sex flies per cup), and provided a cube of granulated sugar and a moistened sponge (placed on the screen cover); the dietary switch to sugar was made to stimulate searching for protein food sources in the field. Medflies were released at 3 to 6 d of age. The insects were held at 23 to 25 °C and 50% to 80% relative humidity under natural photoperiod, about 12:12 h (L:D). Wild *C. capitata* were rare at the study site, because 4 traps baited with trimedlure, a male-specific lure, captured only 4 male medflies during 2 wk of operation just prior to and midway through the study period. Consequently, released medflies were not marked. When used in this study, medflies were 6 to 7 generations removed from the wild.

Released *B. dorsalis* were derived from a laboratory colony started with 2,000 wild adults reared from infested guava (*Psidium guajava* L.; Myrtaceae) collected on the island of Hawaii (Big Island) near Hilo, Hawaii, USA, and rearing methods followed Shelly et al. (2020). Adults used in the releases were separated by sex within 3 to 4 d of eclosion, well before reaching sexual maturity at 12 to 14 d (Shelly, unpublished data) and supplied unlimited food and water as noted above. Because a wild population of *B. dorsalis* was present at the study site, released adults were marked as follows. For each sex, 200 individuals were transferred to plastic vials (Fisher Scientific, Waltham, Massachusetts, USA), which then were placed in crushed ice and chilled for 5 to 10 min. The immobile flies then were marked by placing a small dot of enamel paint on the dorsum of the thorax. This procedure is used commonly in tephritid research, and appears to have no long-term effects on fly survival or behavior. Flies (both males and females) released on a given date were marked the same color, and different colors were used for successive releases. Marking was performed 1 to 3 d before release and, as with medfly, oriental fruit flies were transferred to plastic cups (50 flies per sex per cup) and provided sugar and a wet sponge 1 d before release. Individuals of *B. dorsalis* were released at 11 to 15 d of age. Holding conditions for *B. dorsalis* were the same as those noted above for *C. capitata*. When used in this study, *B. dorsalis* flies were approximately 15 generations removed from the wild.

For both species, flight ability was assessed for adults taken randomly from the same batches used in the releases. Based on the internationally accepted protocol (FAO/IAEA 2014), both species had high proportions of flight-capable individuals. Flight tests were conducted for 4 releases (of 21 total releases), and for medfly, the proportion of fliers was ≥ 95% in all 4 tests for both sexes, while for the oriental fruit fly the corresponding proportion was ≥ 96%. Additionally, as evident from the above description, the released flies were presumably of uniform physiological condition. Consequently the potential effects of age, diet, and reproductive status, among other factors on capture probability, were not assessed in this study. For a review of this topic, Díaz-Fleischer et al. (2014) should be consulted.

TRAPS AND LURES

The torula yeast borax slurry was dispensed from a Multilure® trap (Better World Manufacturing Inc., Fresno, California, USA). The top portion is clear plastic, while the bottom is bright yellow and holds liquid food bait or an aqueous preservative. Flies enter the bottom of the trap via an open-ended invagination and fall into the liquid reservoir, which serves as the killing mechanism. A wire hanger at the top of the trap is used to suspend the trap from tree branches.

The food solution was prepared 1 d before field deployment by adding 1 torula yeast borax pellet (Scentry Biologicals Inc., Billings, Montana, USA) per 100 mL of a water/antifreeze solution (90% and 10%, respectively; SPLASH RV & Marine Antifreeze [14% propylene glycol], SPLASH Products Inc., St. Paul, Minnesota, USA). Antifreeze is added routinely to torula yeast borax bait in order to reduce evaporation and decay of captured insects (FAO/IAEA 2018). In all trials, the Multilure trap was baited with 300 mL of the food slurry.

RELEASE AND RECAPTURE PROTOCOL

A single Multilure trap was placed in a mango tree (termed the focal tree) near the center of the orchard approximately 2 m aboveground in a shaded location; this same trap location was used for all releases. The central trap was deployed immediately before a release and operated for 48 h after the release. Flies were released 5, 10, or 20 m from the trap at 4 sites per distance (corresponding to the cardinal directions), arranged in a circle about the trap. Thus, for each distance, a single release (replicate) actually involved 4 releases corresponding with north, south, east, and west directions. The 5 m releases occurred at the edge of the canopy of the focal tree. The 10 m releases were made at the nearest neighboring trees to the focal tree in each cardinal direction, and the 20 m release trees were made at the next tree beyond the 10 m trees for each direction. On a given d, individuals of both species were released from the same (and single) distance, which was selected randomly. For a given release, 50 females and 50 males of *B. dorsalis* and 100 females and 100 males of *C. capitata* were released at each of the 4 sites (i.e., total flies per release = 400 for *B. dorsalis* and 800 for *C. capitata*). For a given distance, releases were made at the same sites (canopy locations) over the entire study. Flies were released at 9:00 A. M. by holding the plastic cups in the canopy, removing the screen cover, and gently tapping the cage to stimulate flight. Mortality was very low in the cages, and the great majority of individuals flew off immediately upon opening the cups. A total of 7 releases were conducted for each distance for each species (total releases = 3 distances × 7 releases per distance = 21).

ANCILLARY EXPERIMENT

As described below, a marked decline in recaptures was recorded between the 2 closest release distances, i.e., 5 and 10 m. However, because the 5 m release points were located within the same tree as the trap, whereas the 10 m release points were located in different trees than the trap, it is possible that the observed decline was related, not so much to increased distance, but to lower fly movement between trees compared to within a single tree canopy. To examine this possibility, an ancillary experiment, having 2 components, was conducted following the same basic protocols given above. First, trap capture was scored for flies released 10 m from a trap but in the same tree as the trap. This was achieved by releasing and trapping flies on opposite sides of the focal tree for east-west and north-south axes, respectively. Four replicates were performed for each axis (i.e., 8 total replicates), with the release and trap sites switched between successive replicates for each axis. Second, trap capture was scored for flies released 5 m from a trap where release and trap sites were in different trees. Two replicates were performed for each of the 4 cardinal directions (i.e., 8 total replicates), with the trap placed at the canopy edge of the focal tree along each of the cardinal directions and releases made from the corresponding adjacent tree. The ancillary experiment was conducted from 20 Jul to 14 Sep 2020, when, as above, the mango trees bore very few fruits. During this period, daily maximum and minimum air temperatures averaged 30.5 °C (range: 28.8–32.8 °C) and 24.0 °C (range: 22.6–25.5 °C), respectively (National Weather Service, Honolulu International Airport, Honolulu, Hawaii, USA). Methods related to insect rearing, marking, and release, as well as trap deployment and collection, were the same as described above except that, for all replicates, only 100 individuals of each sex were released for each species.

STATISTICAL ANALYSIS

For the principal experiment, numbers of captures for both species were analyzed using a 2-way ANOVA with distance and sex as the principal factors. Data were $\log_{10}$ transformed, and the parametric assumptions of normality and equal variances were met for both species. The Tukey multiple comparisons test was used to identify pairwise differences in captures. A comparison between *B. dorsalis* and *C. capitata* was performed using capture rates (number captured divided by number released computed over both sexes for individual releases), because release numbers differed between the species. For each release distance, capture rates of the 2 species were compared using the Mann-Whitney test (a non-parametric equivalent of the *t*-test; $N_1 = N_2 = 7$ in these tests). The Mann-Whitney test also was used to compare capture rates (computed over both sexes) observed in the ancillary experiment with those obtained in the principal experiment for the 5 and 10 m release distances, respectively ($N_1 = 7$, $N_2 = 8$ in these tests). Finally, this same test was used to compare female versus male captures for each species for the 5 and 10 m releases, respectively, in the ancillary experiment ($N_1 = N_2 = 8$ in these tests). Analyses were performed using SigmaPlot 11.0 (Systat Software, San Jose, California, USA).

Results

PRINCIPAL EXPERIMENT

For *B. dorsalis*, both release distance from the trap ($F_{2, 36} = 110.5$; $P < 0.001$) and sex ($F_{1, 36} = 30.8$; $P < 0.001$) had significant effects on capture probability (Fig. 1A). The interaction term was not significant ($F_{2, 36} = 1.45$; $P = 0.25$). Trap captures decreased with distance for both sexes, and all pair wise comparisons (i.e., 5 vs. 10 m, 5 vs. 20 m, and 10 vs. 20 m) showed significant differences in captures. In addition, more females than males were captured at each release distance. In relative terms,

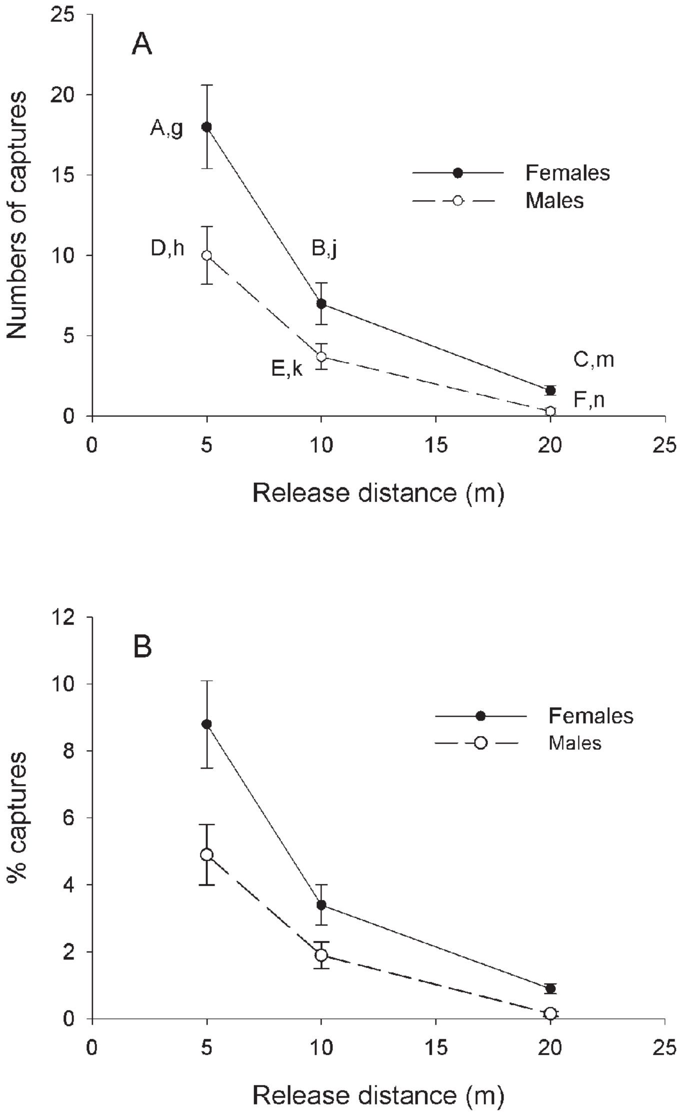

Fig. 1. Number of captures (A) and percentage of captures (B: captures divided by released) for *Bactrocera dorsalis* released from 5, 10, or 20 m from a centrally located trap baited with torula yeast borax solution. For a given replicate, 200 individuals of each sex were released. Symbols represent means with standard error (*N* = 7 replicates in all cases). Within each sex, numbers of captures differed significantly between distances marked with different upper case letters. Within a distance, numbers of captures differed significantly between the sexes if marked with different lower case letters.

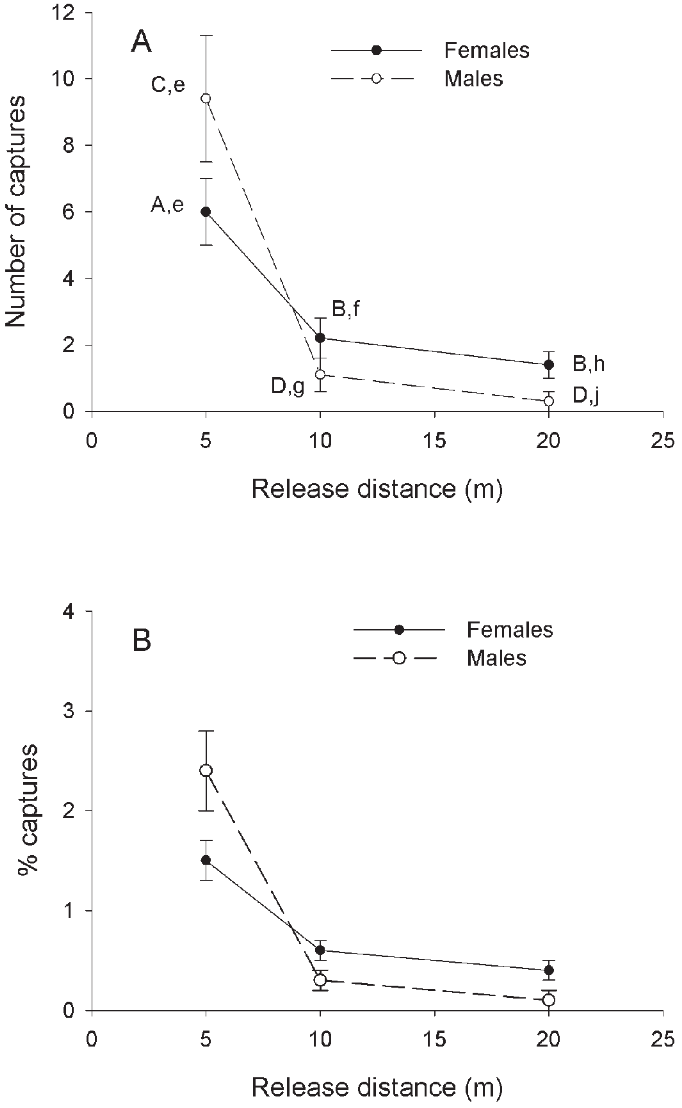

Fig. 2. Number of captures (A) and percentage of captures (B: captures divided by released) for *Ceratitis capitata* released from 5, 10, or 20 m from a centrally located trap baited with torula yeast borax solution. For a given replicate, 400 individuals of each sex were released. Symbols represent means with standard error (*N* = 7 replicates in all cases). Within each sex, numbers of captures differed significantly between distances marked with different upper case letters. Within a distance, numbers of captures differed significantly between the sexes where marked with different lower case letters.

8.9%, 3.5%, and 0.8% of females were captured, on average, at releases made 5, 10, or 20 m from the trap, respectively, whereas the corresponding values for males were 4.9%, 1.9%, and 0.15%, respectively (Fig. 1B).

For *C. capitata*, release distance had a significant effect ($F_{2,36} = 41.9$; $P < 0.001$), but sex did not ($F_{1,36} = 3.2$; $P = 0.08$) (Fig. 2A). However, the interaction term was significant ($F_{2,36} = 5.0$; $P = 0.01$), indicating that the relative numbers of male and female captures were not consistent across the different release distances. In particular, while females were captured more frequently than males at 10 and 20 m release distances, male captures were, on average, 60% greater than female captures at the 5 m release distance, although this difference was not statistically significant. Average capture rates were 1.5%, 0.6%, and 0.3% for *C. capitata* females for releases made 5, 10, or 20 m from the trap, respectively, and the corresponding values for males were 2.3%, 0.3%, and 0.1%, respectively (Fig. 2B).

As the above findings suggest, the proportion of captures differed statistically between the 2 species over the different release distances. Capture rates were significantly greater for *B. dorsalis* than *C. capitata* for both 5 ($T = 77.0$; $P < 0.001$) and 10 m ($T = 77.0$; $P < 0.001$) releases. Capture rates generally were greater for *B. dorsalis* than *C. capitata* for 20 m releases, but the difference was significant only marginally ($T = 68.0$; $P = 0.053$).

ANCILLARY EXPERIMENT

The results of the ancillary experiment indicated that distance from the trap, rather than occurrence of the trap and release points in the same or different trees, was the key determinant of capture probability for both species (Table 1). For the 5 m release distance, capture rates of *B. dorsalis* (sexes combined) were 7.1% and 5.5% for releases made in the same tree containing the trap (principcal experiment) (Fig. 1B),

Table 1. Results of the ancillary experiment in which flies were released either 5 m from a trap baited with torula yeast borax solution located in a different (adjacent) tree or 10 m from a trap baited with torula yeast borax solution located in the same tree. For both species, 100 individuals of each sex were released per replicate. Means (1 SE) are given (*N* = 8 replicates in all cases).

		Release distance	
Species	Sex	5 m (different trees)	10 m (same tree)
Bactrocera dorsalis	Females	7.6 (1.6)	4.2 (1.1)
	Males	3.3 (0.6)	1.8 (0.9)
Ceratitis capitata	Females	2.2 (0.4)	0.6 (0.3)
	Males	1.5 (0.4)	0.2 (0.2)

or in trees adjacent to the focal tree (ancillary experiment) (Table 1), respectively (*T* = 67.0; *P* = 0.23). Similarly, for the 10 m release distance, capture rates of *B. dorsalis* were 2.8% and 3.0% for releases made in different trees from the focal tree (principal experiment) (Fig. 1B), or in the same tree containing the trap (ancillary experiment) (Table 1), respectively (*T* = 58.0; *P* = 0.87). Comparisons between the principal (Fig. 2B) and ancillary (Table 1) experiments indicate similar findings for *C. capitata*, i.e., capture rates (sexes combined) were similar for releases made at the same distance from the trap whether or not trap and release locations were in the same or different trees (5 m: *T* = 59.0; *P* = 0.78; 10 m: *T* = 49.0; *P* = 0.46).

Consistent with the principal experiment, females of *B. dorsalis* were captured in significantly greater numbers than males for both the 5 and 10 m releases in the ancillary experiment (5 m: *T* = 92.0; *P* = 0.01; 10 m: *T* = 90.5; *P* = 0.02). In contrast to the principal experiment, *C. capitata* females were captured in higher numbers than males for the 5 m releases, although this difference was not significant (*T* = 83.0; *P* = 0.13). Likewise, females were captured more often than males following 20 m releases, but captures were low overall, rendering this difference insignificant (*T* = 76.0; *P* = 0.44).

Discussion

A key result of this study was the finding that, within the context of the trap/lure combination used and the study site selected, capture probability in a food-based trap differed between *B. dorsalis* and *C. capitata*. For both species, capture rates decreased with increasing release distance from the food-baited trap but were significantly greater for *B. dorsalis* for both the 5 and 10 m release distances, and marginally higher (*P* = 0.053) for 20 m releases. The ancillary experiment further showed that release distance from the trap, and not differences in within-canopy versus between-tree movement or attraction, was the chief factor affecting capture probability for both species. Whereas overall capture rates differed between species in the principal experiment, within each species females generally were captured in greater numbers than males at a given distance, except the insignificant difference in captures observed for female and male *C. capitata* at 5 m release distance. This female-bias in trap catch is consistent with previous studies on *B. dorsalis* (Leblanc et al. 2010; Shelly et al. 2020) and *C. capitata* (Epsky et al. 1999; Katsoyannos et al. 1999; Alemany et al. 2004).

To my knowledge, only Shelly and Manoukis (2018) have employed a similar experimental design, i.e., a single central trap with releases made at different distances around the trap to measure captures in a food-based trap. In that study, individuals of *Z. cucurbitae* were subject to different dietary treatments relating to varying intervals of protein deprivation, and were released at 10, 25, or 50 m from a torula yeast borax trap. One group was provided yeast hydrolysate continuously (i.e., no protein deprivation) and was most similar (with respect to nutritional history) to the flies released in the present study. With data combined for the sexes, 2.5% and 1% of *Z. cucurbitae* fed yeast hydrolysate continuously were captured for 10 and 25 m release distances, respectively, which are similar to those reported here for *B. dorsalis* for 10 and 20 m release distances (2.6% and 0.5%, respectively), but greater than those reported here for *C. capitata* for 10 and 20 m release distances (0.4% and 0.2%, respectively).

Studies of several tephritid species, including *B. dorsalis* (Cornelius et al. 2000) and *C. capitata* (Prokopy et al. 1996), as well as *Anastrepha ludens* (Loew) and *Anastrepha obliqua* (Macquart) (both Diptera: Tephritidae) (Díaz-Fleischer et al. 2009), have demonstrated that protein deprivation increases attraction to and capture in food-based traps. Thus, the capture rates observed here presumably represent "baseline" values, below those expected for flies experiencing partial or complete protein-deprivation. This caveat notwithstanding, under the experimental design employed, capture rates likely would still be low for protein-starved *B. dorsalis* or *C. capitata*, because Shelly and Manoukis (2018) found that, among *Z. cucurbitae* adults fed sugar exclusively, only 4.2% of released flies were captured after release 10 m from a torula yeast-baited trap.

The recapture rates reported here, and in Shelly and Manoukis (2018), are much lower than recapture rates observed in other studies involving food-based traps. Working with *C. capitata*, Delrio and Zümreoğlu (1982) and Epsky et al. (2010) found that 2% to 9% of released males and 16% of released flies (males and females), respectively, were captured in food-based traps placed 10 m from the release point. Similarly, Kendra et al. (2010) measured trap catch for the Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), and reported that approximately 16% of released feral females were captured in food-based traps < 10 m from a release point (see also, Calkins et al. 1984). In the present study, by contrast, capture rates (over both sexes) for releases made 10 m from the trap were only 2.7% and 0.5% for *B. dorsalis* and *C. capitata*, respectively. This discrepancy almost certainly reflected the use of different experimental designs. Whereas the present study released flies at multiple points about a single trap, the other studies cited released flies at a single, central point surrounded by multiple traps deployed in either circular or grid arrays. In the case of a single, central trap, random flight upon release would take flies away from the trap 50% of the time, whereas when releases occurred within a network of regularly spaced traps, random movement likely would result in more flies approaching, and then responding, to a trap.

Measurement of recapture rates allows estimation of the effective sampling range of traps, which has been defined as the maximum distance from which an insect can reach an attractive source in a given time (Wall & Perry 1987). Kendra et al. (2010), who used a central release point within a circular trap array, operationally defined effective sampling range as the maximum trapping distance at which relative trapping efficiency (proportion of captured flies observed within a given distance category) was ≥ 25% with trap catch recorded 24 h after releases. Based on this criterion, these authors estimated that the effective sampling range was 30 m for *A. suspensa*. The corresponding range for *C. capitata* appears much shorter. Again, using a central release point within circularly placed traps, Epsky et al. (2010) found that approximately 60% of released medflies were recorded for traps 10 m from the release point, and relative efficiencies of more distant traps were all less than 20% total capture. Similarly, Delrio and Zümreoğlu (1982) found that, at 2 of 3 study sites, > 90% of captures of released *C. capitata* were at traps located only 10 m from the release point. Given the converse experimental approach used here, effective sampling range becomes the maximum release distance at which relative trapping efficiency (proportion of captured flies that were released at a given distance from the trap) was ≥ 25%. Adopting this guideline, the effective sampling range (computed over both sexes) was 10 m for *B. dorsalis* (releases at 5 and 10 m comprised 69% and 26% of total captures, respectively) and 5 m for *C. capitata* (releases at 5 m comprised 75% of total captures).

In conclusion, the present data allow broad, quantitative comparisons of the attractiveness of torula yeast borax solution and the male lures methyl eugenol and trimedlure. Because male lures are powerful attractants, males usually are not released closer than 25 m from a central trap. For *B. dorsalis*, capture rates for males released 25 m from a methyl eugenol-baited trap varied between 20% to 55% (Shelly & Nishimoto 2011), whereas in the present study a capture rate of only 0.5% was observed for flies (both sexes) released 20 m from the central food bait. For *C. capitata*, capture rates for males released 25 m from a trimedlure-baited trap varied between 2% to 7% (Shelly et al. 2014), and in the present study a capture rate of 0.2% was observed for flies (both sexes) released 20 m from the central food bait. Rough estimates thus indicate that methyl eugenol is 40 to 110 times more attractive than the torula yeast borax slurry for *B. dorsalis*, and that trimedlure is 10 to 35 times more attractive than the food bait for *C. capitata*. Because methyl eugenol is a more powerful male lure than trimedlure (see also, Manoukis et al. 2015), torula yeast borax solution, relative to male lures, is a more effective detection tool for *C. capitata* than for *B. dorsalis*.

Acknowledgments

I thank the staff and volunteers of the Urban Garden Center, University of Hawaii, Honolulu, Hawaii, USA, and particularly Steve Nagano, for cooperation and permission to conduct fieldwork at this facility.

References Cited

Alemany A, Alonso D, Miranda MA. 2004. Evaluation of improved Mediterranean fruit fly attractants and retention systems in the Balearic Islands (Spain), pp. 355–359 *In* Barnes BN [ed.], Proceedings of the 6th International Symposium on Fruit Flies of Economic Importance. Isteg Scientific Publications, Irene, South Africa.

Berec L, Kean JM, Epanchin-Niell R, Liebhold AM, Haight RG. 2015. Designing efficient surveys: spatial arrangement of sample points for detection of invasive species. Biological Invasions 17: 445–459.

Calkins CO, Schroeder WJ, Chambers DL. 1984. Probability of detecting Caribbean fruit fly, *Anastrepha suspensa* (Loew) (Diptera: Tephritidae), populations with McPhail traps. Journal of Economic Entomology 77: 198–201.

Cornelius ML, Nergel L, Duan JJ, Messing RH. 2000. Responses of female oriental fruit flies (Diptera: Tephritidae) to protein and host fruit odors in field cage and open field tests. Environmental Entomology 29: 14–19.

Cunningham RT, Couey HM. 1986. Mediterranean fruit fly (Diptera: Tephritidae): distance/response curves to trimedlure to measure trapping efficiency. Environmental Entomology 15: 71–74.

Delrio G, Zümreoğlu A. 1982. Attractability range and capture efficiency of medfly traps, pp. 445–450 *In* Cavallora R [ed.], Fruit Flies of Economic Importance: Proceedings of the CEC/IOBC International Symposium, 16–19 Nov 1982. Athens, Greece.

Díaz-Fleischer F, Piñero JC, Shelly TE. 2014. Interactions between tephritid fruit fly physiological state and stimuli from baits and traps: looking for the Pied Piper of Hamelin to lure pestiferous fruit flies, pp. 145–172 *In* Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R [eds.], Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Springer, Dordrecht, The Netherlands.

Díaz-Fleischer F, Arredondo J, Flores S, Montoya P, Aluja M. 2009. There is no magic fruit fly trap: multiple biological factors influence the response of adult *Anastrepha ludens* and *Anastrepha obliqua* (Diptera: Tephritidae) individuals to Multilure traps baited with BioLure or NuLure. Journal of Economic Entomology 102: 86–94.

Drew RAI, Hooper GHS. 1981. The responses of fruit fly species (Diptera: Tephritidae) in Australia to various attractants. Journal of the Australian Entomological Society 20: 201–205.

Enkerlin W. 1997. Economic Analysis of Management for the Mediterranean Fruit Fly *Ceratitis capitata*. PhD Dissertation. University of London, London, United Kingdom.

Epsky ND, Espinoza HR, Kendra PE, Abernathy R, Midgarden D, Heath RR. 2010. Effective sampling range of a synthetic protein-based attractant for *Ceratitis capitata* (Diptera: Tephritidae). Journal of Economic Entomology 103: 1889–1895.

Epsky ND, Hendrichs J, Katsoyannos BI, Vásquez LA, Ros JP, Zümreoglu A, Pereira R, Bakri A, Seewooruthun SI, Heath RR. 1999. Field evaluation of female-targeted trapping systems for *Ceratitis capitata* (Diptera: Tephritidae) in seven countries. Journal of Economic Entomology 92: 156–164.

FAO/IAEA – Food and Agriculture Organization/International Atomic Energy Agency. 2014. Product Quality Control for Sterile Mass-reared and Released Tephritid Fruit Flies. Version 6.0. International Atomic Energy Agency, Vienna, Austria.

FAO/IAEA – Food and Agriculture Organization/International Atomic Energy Agency. 2018. Trapping Guidelines for Area-wide Fruit Fly Programmes, 2nd edition. Enkerlin WR, Reyes-Flores J [eds.]. Food and Agriculture Organization, Rome, Italy.

Gonzalez J, Troncoso P. 2007. The fruit fly exclusion programme in Chile, pp. 641–651 *In* Vreysen MJB, Robinson AS, Hendrichs J [eds.], Area-wide Control of Insect Pests: From Research to Field Implementation. Springer, Dordrecht, The Netherlands.

Jessup AJ, Dominiak B, Woods B, De Lima CPF, Tomkins A, Smallridge CJ. 2007. Area-wide management of fruit flies in Australia, pp. 685–697 *In* Vreysen MJB, Robinson AS, Hendrichs J [eds.], Area-wide Control of Insect Pests: From Research to Field Implementation. Springer, Dordrecht, The Netherlands.

Katsoyannos BI, Heath RR, Papadopoulos NT, Epsky ND, Hendrichs J. 1999. Field evaluation of Mediterranean fruit fly (Diptera: Tephritidae) female selective attractants for use in monitoring programs. Journal of Economic Entomology 92: 583–589.

Kendra PE, Epsky ND, Heath RR. 2010. Effective sampling range of food-based attractants for female *Anastrepha suspensa* (Diptera: Tephritidae). Journal of Economic Entomology 103: 533–540.

Lance DR. 2014. Integrating tephritid trapping into phytosanitary programs, pp. 559–588 *In* Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R [eds.], Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Springer, Dordrecht, The Netherlands.

Lance DR, Gates DB. 1994. Sensitivity of detection trapping systems for Mediterranean fruit flies (Diptera: Tephritidae) in southern California. Journal of Economic Entomology 87: 1377–1383.

Leblanc L, Vargas RI, Rubinoff D. 2010. Captures of pest fruit flies (Diptera: Tephritidae) and nontarget insects in BioLure and torula yeast traps in Hawaii. Environmental Entomology 39: 1626–1630.

Manoukis NC, Gayle SM. 2016. Attraction of wild-like and colony-reared *Bactrocera cucurbitae* (Diptera: Tephritidae) to cuelure in the field. Journal of Applied Entomology 140: 241–249.

Manoukis NC, Siderhurst M, Jang EB. 2015. Field estimates of attraction of *Ceratitis capitata* to trimedlure and *Bactrocera dorsalis* (Diptera Tephritidae) to methyl eugenol in varying environments. Environmental Entomology 44: 695–703.

Prokopy RJ, Resilva SS, Vargas RI. 1996. Post-alighting behavior of *Ceratitis capitata* (Diptera: Tephritidae) on odor-baited traps. Florida Entomologist 79: 422–428.

Royer JE. 2015. Responses of fruit flies (Tephritidae: Dacinae) to novel male attractants in north Queensland, Australia, and improved lures for some pest species. Austral Entomology 54: 411–426.

Shelly TE, Manoukis NC. 2018. Capture of melon flies, *Zeugodacus cucurbitae* (Diptera: Tephritidae), in a food-baited Multilure trap: influence of distance, diet and sex. Journal of Asia-Pacific Entomology 21: 288–292.

Shelly TE, Nishimoto J. 2011. Additional measurements of distance-dependent capture probabilities for released males of *Bactrocera cucurbitae* and *B. dorsalis* (Diptera: Tephritidae) in Honolulu. Journal of Asia-Pacific Entomology 14: 271–276.

Shelly T, Kurashima R, Fezza T. 2020. Field evaluation of three-component solid food-based dispenser versus torula yeast for capturing Mediterranean and oriental fruit flies (Diptera: Tephritidae). Journal of Asia-Pacific Entomology 23: 825–831.

Shelly TE, Nishimoto J, Kurashima R. 2014. Distance-dependent capture probability of male Mediterranean fruit flies in trimedlure-baited traps in Hawaii. Journal of Asia-Pacific Entomology 17: 525–530.

Shelly TE, Nishimoto J, Diaz A, Leathers J, War M, Shoemaker R, Al-Zubaidy M, Joseph D. 2010. Capture probability of released males of two *Bactrocera* species (Diptera: Tephritidae) in detection traps in California. Journal of Economic Entomology 103: 2042–2051.

Stringer LD, Soopaya R, Butler RC, Vargas RI, Souder SK, Jessup AJ, Woods B, Cook PJ, Suckling DM. 2019. Effect of lure combination on fruit fly surveillance sensitivity. Scientific Reports 9: 2653. doi: 10.1038/s41598-018-37487-6

Tan KH, Nishida R, Jang EB, Shelly TE. 2014. Pheromones, male lures, and trapping tephritid fruit flies, pp. 15–74 *In* Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R [eds.], Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Springer, Dordrecht, The Netherlands.

Wall C, Perry JN. 1987. Range of action of moth sex-attractant sources. Entomologia Experimentalis et Applicata 44: 5–14.

White IM, Elson-Harris MM. 1992. Fruit Flies of Economic Significance: Their Identification and Bionomics. CABI, Wallingford, United Kingdom.

Wong TTY, Whitehand LC, Kobayashi RM, Ohinata K, Tanaka N, Harris EJ. 1982. Mediterranean fruit fly: dispersal of wild and irradiated and untreated laboratory-reared males. Environmental Entomology 11: 339–343.