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Distance-dependent capture probability of male Mediterranean fruit flies in trimedlure-baited traps in Hawaii

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ABSTRACT

Many countries operate regional trapping programs for the detection of exotic tephritid fruit flies, which because of their polyphagous habits pose a serious threat to fruit and vegetable crops. Detection of the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann), relies primarily on trimedlure (TML), a synthetic male-specific lure, yet few studies have measured the relationship between distance from TML-baited traps and the probability of male capture, and consequently the detection sensitivity of medfly trapping programs is largely unknown. The present study measured distance-dependent capture probabilities for male *C. capitata* in TML-baited traps using mark–release–recapture procedures. Releases were performed at distances of 25, 50, 100, and 200 m at 4 sites in Hawaii, and the resulting capture rates were used to estimate the minimum detectable population size (detection probability > 99.9%) for a trapping density of 5 TML traps per 2.59 km^2 (=1 mi^2, the density used in California, USA). Capture rates were similar for 3 of the sites (6.5%, 3.8%, 1.1%, and 0.1% for the 4 distances, respectively) and yielded an estimated minimum detectable population of ≈2300 males, a value similar to that obtained in a comparable study conducted in California. For unknown reasons, capture rates were significantly lower at the remaining site (1.8%, 0.6%, 0.1%, 0.04%) and the estimated minimum detectable population was correspondingly much larger (≈10,000 males). Implications of these results for medfly detection programs are discussed.

Introduction

Early detection of invasive insect pests is critical to safeguarding agricultural commodities. By identifying infestations quickly, when they involve small populations occupying relatively small areas, effective surveillance allows for rapid delimitation and prompt initiation of eradication strategies. Quick action limits potential damage to crops and minimizes costs associated with eradication. Detection efforts assume a variety of forms, including, among others, visual inspection for pests (Sétamou et al., 2008; Mercader et al., 2012) or pest damage (Smitley et al., 2008), acoustic sampling (Mankin et al., 2008), ultrasound imaging (Fleming et al., 2005) and aerial sampling using suction traps (Teulon and Scott, 2006). However, the predominant detection tool for invasive insect pests is trapping based on pheromones or other olfactory attractants (e.g., Sharov et al., 1995; Gandhi et al., 2010; Mori and Evenden, 2013).

Many countries operate regional trapping programs for the detection of exotic tephritid fruit flies, particularly invasive species of the genera *Bactrocera* and *Ceratitis* (e.g., Gonzalez and Troncoso, 2007; Jessup et al., 2007), which because of their polyphagous habits pose a serious threat to fruit and vegetable crops (White and Elson-Harris, 1992). Among these, the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann), infests several hundred host plant species (Liquido et al., 1990) and has spread from tropical Africa to islands in the Indian Ocean, the Mediterranean region, South and Central America, Western Australia, and Hawaii (White and Elson-Harris, 1992). In the USA, southern states with large fruit and vegetable production, particularly California, Florida, and Texas, continuously monitor for the presence of *C. capitata* using traps baited with food-based attractants or the male-specific compound trimedlure (TML hereafter; IPRFFSP, 2006). The capture of a wild medfly triggers a delimitation response and may, if multiple flies are found, prompt an eradication effort entailing heightened trapping, fruit stripping, and restrictions on the movement of agricultural commodities from the infested area (Dowell et al., 2000).

The effectiveness of medfly surveillance programs in rapidly identifying local infestations depends on many factors, but clearly the attractiveness of the trap baits is a key component. Food baits (typically, yeast solutions) are generally considered less powerful than TML (Ware, 2002), and hence knowledge regarding the attractiveness of TML to male medflies is necessary to evaluate the sensitivity of trapping programs in detecting incipient populations. Despite the large financial repercussions associated with medfly invasion, surprisingly few empirical

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data have been gathered that allow quantification of detection probabilities for infestations of varying size. Various studies (Baker et al., 1986; Baker and Chan, 1991a,b; Plant and Cunningham, 1991; Paranhos et al., 2010; Gavriel et al., 2011) have described dispersal patterns for medflies released from a central point within a network of TML-baited traps, and while the resulting data are valuable, interference among traps (i.e., the interception of flies by nearby traps before their approach to more distant traps) confounds their interpretation.

An alternative approach involves the release of known numbers of marked medfly males and the calculation of capture probabilities for flies released at varying distances around a centrally located TML-baited trap (Cunningham and Couey, 1986; Meats and Smallridge, 2007). Working in residential areas of Los Angeles, Lance and Gates (1994) adopted this approach and weighted each distance probability by the relative area of a single trap's coverage zone associated with that distance to estimate detection sensitivity (probability of capturing ≥1 fly) for populations of varying size. Considering a network of 10 TML-baited traps per 2.59 km^2 (1 mi^2), these authors reported that detection within a single generation was certain for populations exceeding approximately 2000 males. Applying their analytical methods to the data of Cunningham and Couey (1986) for a Hawaiian macadamia nut orchard, Lance and Gates (1994) reported that medfly detection in that instance would approach 100% when the population reached approximately 6000 males. This same approach was adopted to estimate detection sensitivity of trapping grids for *Bactrocera* species as well (Shelly et al., 2010; Shelly and Nishimoto, 2011).

The goal of the present study was to supply additional data on distance-dependent capture probabilities for male *C. capitata* in TML-baited traps and so obtain further estimates of the sensitivity of detection trapping systems for this species. The present research expands upon prior work in three main ways. First, the areas used differed greatly from those used in previous studies. The present study was performed in residential areas of Oahu, Hawaii, i.e., a subtropical region that was (i) climatically and botanically distinct from the Californian neighborhoods used by Lance and Gates (1994) and (ii) more heterogeneous — both botanically and physically — than the Hawaiian (monoculture) agroecosystem used by Cunningham and Couey (1986). Second, as described below, the two residential areas used in the present study were situated in rural and urban locations, respectively, thus permitting comparisons between these habitats. Third, we conducted our study using wild-like flies (see below), whereas other similar studies (Cunningham and Couey, 1986; Lance and Gates, 1994; Meats and Smallridge, 2007) used mass-reared, irradiated (sterilized) males. This distinction appears important as data indicate that wild and mass-reared males vary in their responsiveness to TML (Wong et al., 1982; Shelly and Edu, 2009).

Materials and methods

Study insects

The flies used in this study derived from a laboratory colony started with approximately 500 individuals that emerged from coffee (*Coffea arabica* L.) berries collected from a commercial field near Haleiwa, Oahu, during October–November, 2012. The berries were held for 2 weeks in screen–mesh baskets over vermiculite, which served as a pupation substrate. Pupae were sifted and then placed in screen cages (60 cm × 45 cm × 30 cm) along with food (5:1 mixture (v:v) sugar: yeast hydrolysate) and water for the emerging adults. Perforated plastic bottles (volume 250 ml) containing sponges soaked in orange juice were introduced into the cages for 24 h for oviposition. Eggs were rinsed from the bottles with tap water and placed on standard larval diet (Tanaka et al., 1969) in trays placed over vermiculite. As the colony increased in size, we placed 50 ml of pupae (≈2500 pupae) per cage. All developmental stages were held at 22–27 °C, 50–75% RH, and under natural photoperiod (approximately 12:12 L:D). When used in the releases, the flies were 3–6 generations removed from the wild.

The males used for releases were separated from females within 48 h of eclosion (well before flies became sexually mature), held in cubical screen cages (30 cm per side; ≈500 males/cage), and released when 7–9 days old. In field-cage mating tests (Shelly, unpublished data), we observed intense calling and mating activity by males from 5 to 7 days of age onward, and therefore the released males were assumed to be sexually mature. Released males were marked with different colors of fluorescent dye corresponding to different release distances from a trap site. Powdered dye was applied at the rate of 2 g/L to pupae 2 days prior to emergence. Emerged adults retain dye particles on the collapsed ptilinum, which may be viewed with a dissecting microscope under UV (blacklight) by crushing the head with a forceps. In most cases, dye was also visible on the exterior body surface. Males were marked with a distance-specific color for 3 of the 4 release distances (see below; 25 m — signal green; 100 m — blaze orange; 200 m — horizon blue; DayGlo Color Corp., Cleveland, OH, USA) but were unmarked for 1 of the release distances (i.e., 50 m). Wild medflies have been found in the 2 areas used in this study (described below) but only sporadically and in very low numbers (Shelly, unpublished data). Consequently, we assumed that any trapped, unmarked male was a released fly. Released flies were not irradiated.

During colony initiation and establishment, we conducted flight ability tests according to an internationally accepted protocol (FAO/IAEA/USDA, 2003), which entails placing a known number of pupae in a test container (vertical tube) and then recording the number of adults that later exit (i.e., fly out of) the test container. Based on 10 replicates (tubes), these flight ability scores averaged 81% (range: 72%–90%). As is evident, however, this measure is a composite index that includes both adult emergence and subsequent flight from test containers. As our releases involved only fully emerged, morphologically intact males, we also computed an adjusted flight ability, which described the relative number of flies escaping the containers based on the number of successfully emerged adults. On average, the adjusted flight ability was 88% (range: 83%–95%), and, as described below, this value was used to modify (i.e., increase) release numbers to account for morphologically intact, yet non-flying, adult males.

Study sites

Releases were conducted in two lowland areas (<100 m elevation) on Oahu during February–April, 2013. Waimanalo was a rural location, with houses scattered amidst commercial nurseries and farms as well as undeveloped lots with various woody and herbaceous plants. Common host plants included citrus (*Citrus* spp.), papaya (*Carica papaya* L.), mango (*Mangifera indica* L.), and guava (*Psidium guajava* L.). The other site, Manoa, was an urban, residential neighborhood of Honolulu that contained single-family homes with small lawns and backyard gardens. Host plants present included primarily mango, papaya, and citrus trees. At both locations, average daily minimum and maximum temperatures were approximately 21 °C and 27 °C, respectively, during the study period.

Trimedlure-baited traps

Jackson traps (Scentry Biologicals, Inc., Bozeman, Montana) were used exclusively following IAEA (2003) guidelines. Traps contained a removable sticky insert to entrap the flies and were baited with polymeric plugs containing 2.0 g of TML (Scentry Biologicals, Inc.), a male-specific attractant used in medfly detection programs worldwide (IAEA, 2003). The traps contained no insecticide. TML plugs remain effective for long periods (≈6 weeks, IAEA, 2003), but to avoid potential effects of weathering on lure attractiveness, we replaced plugs every 2–3 weeks in the individual traps. Traps were suspended 1.5–2.0 m above ground within the foliage on available (i.e., rooted, not potted) non-host plants.