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Assessing the impact of areawide pheromone trapping, pesticide applications, and eradication of infested date palms for *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) management in Al Ghowaybah, Saudi Arabia☆

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ABSTRACT

The red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is a highly destructive pest of date palms, *Phoenix dactylifera* L. (Arecales: Arecaceae), in Saudi Arabia. Data spanning a six year period (2007–2012) from Al Ghowaybah, a 1104 ha date producing region in the Al Ahsaa Directorate in Saudi Arabia, were analyzed to assess the impact enhanced management efforts that commenced in Oct. 2009 had against this pest. Within six months of initiating the areawide management program significant reductions in the mean monthly number of weevils trapped and percentage traps with *R. ferrugineus* were detected. Mean monthly trap captures of *R. ferrugineus* and the percentage of traps capturing weevils declined significantly from 2009 to 2012 by an average of 65% and 90%, respectively, indicating that trapping and dispersal pressure was significantly reduced. By 2011, average monthly trap captures and percentage of traps with *R. ferrugineus* were significantly lower than all pre-management capture data and this was maintained through 2012 when data collection ceased. Additionally, over the period 2010–2012, insecticide application and palm eradication rates dropped by 91% and 89%, respectively. The total number of *R. ferrugineus* captured in 2012 declined by 86% when compared to total captures for 2010. At the end of 2012, the estimated infestation rate of date palms in Al Ghowaybah was 0.36%, which was below the economic threshold of a 1% infestation rate set by the Directorate of Agriculture supervising the program. It is concluded that the mandatory areawide management program that commenced in Oct. 2009 against *R. ferrugineus* in Al Ghowaybah had a significant and rapid impact against this pest.

1. Introduction

Red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), is native to south and southeast Asia where it is a notorious pest of coconut palms, *Cocos nucifera* L. (Arecales: Arecaceae) (Faleiro, 2006; Murphy and Briscoe, 1999). The international movement of live coconut palms from Southeast Asia inadvertently resulted in the spread of *R. ferrugineus* into new areas. *R. ferrugineus* was first recorded outside of its home range in 1985, when it was found attacking date palms, *Phoenix dactylifera* L. (Arecales: Arecaceae) in the United Arab Emirates (Zaid et al., 2002; Faleiro et al., 2012). Subsequent movement of infested plant material introduced this pest into Saudi Arabia in 1987 where it presented a significant threat to this country's multi-million dollar date industry (Faleiro et al., 2011, 2012; Murphy and Briscoe, 1999). *R. ferrugineus* is considered the most serious arthropod pest

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attacking *P. dactylifera* in the Middle East and parts of the Maghreb region of North Africa (Faleiro et al., 2012). Up to 50% of date producing nations (El-Mergawy and Al-Ajlan, 2011), which collectively produce 67% of the world's dates (El-Juhany, 2010), have recorded the presence of *R. ferrugineus*. This weevil has also caused significant mortality of Canary Island palms, *Phoenix canariensis* Chabaud, an important ornamental palm, around the Mediterranean (Dembilio et al., 2012; Faleiro, 2006). Ecological niche modeling has identified numerous additional areas that are predicted to be susceptible to invasion by *R. ferrugineus* (Fiaboe et al., 2012).

R. ferrugineus induced palm mortality results from internal feeding by weevil larvae and to a lesser extent, adults. The entire larval life cycle is concealed within the palm. For *P. dactylifera*, attacks commence when females lay eggs on wounds, or cracks and crevices on the trunk around the collar region near the roots or offshoots, or the base of fronds in young date palms, with trees <20 yr old being most preferred (Faleiro et al., 2012). In date palms, 90% of infestations are reported to occur on the palm trunk within 100 cm from the ground (Sallam et al., 2012). In Saudi Arabia, it is estimated that 70% of infested *P. dactylifera* are <20 yr of age, with 75% of this cohort being in the age group six to 15 yr (El-Sabea et al., 2009). This internal feeding, when severe enough, can weaken the trunk causing the collapse and premature death of *P. dactylifera* (Faleiro, 2006). Conversely, female *R. ferrugineus* preferentially oviposit eggs in the crown of *P. canariensis* where they chew holes in the base of fronds into which eggs are laid singly. Females then produce a secretion to seal these oviposition wounds (Dembilio et al., 2012). Larvae hatch from eggs and feed as they burrow towards the center of the palm. *P. canariensis* die once the apical growing area of the palm has been destroyed by larval and adult feeding over the course of 2–3 generations (Llácer et al., 2012). Prepupal larvae form distinct pupal cases from palm fibers within which they pupate (Murphy and Briscoe, 1999). Pupal cases can be found tightly wedged in tunnels and holes at the bases of fronds. Occasionally, pupal cases may be found on the ground under heavily infested palms.

Control of *R. ferrugineus* with pesticides in either a preventative or curative approach is particularly challenging because this pest is concealed deep inside palm trunks (Faleiro, 2006; Llácer et al., 2010; Murphy and Briscoe, 1999). Systemic insecticides may be the best chemistries available for controlling *R. ferrugineus* once palms are infested (Llácer et al., 2012). Ambient temperatures exert a very strong effect on the oviposition behavior of females and developmental times for all pre-imaginal stages of *R. ferrugineus*. This subsequently affects larval survivorship rates and the number of generations expected in any geographic location, which in turn affects infestation severity (Dembilio and Jacas, 2011; Dembilio et al., 2012). However, fermentation processes which occur within *R. ferrugineus* infested palms may obviate predictions based on ambient air temperatures because internal temperatures are unlikely to be the same as those recorded outside of the palm (Llácer et al., 2012).

Saudi Arabia is the second largest producer of dates globally. Plantations occupy ~151, 000 ha and 23 million trees comprised of 320 varieties produce ~970,000 tonnes of fruit per year, which accounts for ~15% of world production (El-Juhany, 2010). It has been estimated that loses due to eradication of date palms infested with *R. ferrugineus* costs Saudi producers US$1.74–8.69 million annually (El-Sabea et al., 2009). The destructiveness of *R. ferrugineus* in Saudi Arabia has been attributed, in part, to flood irrigation methods that favor *R. ferrugineus* survival during dry periods, and harvesting, pruning, and offshoot removal practices that create wounds favorable to attack by weevils, improper quarantines of infested planting material to prevent spread, and an overall lack of effective coordinated areawide management programs (Mukhtar et al., 2011). Infestation problems may be further exacerbated by the widespread planting of the most popular date variety, 'Khalas', which appears to be a very good host for *R. ferrugineus* (Sallam et al., 2012).

Development of management plans for *R. ferrugineus* advanced significantly with the characterization (Hallet et al., 1993) and subsequent commercialization of the male aggregation pheromone, a two component blend of "ferrugineol" (4-methyl-5-nonanol) and "ferrugineone" (4-methyl-5-nonane). Pheromone technology has been widely used to manage *R. ferrugineus* in commercial date plantations (e.g., Saudi Arabia [Faleiro et al., 2010] and the United Arab Emirates [Abbas et al., 2006]) and for monitoring populations in urban areas (e.g., Spain). The *R. ferrugineus* aggregation pheromone has been used in Saudi Arabia since 1994 as part of an evolving areawide pest management program designed to suppress populations through the mass trapping and killing of adult weevils, which occurs in conjunction with pesticide applications to infested *P. dactylifera* plantations and eradication of severely infested palms (Faleiro et al., 2011).

Areawide pest management programs aim to provide long term control of economically important pests using coordinated suppression tactics over large areas that are defined by a geographic entity (e.g., a production region [Elliot et al., 2008]) rather than temporarily controlling the target pest on a small scale field-by-field basis (Elliot et al., 2008; Faust, 2008). Consequently, areawide management programs are "whole ecosystem experiments" which are subjected to experimental perturbation (i.e., the management program), they are often not replicable (because of cost, public policy, or the uniqueness of the system under study) and they often lack controls (Carpeneter et al., 1995). Ideally, systems are monitored for sufficiently long enough prior to the perturbation and pre and post-perturbation data are compared to assess the effect of the treatment (Carpeneter et al., 1995). Pest suppression technologies used in areawide management programs include biological control, pheromone-baited traps, host plant resistance, eradication of infested plants, and pesticides (Faust, 2008). Program evaluation is needed to assess effectiveness and to ensure suppression goals are being met (Faust, 2008). Assessment metrics include measures of pest densities before and after program initiation (Lloyd et al., 2010; Mau et al., 2007; Vargas et al., 2008), and reductions in crop losses and pesticide application frequencies (Knight, 2008; Vargas et al., 2008) within treatment zones.

A national campaign in Saudi Arabia for areawide control of *R. ferrugineus* is advocating improved sanitation, eradication of heavily infested palms, pesticide treatments of all infested palms, and the use of pheromone traps to mass trap weevils and to use trap capture rates to assess the efficacy of control practices (Mukhtar et al., 2011). The Directorate of Agriculture, Ministry of Agriculture, Kingdom of Saudi Arabia administers the Al Ahsaa (=Al Hassa) oasis in Saudi Arabia's Eastern province, an area with ~3 million date palms. Starting in mid-October 2009, the Directorate moved aggressively against *R. ferrugineus* and implemented a mandatory areawide management program in the Al Ghowaybah District, an important date producing area close to Hofuf, the largest city within the Al Ahsaa Governorate. The Al Ghowaybah date industry is worth ~US$14.8 million per year. To assess the impact of areawide management practices, in particular, pesticide applications, eradication of infested palms, and elevated densities of pheromone traps for suppressing *R. ferrugineus* in date plantations in Al Ghowaybah, a six year data set (2007–2012) was analyzed, and was comprised of three years of data prior to the initiation of the program and three years of data under areawide management. The results of analyses assessing pesticide application frequencies and tree eradication rates, on weekly weevil trapping records are presented here.

2. Materials and methods

2.1. Characterization of the Al Ghowaybah district and R. ferrugineus treatments

The Al Ghowaybah treatment district is composed of 1140 ha divided into five sectors; (A) 260, (B) 165, (C) 170, (D) 495, and (E) 50 ha which encompass 222 date plantations that range in size from 5 to 20 ha. Of the ~185,000 palms in Al Ghowaybah, the 'Khalas' cultivar accounts for ~85% of dates grown and ~70% of palms are less than 25 yr of age with the remaining ~30% being less than 5 yr. Palms in these age categories are extremely vulnerable to infestation by *R. ferrugineus* (Faleiro et al., 2012). This area is administered by 15 engineers (officers of the Directorate of Agriculture, Al Ahsaa) that check and service *R. ferrugineus* pheromone traps. The standard 5 l capacity four window bucket trap baited with aggregation pheromone (Ferrolure™ 700 mg manufactured by ChemTica International S.A., Costa Rica), ~200 g of fermented dates as food bait, and 1 l of water was used to trap and kill weevils (ethyl acetate synergist and insecticides were not added to traps). Traps were partially inserted into hollowed out date palm trunks set ~0.5 m above the ground. Traps were serviced weekly and dates and water were replaced as needed. Pheromone lures were replaced at ~6 wk intervals. The number and sex of *R. ferrugineus* captured by trap number were recorded each week. From 1 Jan 2006 to 17 Oct 2009, 91 pheromone traps were deployed throughout Al Ghowaybah, a rate of ~0.08 traps per ha. From 17 Oct 2009 to 31 Oct 2009 traps were increased to 300, a rate of ~0.3 traps per ha. By 6 Nov 2009, 1001 traps were deployed, a rate of ~0.9 traps per ha. In addition to increased trap deployment in 2009, the frequency of pesticide applications and tree eradications increased 38 times and three times, respectively, when compared to 2007 and 2008.

Four treatment teams were responsible for scouting plantations for infested palms to be eradicated, for curative pesticide applications to palms suspected to be in the early stages of infestation, and applying preventative or prophylactic treatments to protect uninfested healthy date palms. The insecticides (contact and systemic) and one synergist used for *R. ferrugineus* control are presented in Table 1. The spray program was comprised of 15 different products representing four insecticide classes and nine different active ingredients. Heavily infested palms were removed from plantations and destroyed. The numbers of palms treated with pesticides and eradicated were recorded for each year of this study.

2.2. Data analyses

Mean weekly trap capture rates for *R. ferrugineus* were calculated together with the weekly percentage of traps with weevils. Mean weekly temperatures corresponding to trapping intervals were calculated from "Al Ahsa" (=Al Ahsaa, =Al Hassa) weather station data using the "custom" option available from Weather Underground (http://www.wunderground.com/history/airport/OEAH/2013/02/19/DailyHistory.html) to determine if *R. ferrugineus* flight phenology as determined by percentage of traps with weevils was influenced by mean daily temperatures.

A mixed model with a temporarily correlated covariance structure was used to analyze the temporal trend (i.e., the effects of month and year and their interaction effects) for the mean monthly number of *R. ferrugineus* captured per pheromone trap (a measure of trapping pressure) and the monthly percentage of traps (a measure of dispersal pressure) with *R. ferrugineus*. Because traps were not always sampled at the exact same time intervals, a spatial power law covariance structure was used in which the correlation declined as a function of time (Littell et al., 2008). Data were combined by month, and comparisons were made between months and across years for all data from 2007 to 2012. If necessary, data were log transformed if normality assumptions were not met and all analyses were performed using Proc Mixed in SAS (SAS Inc. 2008) at the 0.05 level of significance. Data presented in Fig. 4A are back transformed.

Table 1
List of insecticides used for *Rhynchophorus ferrugineus* control in Al Ghowaybah, Al Ahsaa, Saudi Arabia.

Active ingredient (A.I.)	Insecticide class	No. of products used with A.I.
Beta-cyfluthrin	Synthetic pyrethroid	3
Carbaryl	Carbamate	1
Chlorpyrifos	Organophosphate	1
Cypermethrin	Synthetic pyrethroid	2
Deltamethrin	Synthetic pyrethroid	2
Dimethoate	Organophosphate	1
Fenitrothion	Organophosphate	2
Imidacloprid	Neonicotinoid	2
Malathion	Organophosphate	1
Piperonyl butoxide	Synergist	1

3. Results

The average numbers of weevils caught per trap per week (trap pressure) were greatest in 2009 with more than six weevils being captured on average per trap from the beginning of May to the end of Aug. (Fig. 1C), which was prior to the enhanced trapping program that started in mid-Oct. 2009. For 2010, 2011, and 2012, average weevil captures per trap typically remained below three (Fig. 1D–F). The proportion of female weevils captured in traps was female biased, and this bias was very consistent across months and years averaging 0.68, 0.68, 0.62, 0.67, and 0.69 for 2007, 2008, 2009, 2010, and 2011, respectively (Fig. 2). Sex ratio data were not available for 2012, but across all months and years data were available the average proportion of females captured was 0.67 ± 0.01 (SE). Weevil captures, as measured by percentage traps (dispersal pressure) with weevils, tended to be higher over the period Jan.–May which corresponded with warming spring and moderate early summer temperatures. Percentage trap captures were generally lower over Jul.–Dec., when weekly summer temperatures were averaging >35 °C before transitioning in Oct. to lower winter temperatures (Fig. 3A–F). However, this general seasonal trapping trend was least obvious in 2012 when average weevil numbers per trap (Fig. 1F) and percentage traps capturing weevils (Fig. 3F) were the lowest recorded during this study.

The mixed model analysis indicated a significant effect of month ($F = 9.83$, d.f. = 11, $P < 0.0001$), year ($F = 169$, d.f. = 5, $P < 0.0001$) and month*year interaction ($F = 3.39$, d.f. = 55, $P < 0.0001$) for the mean number of *R. ferrugineus* captured per trap each month, indicating that the monthly mean number of weevils captured differed significantly between months and trapping trends were significantly different across years (Fig. 4A). The mean monthly number of *R. ferrugineus* was significantly greater for 11 of 12 months in 2009 where compared to other years (Fig. 4A). Following 2009 when areawide management was aggressively implemented, the mean number of *R. ferrugineus* trapped per month fell to the lowest levels recorded in 2011 and remained there through 2012. Average monthly trap captures for 2011 and 2012 were significantly lower than 2007 and 2008 capture rates prior to areawide program implementation (Fig. 4A). This result indicated that trapping pressure declined significantly and was maintained at low levels as a result of the control program. For the percentage of traps capturing *R. ferrugineus* each month, there was a significant effect of month ($F = 15.33$, d.f. = 11, $P < 0.0001$), year ($F = 197$, d.f. = 5, $P < 0.0001$),

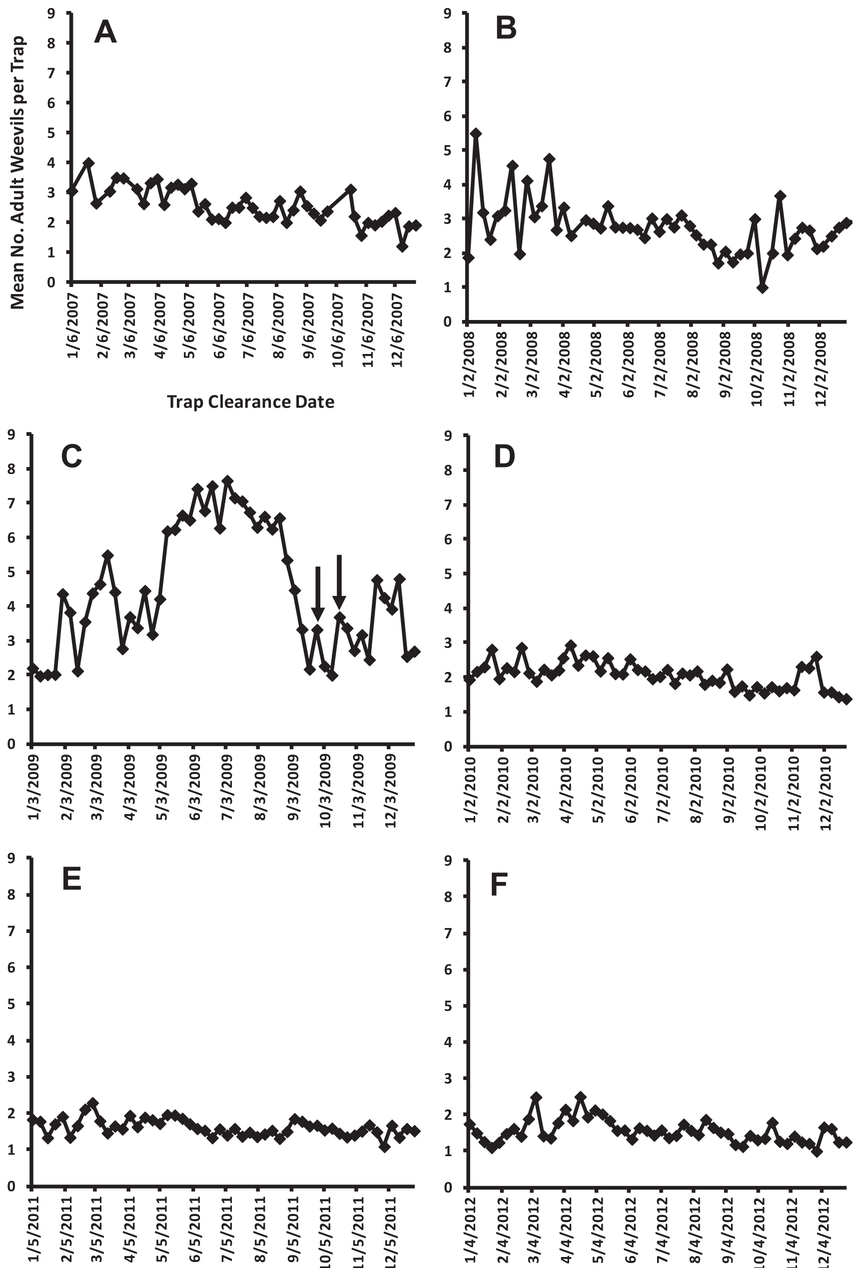

Fig. 1. Mean weekly captures per pheromone bucket trap for *Rhynchophorus ferrugineus* in Al Ghowaybah in 2007 (A), 2008 (B), 2009 (C), 2010 (D), 2011 (E), and 2012 (F). Arrows in C indicate Oct. 17 and Nov. 6 2009, the times when pheromone traps were increased from 91 to 300, and from 300 to 1001, respectively.

and month*year interaction ($F = 3.47$, d.f. = 55, $P < 0.0001$) indicating that the percentage of traps that captured *R. ferrugineus* each month changed significantly during the course of a year and these trends were also significant between years (Fig. 4B). Monthly percentage records for traps with *R. ferrugineus* were significantly lower by 2011, and this steep downward trend commenced in May 2010, approximately six months after the initiation of the areawide management program in Oct–Nov 2009. By 2010, the yearly average percentage (i.e., the grand average across all months in that year) of traps with weevils was 35% ± 4% (SE) (in 2009 the yearly average was 62% ± 6%), and by 2011 and 2012, yearly average percentage of traps with *R. ferrugineus* had dropped to 17% ± 2% and 6% ± 1%, respectively (Fig. 4B).

Increased management efforts that commenced in Oct. 2009 and their subsequent impacts resulted in an 86% decrease in the total number of adult *R. ferrugineus* captured in 2010 (peak of total weevil captures which resulted from the 11 fold increase in pheromone traps in Oct. 2009) when compared to total captures for 2012 (Fig. 5A). A 91% decrease in the total number of palms being preventatively sprayed or curatively treated for *R. ferrugineus* infestations was observed between 2009 and 2012 (Fig. 5B), and an 89% decrease in the total number of palms eradicated from 2009 to 2012 was recorded (Fig. 5C). At the end of 2012, surveys of date plantations in Al Ghowaybah by the Directorate of Agriculture, Al Ahsaa, concluded that 0.36% of date palms surveyed in the District were infested with *R. ferrugineus*, which was below the target 1% palm infestation rate set by the Directorate.

4. Discussion

R. ferrugineus infestations of date palms in Al Ghowaybah increased significantly in 2009. In response to this outbreak, the

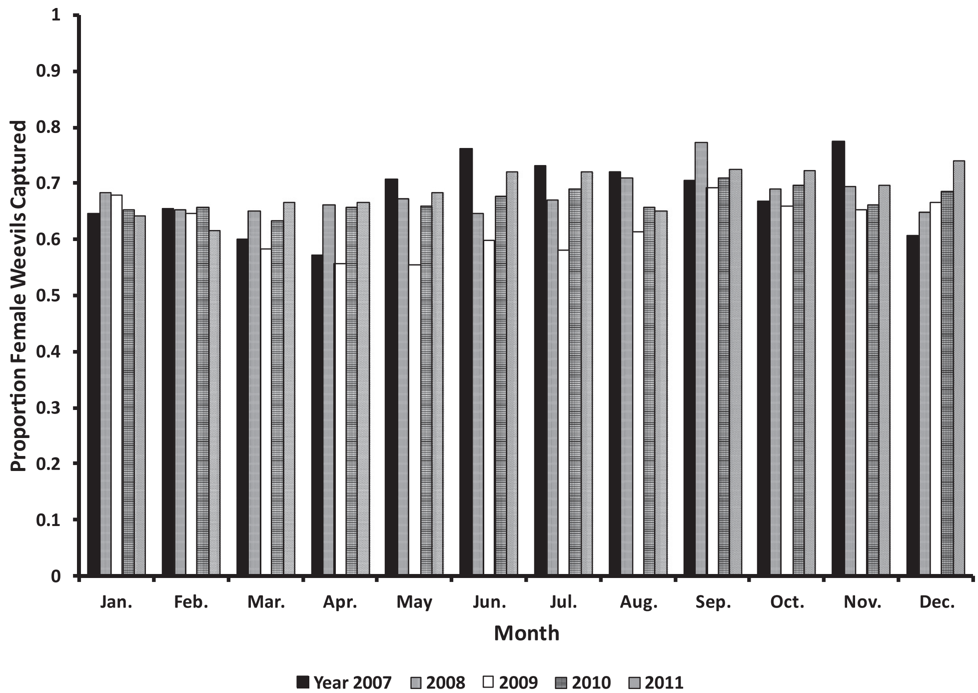

Fig. 2. Proportion of female *Rhynchophorus ferrugineus* captured monthly across years in pheromone bucket traps deployed in Al Ghowaybah.

Directorate of Agriculture in Al Ahsaa increased areawide treatments against *R. ferrugineus* on three different fronts: (1) the number of pheromone traps throughout the 1140 ha management area was increased 11 fold from 91 ($\sim$0.3 traps per ha) in mid-Oct. 2009 to 1001 ($\sim$0.9 traps per ha) traps by early Nov. 2009; (2) the number of date palms treated with pesticides increased 48 fold from 11,000 palms in 2008 to 531,590 in 2009, and (3) eradication of *R. ferrugineus* infested palms increased three fold from 2008 (1026 infested palms removed and destroyed) to 2009 (3097 date palms eradicated). These enhanced management practices in Al Ghowaybah had a rapid effect on *R. ferrugineus* populations as determined by the average number of weevils captured monthly in pheromone bucket traps and the monthly percentage of traps with weevils. In 2009, prior to the Oct. increase in pheromone trap numbers, $\sim$5 adult weevils were captured per trap per week, compared to an average of 1.6 weevils per trap for 2012, which represents an $\sim$68% decrease in the average number of weevils captured per trap. The percentage pheromone traps capturing *R. ferrugineus* in 2009, prior to the Oct. trap increase was 70%. By 2012, the average yearly percentage of pheromone traps capturing weevils was 6.5%. Similarly, programs in Egypt that used a combination of control strategies (i.e., pheromone traps combined with either applications of entomopathogenic fungi or insecticides in date plantations) to control *R. ferrugineus* showed significant declines in weevil densities and percentage of infested palms within a 12-month period (Sewify et al., 2010). This result supports the observations made here that sustained control tactics can help to quickly reduce *R. ferrugineus* densities and associated economic losses.

Female *R. ferrugineus* captured in pheromone traps from date plantations of Saudi Arabia tend to be young and gravid and capable of laying sizeable clutches of fertile eggs that subsequently hatch into damage inflicting larvae (Abraham et al., 2001). The enhanced trapping program in Al Ghowaybah since Oct. 2009 significantly increased the capture of female weevils, which significantly curtailed pest pressure from 2010 to 2012 as evidenced from reduced trap captures and eradication of infested palms over this time period. Specifically, pest pressure reduction was reflected in estimates of trapping and dispersal pressure, which declined significantly from 2009 to 2012 by 65% and 90%, respectively. The data sets used for these analyses, which span six years, may also be of significant use for geographic information system (GIS) analyses to assess control impacts by specific localities (Massoud et al., 2012) and to pinpoint regions where greater control efforts could be needed. Additionally, GIS may elucidate critical factors either enhancing or diminishing pest suppression (e.g., tree age, spacing between palms, cultivar type, or irrigation practices).

It is likely that intensive *R. ferrugineus* management practices in Al Ghowaybah will need to be sustained at this current high level as long as new plantations are being developed and the majority of dates are <20 yr old, an age susceptible to attack (Faleiro et al., 2012). The efficacy of any management program is highly dependent on accurate and time efficient pest sampling. The recommended action threshold for executing *R. ferrugineus* treatments (mass pheromone trapping and pesticide applications) is when 1% of date palms are infested (Faleiro et al., 2010). Sequential sampling plans based on the number of infested palms detected per unit area sampled have been developed to guide decisions pertaining to the initiation of control programs based on a 1% action threshold (Faleiro et al., 2010). This decision-making approach based on tree inspections is considered more accurate than relying on pheromone trap capture rates which may either under or over estimate pest and subsequent infestation severity in the field (Faleiro et al., 2010). However, weevil infestations in plantations are highly aggregated and the major shortcoming with tree inspections for *R. ferrugineus* management is being able to quickly and accurately identify palms in the very early stages of infestation when curative treatments are most likely to be successful. Several detection methods have been investigated including acoustic sensors (Mankin, 2011), and dogs trained to respond to odors released by infested palms (Mukhtar et al., 2011), but these are not amenable to rapid processing. Future efforts in early detection research could focus on the use of field-deployable automated electronic sensors

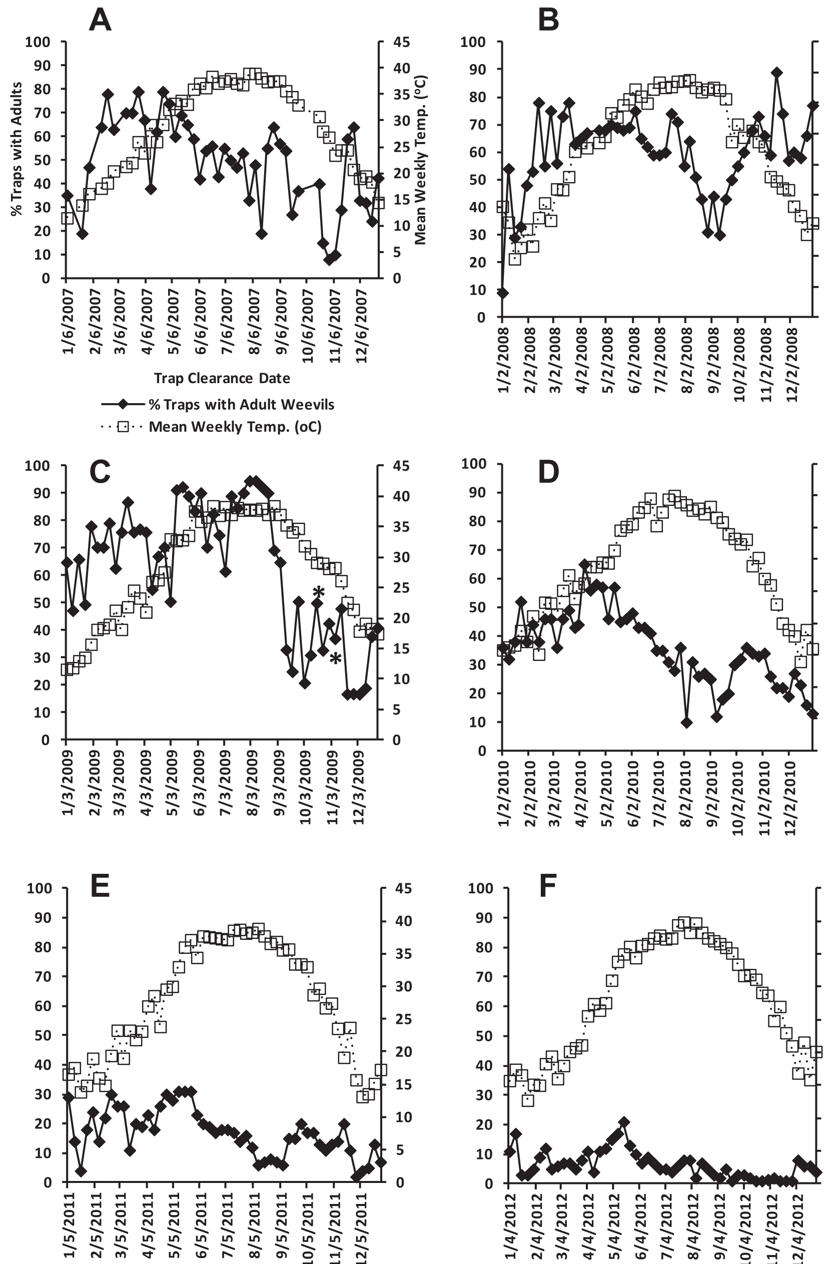

Fig. 3. Weekly percentage of pheromone bucket traps with *Rhynchophorus ferrugineus* captured in Al Ghowaybah and mean weekly temperatures in 2007 (A), 2008 (B), 2009 (C), 2010 (D), 2011 (E), and 2012 (F). Asterisks in C indicate Oct. 17 and Nov. 6 2009, the times when pheromone traps were increased from 91 to 300, and from 300 to 1001, respectively.

that rapidly identify unique volatile chemical signatures specific to *R. ferrugineus* infested palms.

If pheromone traps are to be a significant component of management efforts, findings by Faleiro et al. (2011) suggest that 1 trap per ha is sufficient to mass trap *R. ferrugineus* when palm infestation rates are <1%. If palm infestation rates are >1% then 10 traps per ha are recommended, but 4–7 traps per ha may be sufficient if resources are limited (Faleiro et al., 2011). Mass trapping programs in Israel utilizing ~10 traps per ha and insecticide treatments were very effective at reducing *R. ferrugineus* densities and date palm infestation rates (Soroker et al., 2005). The current estimated infestation rates for date palms in Al Ghowaybah is 0.36%, a level at which 1 pheromone trap per ha should be capable of suppressing outbreaks of *R. ferrugineus* (Faleiro et al., 2011). Despite their efficacy, baited pheromone traps require a very high level of servicing, as bait and water need to be replaced regularly and captured weevils removed. Management time and cost increases if insecticides are being added to bucket traps, and pheromone lures and synergists need to be replaced. A promising alternative to baited pheromone bucket traps are bait-free attract and kill technologies which use an inert synthetic matrix from which ferrugineol (15%), the aggregation pheromone is released, and within which a contact insecticide (5%) is contained (El-Shafie et al., 2011). In Al Ahsaa, bait-free attract and kill traps have been shown to be as effective as traditional pheromone bucket traps for attracting *R. ferrugineus*. Importantly, the inert matrix containing aggregation pheromone and insecticide can be applied directly to the trunks of palms >20 yr or non-host trees at heights where they pose no risk to non-target organisms (e.g., domestic animals and people). Weevils are attracted the matrix because of the pheromone and are

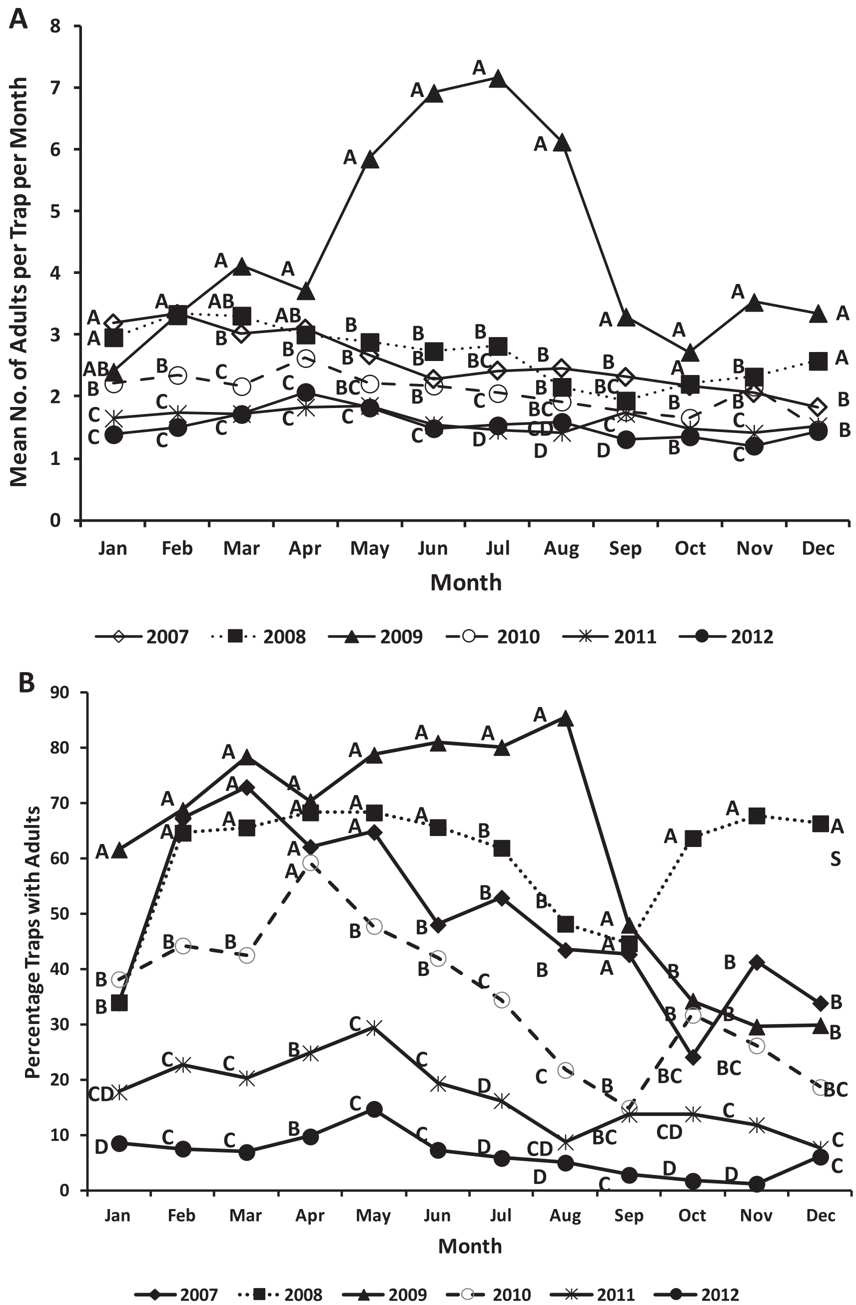

Fig. 4. Mean monthly trap captures of *Rhynchophorus ferrugineus* (A) and monthly percentage of traps with adult weevils (B) over the period 2007 to 2012. Data points with different letters within a month across years indicate significant differences at the 0.05 level.

killed or incapacitated when they make contact with the insecticide impregnated matrix. Bait-free attract and kill strategies may significantly reduce costs and could allow per ha deployment of pheromone at rates much greater than what is feasible with baited bucket pheromone traps for *R. ferrugineus* management (El-Shafie et al., 2011).

In conclusion, *R. ferrugineus* is an extremely destructive pest that is very difficult control because it is concealed within the trunks of date palms for most of its life cycle. Effective management techniques are available and include pheromone traps, insecticides, and rouging of infested palms. However, these treatments are costly and very labor intensive, and limited to some degree by the lack of accurate detection systems that can rapidly identify palms in the early stages of infestation when curative pesticide treatments are most likely to be effective. Aggressive implementation of mass trapping, pesticide applications and tree eradication had a marked impact on *R. ferrugineus* in Al Ghowaybah, but a very high reliance on just four insecticide classes in this program may make the development of pesticide resistance likely, which could jeopardize the efficacy and future use of attract and kill baits. Management of *R. ferrugineus* may be enhanced from research addressing the effects of irrigation methods, spacing designs that reduce humidity levels and increase sun penetration between palms in plantations, mixed cultivar plantings on pest infestation rates, and perhaps, the development of transgenic dates that express insecticidal genes lethal to red palm weevil larvae and adults.

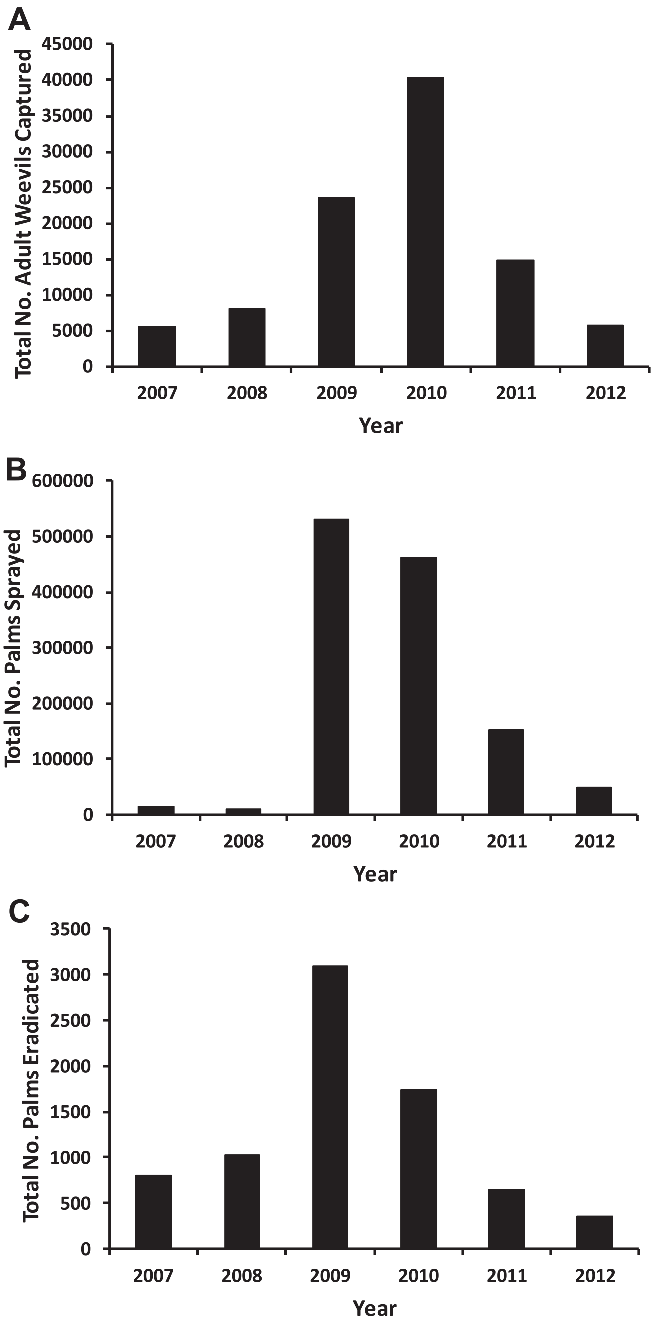

Fig. 5. Total number of adult *Rhynchophorus ferrugineus* captured per year in pheromone bucket traps (A), total number of date palms treated with pesticides per year (B), and the total number of date palms eradicated per year in Al Ghowaybah.

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