AFPP – PALM PEST MEDITERRANEAN CONFERENCE
NICE – 16, 17 AND 18 JANUARY 2013

EARLY DETECTION AND MONITORING OF RED PALM WEEVIL: APPROACHES AND CHALLENGES

V. SOROKER[1], P. SUMA[2], A. LA PERGOLA[2], Y. COHEN[1], Y. COHEN[1], V. ALCHANATIS[1], O. GOLOMB[1], E. GOLDSHTEIN[1], A. HETZRONI[1], L. GALAZAN[1], D. KONTODIMAS[3], C. PONTIKAKOS[3], M. ZOROVIC[4], M. BRANDSTETTER[5]

[1]Agricultural Research Organization, The Volcani Center, Israel, sorokerv@volcani.agri.gov.il
[2]Dipartimento di Gestione dei Sistemi Agroalimentari e Ambientali - Applied Entomology section University of Catania, Italy, suma@unict.it
[3]Benaki Phytopathological Institute, Stefanou Delta Street, Athens 14561, Greece, d.kontodimas@bpi.gr.
[4]National Institute of Biology, Ljubljana, Slovenia, Maja.Zorovic@nib.si
[5]Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft Institut für Waldschutz, Austria, martin.brandstetter@bfw.gv.at

SUMMARY
The manuscript reviews the current state of knowledge as well as research and development on detection and monitoring of the Red Palm Weevil (RPW). Despite the intensive effort that has been put in the development of the RPW detection techniques, technologies including chemical and acoustical methods, are yet falling back from being practical or feasible, leaving detection dependent mainly on visual inspection in most areas. Pros and cons of various detection methods are presented in Table 4. Considerable effort is still required to improve the efficacy and sensitivity of the already available methods such as acoustic and olfactory detection by dogs; protocols for inspection of commonly affected palms are needed, while visual thermal detection is under evaluation. No single method is adequately sensitive and cost effective and there is still no good solution for area wide detection. Remote detection by thermal and olfactory cues is very promising for area wide inspection but still far from application. At the moment a combination of methods and technologies is required to form an optimal solution.

Key words: *Rhynchophorus ferrugineus*, detection, acoustics, olfaction, remote imaging.

RESUME
Cet article fait la synthèse des connaissances actuelles, des recherches et des développements en cours sur la détection et la surveillance du Charançon Rouge du Palmiers (CRP). En dépit d'efforts importants pour développer des outils de détection du CRP, les technologies de détection chimique et acoustique ne fournissent pour le moment aucun moyen pratique et applicable et la détection repose essentiellement sur l'inspection visuelle. Les pour et les contre des différentes méthodes de détection sont présentés au tableau 4. Un effort important reste nécessaire pour améliorer l'efficacité et la sensibilité des méthodes disponibles basée sur l'acoustique et l'olfaction notamment pour utiliser des chiens ; des protocoles pour la détection visuelle des palmiers les plus couramment infestés manquent ; et la détection par imagerie thermique est en cours d'évaluation. Aucune méthode n'est par elle-même suffisamment sensible et rentable et il n'existe encore aucune solution satisfaisante applicable à grande échelle. La détection optique ou olfactive à distance est très prometteuse pour cela encore loin d'une application. L'association de plusieurs méthodes et techniques demeure nécessaire aujourd'hui pour une détection optimale.

Mots-clés : *Rhynchophorus ferrugineus*, détection, acoustique, olfaction, télédétection

INTRODUCTION

Management of any pest requires accurate monitoring of pest population, forecasting its dispersal and evaluating the success of eradication efforts. Early detection of Red palm weevil (RPW, *Rhynchophorus ferrugineus* Olivier, 1790) infestation is particularly crucial as palms at early infestation stage, with apical meristem (the palm heart) not yet damaged and with the trunk still stable, can be treated and usually recover. However, as RPW is developing inside the palm, well hidden from human eye, the detection process is a challenge. Prevention of further spread of this invasive pest requires RPW monitoring especially at ports of entry and at new infestation foci.

Various methods and approaches were evaluated over the years for early detection of RPW infestations. Here we aim to review common, recently developed detection methods, developing approaches, discussing their advantages, pitfalls, and potential future implementation in RPW management.

VISUAL INSPECTION

The most obvious approach to infestation detection is visual examination of a tree. Visual symptoms of RPW activity depend on the infestation stage: tunnels on the trunk and at the bases of frond's petiole; oozing of thick brown liquid, frass composed of chewed plant tissue with fermenting odor; remains of weevils and their pupae cocoons around the tree; and at the most severe cases of infestation breaking of trunk or the topping (Faleiro, 2006). However, except for the last stage of infestation (dead or broken palm), early symptoms are very much dependent on the site of infestation, on the physiological age and status of the attacked palm and also on the palm species. For example, if the RPW develops in the lower part of the trunk, which is common in date palms (*Phoenix dactylifera* L.), oozing wounds may be observed but more often, symptoms remain hidden amid offshoots, leaf bases or stem fibers. The palm may appear healthy until the damage to the trunk tissues over powers and the tree collapses. Crown infestation is common with Canary island date palms (*Phoenix canariensis* Hort. ex Chabaud), oozing does not occur but changes in crown symmetry appear. In coconut (*Cocos nucifera* L.) and Canary palms inner crown fronds tend to wilt. This is less common in date palms. Table 1 depicts some of the RPW infestation symptoms in *P. canariensis* and the associated ability to save the palm. As chewing symptoms in inner leaves is not easy to detect from a distance the cutting of an inspection/treatment "window" into the palm canopy 50-60 cm wide from the base of the canopy up to the center is advised in some areas to assist detection of early symptoms. However, this method is laborious, thus not feasible on large scale and, must be conducted with precaution since wound-released volatiles might attract wandering weevils to yet uninfested palm trees. Palm trees might not be always visibly accessible, making direct inspection unfeasible. All these make conventional early detection of RPW infestation laborious for the expert, time consuming, costly and yet inaccurate. Nevertheless specific protocols for evaluation of the most common palm species could assist for infestation assessment and monitoring palms' recovery after treatment especially if supplemented by other detection methods and thus need to be developed.

To overcome the problems of visual inspection, several approaches have been undertaken, using chemical (odour) cues, acoustic and thermal imaging techniques. Advantages and limitations of each approach and possibilities of use are discussed below.

Table 1: Assessment of RPW infestation level in the Canary palm (établissement du degré d'infestation par le CRP sur palmier des Canaries)

Characteristic	Possibility to save the tree
 Holes in one or more leaves	high
Some chewing symptoms in inner leaves	high
  Extensive chewing symptoms of ">" shape	high
Some leaves collapsed	medium
Asymmetric inner leaf growth	medium
Crown partially collapsed	low and laborious
No new inner leaves	very low
 All the crown leaves collapsed into an "umbrella" shape	None - palms cannot be recovered

CHEMICAL DETECTION

The possibility of chemical detection is based on the assumption that weevil infested palms emit characteristic volatile cues. These are derived directly from the weevils, weevils' frass, thick brown liquid, composed of chewed plant tissue with fermenting odor oozing from the wounds in the infested palm, or herbivore-induced cues. None of the specific cues emitted by the wounded palm have yet been identified. The chemical detection approach has been tested so far using sniffing dogs. Dogs are well known for their ability to detect scents of various origins such as explosives, drugs and invasive species. Dogs were previously reported to detect infested plant material (Wallner and Ellis, 1976; Welch, 1990; Schlyter, 2012). A variety of dog breeds have been employed in the past for sniffing tasks. Breeds such as Labradors, Rottweilers, Beagles and Golden Retriever are often preferred for these tasks thanks to their proven performance, easy disposition and good interaction with the public. In relation to palm pests and RPW in particular the feasibility of this approach was proven at least twice. Nakash *et al.* (2000) confirmed the ability of Golden Retrievers to successfully detect the oozing secretion collected from RPW infested date palms but the ability of trained dogs to detect the infested palm *in situ* was not proven. Suma *et al.* (unplublished data) proved the ability of one Rottweiler and two Golden Retrievers to detect various numbers of RPW larvae and/or adults partially buried in vented containers at the base of different palm species of variable age and size (*i.e. Phoenix* spp., *Chamaerops humilis* L., *Washingtonia* spp., *Sabal* spp.). After a 6-month training period, trained dogs were more than 70% accurate in finding the artificially infested canary palms regardless of the weevil instar used in the trials (Table 2).

Table 2: Mean percentages of positive indications by canine RPW detectors when allowed to inspect artificially infested Canary palms with different pest stages (pourcentages moyens de détection positive par des chiens de la présence de CRP dans des palmiers des Canaries infestés artificiellement avec différents stades du ravageur).

Type of dog*	males	larvae	females	couples
RW	61.1	72.2	61.1	61.1
GR adult	55.6	72.2	88.9	83.3
GR young	77.8	77.8	77.8	88.9
mean	**64.8**	**74.1**	**75.9**	**77.8**

*RW= Rottweiler; GR = Golden retriever

It should be noted that under conditions of natural infestation, palm volatile response to the RPW may be species specific, thus different palms producing distinct response to the red palm infestation. Nevertheless, the above mentioned experiments indicate the feasibility of employing dogs as an effective and rather inexpensive tool for the detection of infested palms once an efficient training protocol is established and a dedicated team with specially trained dogs is maintained.

Still, based on our preliminary studies in date plantation, dogs-assisted detection has its shortcomings: it does not appear to be applicable for large scale operations such as occur in date plantations with hundreds or even thousand palms. Dogs' working abilities have physiological constrains especially during the hot time period (*i.e.* in the summer time) limiting their working ability to just a few hours a day. The effective range of dogs' sensitivity is yet to be determined. With crown infestation it is still a question whether the dogs will be able to detect the correct tree. At this stage, dog-assisted detection seems to fit well for palm inspection at nurseries, ports of entry and/or quarantine facilities.

Chemical detection can be taken further towards automatic target detection on large scale by applying olfactory sensors (electronic nose or tongue). Automatic olfactory detection is increasingly implemented in industry for quality control, environment monitoring health and security (Sindhuja *et al.*, 2012). The sensory system is typically relying on pattern recognition to isolate the chemical signature from an array of sensors. Although still far from practical implementation for detection of RPW infestation, this approach seems plausible for routine inspection. Depending on the identity/volatility of the cues the future application of this tool can be determined: direct contact with the suspected tree by 'electronic tongue' or remotely sensed by an 'electronic nose'.

ACOUSTIC DETECTION

Acoustic detection of RPW larvae activities was suggested based on distinct sounds reported from the pest infected palms. Gnawing sounds are produced as an effect of larvae chewing and moving. Acoustic detection of such sounds has been used to monitor termites in wood (Scheffrahn *et al.*, 1993), adult insects and larvae in stored products (Mankin *et al.*, 1997; Potamitis *et al.*, 2009), presence or absence of RPW larvae in suspected coconut palm trees (Siriwardena *et al.*, 2010), grubs in soil (Mankin *et al.*, 2000) and RPW larvae in offshoots (Hetzroni *et al.*, 2004; Soroker *et al.*, 2004). When a large number of large larvae reside inside palm tissue, then larval sounds can be even detected with the naked trained ear. The problem is at early infestation stages when the generated sound is too low to distinguish from the background.

Study by Pinhas *et al.* (2008) evaluated human labelling of audio clips and found that the human detection is unreliable. Some of the problems in achieving adequate acoustic detection include: identification of the specific acoustic patterns associated with larva activities, detection of young larvae in the trunk, and discriminating larva sounds from physiological sounds produced by the host plants (Jolivet, 1998) augmented by sounds produced by other inhabitants, such as other arthropods, rodents or ambient noise like birds and wind.

Various research groups proposed a selection of bioacoustics features based on analysis in the frequency domain (Mankin *et al.*, 2011). Hetzroni *et al.* (2004) recognized and isolated several dominant frequencies that indicate typical larval activities. Hussein *et al.* (2010) indicated 94% detection in cut infected trunk in quarantine, with absence of any other apparent inhabitants. Gutiérrez *et al.*, (2010) indicated detecting activity of 2-week old larvae in a controlled environment exploiting sound intensity. Temporal and spectral features of sounds of wood-boring beetle larvae were used for identifiable patterns of activity and enabled improved discrimination from background noise. It was found that RPW larval sounds typically are produced as bursts (trains of 7-200 individual, 3-30 ms impulses spaced <0.25 s apart) interspersed by longer, quiet intervals (Mankin *et al.*, 2008).
Spectral approach was augmented with techniques adopted from speech recognition domain namely 'text-independent speaker identification'. The developed algorithm detected successfully ratios 99% of the sound samples which were recorded from infested palms in a sound insulated chamber (Pinhas *et al.*, 2008).
Effectively attaching a sensitive microphone to the soft tissue of the palm tree is a challenge (Mankin *et al.*, 2011). To solve this problem, laser vibrometer could be used as a non-contact acoustic sensor. This was tested by conducting parallel recordings from canary and date palm trees using contact (microphone) and laser sensors. Some of the palm trees were infested by 1-3 larvae while others were left uninfected for control. The recordings made from infested palms by digital laser vibrometer (PDV-100, Polytec, Waldbronn, Germany) exhibited a good signal-to-noise ratio, comparable or superior to other acoustic methods tested in previous studies (Mankin *et al.*, 2011).
Two types of RPW larval feeding sounds were recorded by digital laser vibrometer. Basic, very short 'clicks' or 'snaps' lasted 1 to 4 ms (Fig. 1; left) and have most of the energy between 1 and 8 kHz. Longer lasting sounds termed 'rasps' or 'bites' (Fig. 1; right) were seemingly fused from short sound events and their maximum energy lay below 3 kHz, although some frequency peaks reached up to 16 kHz, They lasted on average 440 ms (±260 ms; n=45) and were sometimes repeated very regularly (Fig. 1; right, upper oscillogram).

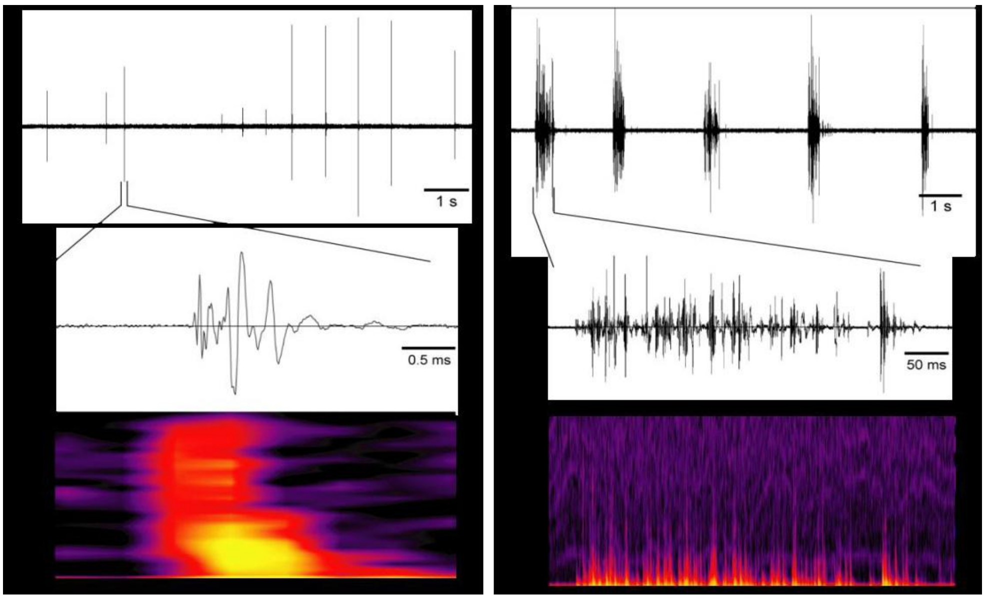

Figure 1. Oscillograms and sonograms of the RPW larvae feeding sounds recorded using a digital laser vibrometer: left – Short sounds termed 'clicks' were recorded from a canary palm; right – Longer lasting 'rasps' were recorded from a date palm
(Oscillogrammes and sonogrammes de sons émis par des larves de CRP qui s'alimentant enregistrés par vibromètre laser. Gauche : sons brefs appelés 'clics' enregistrés à partir d'un palmier des Canaries ; droite : sons plus prolongés de 'râpe' enregistrés à partir d'un dattier).

Recordings of larval activity using a tactile microphone and a laser vibrometer were evaluated by a human observer and compared with results of tree dissection to find if it was infested by the weevil (Table 3). Observer (+) indicates the number of cases in which the observer identified larvae activity from the recorded sounds, while observer (-) represents the number of instances where the observer could not identify larvae activity. Using the tactile microphone, the observation error was 18% based on the count of infested trees, or 14% based on the infestation confirmed by palm dissection (Table 3). Similar analysis conducted on sounds recorded from the trees using a laser vibrometer (Table 3) indicated observation error of 9% based on count of infested trees, or 14% based on the infestation confirmed by dissection. The calculated sensitivity/specificity values for the tactile microphone and the laser vibrometer were 0.84/0.66 and 0.89/1.00, respectively.

Table 3: Compared positive and negative detections by human observer using two sound recording techniques (tactile microphone and laser vibrometer) *vs.* number of infected trees. Numbers in parentheses indicate findings based on infestation found at dissection
(Taux comparés de detection de larves de CRP par analyse humaine d'enregistrements réalisés par microphone de contact ou vibromètre laser par rapport aux nombres réels de palmiers infestés validés par dissection, entre parenthèses).

Sounds recorded by	**Observer's evaluations***	**Larva Present**	**Larva Absent**
Tactile microphone	(N=28)		
	(+)	21 (19)	1 (3)
	(-)	4 (1)	2 (5)
Laser vibrometer	(N=21)		
	(+)	17 (15)	0 (2)
	(-)	2 (1)	2 (3)

*The observer concluded to infestation (+) or to no infestation (-)

These data indicate that the determination of human observer regarding whether a tree was infested was similar with the help of recordings taken by tactile microphone or laser vibrometer. Nevertheless the ease of sound sensing using the laser vibrometer *vs.* the hassle of attaching the tactile microphone is incomparable. Yet, the use of the laser allows us to sense the sound energy on the outer surface of the trunk, while the tactile microphone could be inserted into the heart of the trunk thus, possibly, improve the signal to noise ratio.
These various approaches indicate that acoustic identification of concealed activity within the palm trunk is feasible. The major flaws of acoustic technique are in the ambient interference with the low energy emitted by younger larvae, and the need to perform the detection on each tree individually. We therefore consider this method to be applicable in controlled environment such as in quarantine facilities, especially at ports of entry. Some of the obstacles ahead include adapting a monitoring (microphone) system that is not affected by ambient noise and is affordable.
The other limitation of acoustic detection is insect activity. Both larval diurnal activity patterns and length of the life cycle should be taken into consideration prior to mass implementation of acoustic detection as dormant insect stages such as egg and pupae cannot be detected acoustically while larvae may not be active continuously.

VISUAL/THERMAL IMAGING DETECTION

Since direct visual detection of the infestation is quite difficult, alternatives have been evaluated. Preliminary study by Bokhari and Abuzuhairah (1992) indicated the possibility of detection of physiological changes in the infested palms. Several observations reported

temperature elevations at the trunks of infested palms as detected by infrared cameras. Pest feeding within the palm trunk causes intensive fermentation of plant tissue which increases the local temperature inside the crown/trunk above the ambient levels (30°C and above 45°C) (Abe *et al.*, 2010; Soroker *et al.* personal observations; Suma and Longo, 2009). Although rather dramatic, the temperature raise in the center of the crown of heavily infested palms could be detected only when viewed from above, the natural insulation of the palm tissue prevented detection in lateral view. Moreover, solar radiation interferes with the thermal imaging. At this stage the temperature assessment cannot be considered as a confirmed application (ARO team personal experience).
On the other hand, the tunneling insects destroy the vascular system of the palm and create local conditions of water stress. This "crop water status" could be sensed through inspection of the thermal portion of the spectrum of the reflected irradiation (Tanner, 1963; Gates, 1964; Ehrler, 1973). Recent technological advances in remote thermal images offer the potential to acquire spatial information on surface temperature, and thus facilitate the mapping of canopy temperature variability over large areas. Thermal imaging is a viable alternative to point measurements. Since the temperature of the whole field of view can be acquired at once, a map of the plant water status distribution in the field can be produced. High-resolution thermal imaging systems have been used to evaluate water status of cotton (Cohen *et al.*, 2005; Alchanatis *et al.*, 2010; Meron *et al.*, 2010), wheat (Tilling *et al.*, 2007), vineyards (Grant *et al.*, 2007; Möller *et al.*, 2007) and olives (Sepulcre-Canto *et al.*, 2006; Berni *et al.*, 2009; Ben-Gal *et al.*, 2010). Recently we have shown that aerial thermal images are a promising tool to map water status of date palm trees on a commercial scale (Cohen *et al.*, 2012). For this purpose, we developed a semi-automated procedure based on the watershed segmentation analysis which allowed detection of all palm trees in the thermal image with no false alarms and the extraction of canopy temperature of individual palm trees (Cohen *et al.*, 2012). Likewise detection of the canopy temperature based on aerial thermal images using semi-automated procedures can be used to map potential infestation in palm trees in homogeneous plantations on a wide area scale.
Our preliminary experiments showed that in some infested palms trees the RPW larvae caused water stress which was reflected by both higher canopy temperature (extracted from thermal images) and lower stomatal conductance compared with healthy trees. The water stress was detected 25 days after infestation, three weeks before visual symptoms were observed (Fig. 2).

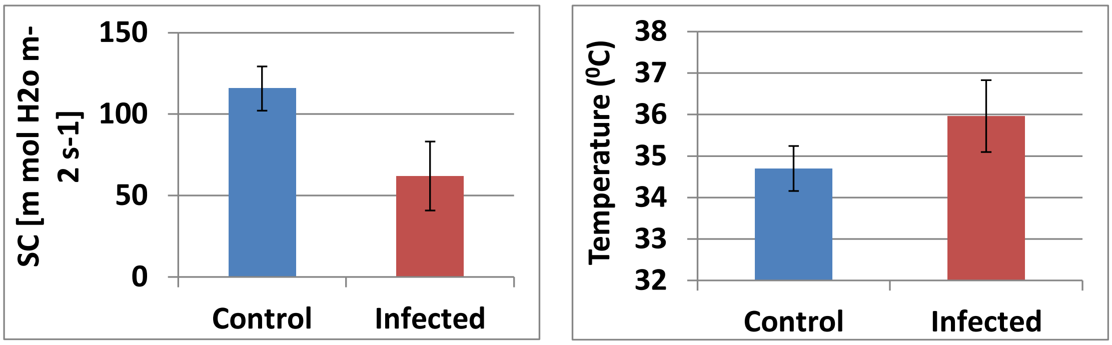

Figure 2. Stomatal conductance and canopy temperature of infected and not-infected canary seedlings. Bars represent confidence intervals of 95%
(Conductance stomatique et température de la canopée de jeunes plants de palmiers des Canaries infestés et sains (le trait représente l'intervalle de confiance à 95%).

INSPECTION OF OPEN AREAS

Inspection of palms in a larger scale *i.e.* urban, agricultural or natural habitat areas and decision making for control management is challenging. The task is difficult in particular in non-agricultural regions where large number of trees, often several thousands in an inspected region, of various species, ages and growth conditions need to be routinely monitored for pest infestation, and treatment success. Data acquisition of the RPW dispersal and infestations in these areas requires rapid positioning and visual management of the acquired data. Such a system could be based on Internet and Web applications Graphical

User Interface (GUI) to produce and display spatial and timed information to support application decisions. Electronic field data acquisition has been recently widely adopted (Montoya, 2003). Moreover, mobile Geographical Information Systems (GIS) provide location-aware monitoring and facilitate the collection of real-time agro-environmental data and in particular distribution patterns of an insect pest population (Sciarretta *et al.*, 2001; Papadopoulos *et al.*, 2003; Hetzroni *et al.* 2009). Systematic accumulation of information concerning pest distribution and host tree (palm) distribution and condition along with the treatment history are the bases of the decision-making process.

PEST DATA COLLECTION

RPW is capable of rather distant flights (Abbas *et al.*, 2006) and its distribution in coconut plantations is clumped (Faleiro *et al.*, 2002). Often decisions to implement area-wide management of RPW are based on weevil captures in surveillance traps with a specific lure based on RPW aggregation pheromone and plant kairomone mixture (Faleiro, 2006). The traps, employed for this purpose, are usually placed on the soil or partially buried and baited with the attractants ferrugineol and ethyl acetate, together with pieces of palm stem and/or molasses in water (El Sebay, 2003; Soroker *et al.*, 2004; Faleiro, 2006). Given that both male and female weevils are attracted to this pheromone, the monitoring of RPW adults with ferrugineol and host volatiles baited traps is a basic tool to detect the presence of the pest so as to act with preventive chemical treatments as soon as adults are detected.

Although the monitoring of RPW by trapping is rather efficient and some recommendations can be found in the literature (Faleiro, 2006), much remains to be studied in relation to the optimal trapping methodology in particularly in relation to lure composition, trap structure and distribution. Being a rather expensive operation in terms of the labor cost involved, decisions on trap distribution are mostly based on the economics and not on the pest spatio-temporal behavior. For example, Israel currently operates routine monitoring in infested urban areas and high risk agricultural areas, at a variable density from about one trap / 1 ha to 1 / 50 ha and large areas under jeopardy still remain unmonitored. A different approach was adopted in Greece where traps are operated only for a limited time and period in a year due (Aggelakopoulos *et al.*, 2012). Still, the potential area covered by each trap is not well defined and a recommendation for the number of traps necessary to detect primary invasion is still to be determined.

PALM DISTRIBUTION AND CONDITION

Palm location database, is extremely important in non agricultural areas for monitoring, treatment and risk assessments. About 20 palm species are considered hosts of the red palm weevil (EPPO, 2006). Palm evaluation is rather simple in the monocultural plantations, but not in the other sectors. In Mediterranean area palms of various species are extremely common in landscaping, making individual evaluation of all potential hosts impossible. As the most commonly affected species are *P. canariensis*, *P. dactylifera* followed by *Washingtonia*. In particularly *P. canariensis* can be used as the infestation indicators. Systematic accumulation of information concerning palm tree distribution and condition along with the treatment history is the basis of the decision making process. Any evidence of palm conditions is inclusive. Data source can be a trained personnel or the general public.

Recently a Location Aware System (LAS) and Decision Support System (DSS) and the CPLAS (Patent pending), that uses various layers of spatial data (including monitoring and visual palm assessment) to generate spatial risk maps has been developed. The CPLAS utilizes Web-services (W3C, 2009) and integrates GIS, DSS and multimedia technology; it implements location aware services (Küpper, 2005; Pontikakos *et al.*, 2005) for monitoring, risk assessment of the RPW dispersal/infestations and decision support for the control of the pest. The system was already evaluated in real time conditions in the Park ‘Pedion Areos’ in Athens, Greece (approximately 30 ha, 288 palms) in order to determine the infestation risk from RPW and the appropriate control treatments in Canary palms (Pontikakos and Kontodimas, 2010). However, to be implemented in the areas of different and mixed palm species this system will require adjustments and modifications.

The general recommended strategy could be, to proceed from cheaper and less time consuming strategies over large area to more specific but expensive strategies on limited

areas and eventually on suspected trees. For example, in open areas, the first step of detection will be identification of risk areas by analyzing pest presence by dedicated traps and thermal imaging, followed by spatial analysis. A limited number of suspected palms can then be inspected in detail *e.g.* by using dogs and manually by opening inspection window in the crown. In case of trade points, although RPW specific traps can be recommended for a routine monitoring, the olfactory detection by trained dogs is expected to play a central role followed by the acoustic detection of suspected palms. For acoustic detection in particular, quarantine time period will play a significant role enabling repeated testing of suspected palms.
The information gathered by various detection modalities can be combined along with other GIS information by dedicated programs to be used for risk assessment for decision support system.

CONCLUSION

Despite the intensive effort in development of the RPW detection techniques, technologies including chemical and acoustical methods, are yet falling back from being practical or feasible, leaving detection to be dependent mainly on visual inspection in most of the areas. Pros and cons of various detection methods presented above are summarized by different parameters in Table 4. Considerable effort is still required to improve the efficacy and sensitivity in the already available methods such as acoustic and olfactory detection with dogs. No single method is adequately sensitive and cost effective and there is still no good solution for area wide detection. In case of visual detection, protocols for most commonly attacked palms are lacking. Remote detection by visual and olfactory cues is very promising for area wide inspection but still far from application. At the moment a combination of methods and technologies is required to form an optimal solution.

Table 4: Comparison of advantages and costs of detection methods (comparaison des avantages et des coûts des méthodes de détection)

Parameter	Direct visual	Acoustic	Olfactory (dogs)	Thermal Remote sensing
Individual examination	Required	Required	Required	Not necessary
Special equipment	No	Yes	Not necessary (dogs)	Yes
Labor	Intensive	Low if automatic	Medium**	Low if automatic
Trained labor	Medium	No	Yes	Yes
Sensitivity	Medium Accuracy cannot be determined	80-95% under controlled environment	64-75%* Depends on breed and training	Still unknown
Cost	Expensive	Affordable	Affordable	Affordable if aerial images are used
Suitability	Open areas***	Controlled environment /quarantine	Mostly for local detection	Open areas

* Both accuracy and sensitivity are expected to be improved once appropriate training protocol is implemented.
****** Main effort is related to the training process.
*** Depends on accessibility of infested target.

ACKNOWLEDGMENTS

The work on development of RPW detection methods is supported by grants from the European Community's Seventh Framework Programme under grant agreements: No. FP7 KBBE 2011-5-289566 Grant "Palm Protect" and No. FP7 KBBE 2009-3- 245047 Grant "Q-detect". Israeli partners were also supported by the Israeli Ministry of Agriculture Chief Scientist and ICA foundation.

REFERENCES

Abbas M. S. T., Hanounik S. B., Shahad A. S., Al-Bagham S. A., 2006 - Aggregation pheromone traps, a major component of IPM strategy for the red palm weevil, *Rhynchophorus ferrugineus* in date palms. *Journal of Pest Sciences* 79, 69-73.

Abe F., Ohkusu M., Kubo T., Kawamoto S., Sone K., Hata K., 2010 - Isolation of yeast from palm tissues damaged by the red palm weevil and their possible effect on the weevil overwintering. *Mycoscience* 51, 215-223.

Aggelakopoulos K., Karataraki A., Gkounti V., Michaelakis A., Karamaouna F., Kontodimas D. C., 2012 - Establishment of a trap network in the east border of the dispersal of *Rhynchophorus ferrugineus* (Olivier) (Col.: Curculionidae) in Crete. In *IOBC/WPRS Working Group "Pheromones and other semiochemicals in integrated production"* Conference*: "Semiochemicals: The Essence of Green Pest Control", October 1-5, 2012 – Bursa, Turkey:* 124-125.

Alchanatis V., Cohen Y., Cohen S., Möller M., Sprinstin M., Meron M., Tsipris J., Saranga Y., Sela E., 2010 - Evaluation of different approaches for estimating and mapping crop water status in cotton with thermal imaging. *Precision Agriculture*, 11, 27-41.

Ben-Gal A., Koolb D., Agam N., vanHalsema G. E., Yermiyahu U., Yafe A., Presnov E., Erel R., Majdo A, Zipori I., Segal E., Rüger S., Zimmermann U., Cohen Y., Alchanatis V., Dag A., 2010 - Whole-tree water balance and indicators for short-term drought stress in non-bearing 'Barnea'olives. *Agricultural Water Management*, 98, 124-133.

Berni J. A. J., Zarco-Tejada P. J, Sepulcre-Canto G., Fereres E., Villalobos F., 2009 - Mapping canopy conductance and CWSI in olive orchards using high resolution thermal remote sensing imagery. *Remote Sensing of Environment,* 113, 2380-2388.

Bokhari U. G., Abuzuhairah R. A., 1992 - Diagnostic tests for red palm weevil. *Rhynchophorus ferrugineus* infested datepalm trees. *Arab Journal of Scientific research* 10, 93-104.

Cohen Y., Alchanatis V., Meron M., Saranga Y., 2005 - Estimation of leaf water potential by thermal imagery and spatial analysis. *Journal of Experimental Botany*, 56, 1843-1852.

Cohen Y., Alchanatis V., Prigojin A., Levi A., Soroker V., Cohen Y., 2012 - Use of aerial thermal imaging to estimate water status of palm trees. *Precision Agriculture* 13, 123-140.

Ehrler W. L., 1973 - Cotton leaf temperatures as related to soil water depletion and meteorological factors. *Agronomy Journal,* 65, 404–409.

El Sebay Y., 2003 - Ecological studies on the red palm weevil *Rhynchophorus ferrugineus* Oliv., (Coleoptera: Curculionidae) in Egypt. *Egyptian Journal of Agriculture Research,* 81, 523-529.

EPPO, (2006 - http://www.eppo.org/QURANTINE/Alert_List/insects/rhycfe.htm.2006.

Faleiro J. R., 2006 - A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut and date palm during the last hundred years. *International Journal of Tropical Sciences*, 26, 135-154.

Faleiro J. R., Kumar J. A., Rangnekar P. A., 2002 - Spatial distribution of red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut plantations. *Crop Protection* 21, 171-176.

Gates D. M., 1964 - Leaf temperature and transpiration. *Agronomy Journal*, 56, 273–277.

Grant O. M., Tronina L., Jones H. G., Chaves M. M., 2007 - Exploring thermal imaging variables for the detection of stress responses in grapevine under different irrigation regimes*. Journal of Experimental Botany*, 58, 815-825.

Gutiérrez A., Ruiz V., Moltó E., Tapia G., del Mar Téllez M., 2010 - Development of a bioacoustic sensor for the early detection of Red Palm Weevil (*Rhynchophorus ferrugineus* Olivier). *Crop Protection*, 29, 671-676.

Hetzroni A., Meron M., Fraier I., Magrisso Y., Mendelsohn O., 2009 - Data collection and two-way communication to support decision making by pest scouts. Proceedings of the Joint International Agricultural Conference, Wageningen, Netherlands

Hetzroni A., Mizrach A., Nakache Y., Soroker V., 2004 - Developing spectral model to monitor activity of red palm weevil. *Alon Hanotea,* 58, 466-469.

Hussein W. B., Hussein M. A., Becker T., 2010 - Detection of the red Palm Weevil *Rhynchophorus ferrugineus* using its bioacoustics features. *Bioacoustics* 19, 177-194.

Jolivet P., 1998 - Interrelation between Insects and Plants. CRC Press, NY, pp. 99-100.

Küpper A., 2005 - Location-based services. In: Fundamentals and Operation. John Wiley & Sons, Ltd.

Mankin R. W., Brandhorst-Hubbard J., Flanders K. L., Zhang M., Crocker R. L., Lapointe S. L., McCoy C.W., Fisher J.R., Weaver D. K., 2000 - Eavesdropping on insects hidden in soil and interior structures of plants. *Journal of Economic Entomology*, 93, 1173-1182.

Mankin R. W., Mizrach A., Hetzroni A., Soroker V., 2008 - Temporal and spectral features of sounds of wood-boring beetle larvae: identifiable patterns of activity enable improved discrimination from background noise. *The Florida Entomologist*, 91, 241-248.

Mankin R. W., Shuman D., Conffelt J.A., 1997 - Acoustic counting of adult insects with different rates and intensities of sound production in stored wheat. *Journal of Economic Entomology,* 90, 1032-1038.

Mankin R.W., Hagstrum D. W., Smith M. T., Roda A. L., Kairo M. T. K., 2011 - Perspective and Promise: a Century of Insect Acoustic Detection and Monitoring. *American Entomologist*, 57, 30-44.

Meron M., Tsipris J., Orlov V., Alchanatis V., Cohen Y., 2010 - Crop water stress mapping for site-specific irrigation by thermal imagery and artificial reference surfaces. *Precision Agriculture*, 11, 148-162

Möller M., Alchanatis V., Cohen Y., Meron M., Tsipris J., Naor A., Ostrovsky V., Sprintsin M., Cohen S., 2007 - Use of thermal and visible imagery for estimating crop water status of irrigated grapevine. *International Journal of Experimental Botany*, 58, 827-838.

Montoya L., 2003 - Geo-data acquisition through mobile GIS and digital video: an urban disaster management perspective. *Environmental Modelling & Software* 18, 869–876.

Nakash J., Osem Y., Kehat M., 2000 - A Suggestion to Use Dogs for Detecting Red Palm Weevil (*Rhynchophorus ferrugineus*) Infestation in Date Palms in Israel. *Phytoparasitica* 28, 2.

Papadopoulos N.T., Katsoyannos B.I., Nestel D., 2003 - Spatial autocorrelation analysis of a *Ceratitis capitata* (Diptera: Tephritidae) adult population in a mixed deciduous fruit orchard in northern Greece. *Environmental Entomology* 32, 319–326.

Pinhas J., Soroker V., Hetzroni A., Mizrach A., Teicher M., Goldberger J. 2008 - Automatic Acoustic Detection of the Red Palm Weevil. *Computers and Electronics in Agriculture* 63, 131-139.

Pontikakos C., Glezakos T., Tsiligiridis T., 2005 - Location-based services: architecture overview. In: *Proceedings of the International Congress on Information Technology in Agriculture, Food and Environment (ITAFE'05),* Adana.

Pontikakos C., Kontodimas D., 2010 - A Location Aware System for Integrated Management of *Rhynchophorus ferrugineus*. *Dies Palmarum*, San Remo-Italy, 18-20 November, 2010.

Potamitis I., Ganchev T., Kontodimas D.C., 2009. On automatic bioacoustic detection of pests: the cases of *Rhynchophorus ferrugineus* and *Sitophilus oryzae. Journal of Economic Entomology,* 102, 1681-1690.

Scheffrahn R. H., Robbins W. P., Busey P., Su N. Y., Mueller R. K., 1993 - Evaluation of novel, hand-held, acoustic emissions detector to monitor termites (Isoptera: Kalotermitidae, Rhinotermitidae) in wood. *Journal of Economic Entomology,* 86, 1720-1729.

Schlyter F., 2012 - Detection dogs recognize pheromone from spruce bark beetle and follow it source. ESA 60th Annual Meeting Knoxville Presentation 1600.

Sciarretta A., Trematerra P., Baumgartner J., 2001 - Geostatistical analysis of Cydia funebrana (Lepidoptera: Tortricidae) pheromone trap catchesat two spatial scales. *American Entomology,* 47, 174–184.

Sepulcre-Canto G., Zarco-Tejada P. J., Jimenez-Munoz J. C., Sobrino J. A., de Miguel E.,Villalobos F. J., 2006 - Detection of water stress in an olive orchard with thermal remote sensing imagery. *Agriculture and Forest Meteorology*, 136, 31-44.
Sindhuja S., Lav R. K, Suranjan P., 2012 - Biology and applications of olfactory sensing system: A review. *Sensors and Actuators B: Chemical,* 171–172, 1–17.
Siriwardena K. A. P., Fernando L. C. P., Nanayakkara N., Perera K. F. G., Kumara A., Nanayakkara T., 2010 - Portable acoustic device for detection of coconut palms infested by *Rynchophorus ferrugineus* (Coleoptera: Curculionidae). *Crop Protection* 29, 25-29.
Soroker V., Nakache Y., Landau U., Mizrach A., Hetzroni A., Gerling D., 2004 - Utilization of sounding methodology to detect infestation by *Rhynchophorus ferrugineus* on palm offshoots. *Phytoparasitica* 32, 6-8.
Suma P., Longo S., 2009 - Applicazioni di termografia, endoscopia ed analisi indiretta per la diagnosi precoce degli attacchi di punteruolo rosso. In: Regione Siciliana - Assessorato Agricoltura e Foreste. *La ricerca scientifica sul Punteruolo rosso e gli altri fitofagi delle palme in Sicilia.* Vol. 1, pp 103-106. SBN Pal0217180*.*
Tanner C.B., 1963 - Plant temperatures. *Agronomy Journal,* 55, 210-211.
Tilling A. K., O'Leary G. J., Ferwerda J. G., Jones S. D., Fitzgeral G. J., Rodriguez D., Belford R., 2007 - Remote sensing of nitrogen and water stress in wheat. *Field Crops Research*, 104, 77–85.
W3C, 2009 - WEB OF SERVICES. http://www.w3.org/standards/webofservices/
Wallner W.E., Ellis T.E., 1976 - Olfactory detection of gypsy moth pheromone and egg masses by domestic canines. *Environmental Entomology,* 5, 183-186.
Welch J.B., 1990 - A detector dog for screwworms. *J. Econ. Entomol.* 83, 1932-1934.