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Toward practical acoustic red palm weevil detection

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ABSTRACT

The red palm weevil (RPW), *Rhynchophorus ferrugineus*, is a major pest of various palm species including dates and Canary palms. The weevil's larvae develop within the tree stem and crown, damage its vascular system and eventually cause the death of the tree. Early detection of the RPW infestation is particularly challenging as the pests develop within the palm, well hidden from human eye. Our work focused on the acoustic detection of RPW larvae activity. Young date and Canary palms were naturally infested by exposure to adult males and females RPW and were monitored acoustically and visually for several weeks. A piezoelectric sensor was used to capture the larvae's distinct sounds that propagate through the fibrous palm tissue. To determine whether the trees were infested, the sounds were recorded *in situ* and diagnosed by a human listener and by a software ("machine"). All experiments were concluded by dissecting each palm to assess its actual infestation.

Human and machine detection were both efficient in detecting infested trees, with average "true positive rate" (sensitivity) of 75% (maximum 88%) and 80% (maximum 95%) for human and machine detection respectively. The sensitivity was lower during the early phase of infestation (39% and 33% respectively), and significantly improved as larvae developed.

Manual and automated acoustic monitoring was found feasible for monitoring young palm trees. Manual filtering of external stimuli such as wind and ambient noise were sufficient to enable detection in an unshielded natural environment.

1. Introduction

The red palm weevil (RPW), *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), is a pest of various palm species. The larvae develop within the palm tissue, mainly at the stem or crown, damaging the vascular system and eventually causing palm death (Giblin-Davis, 2001). Today RPW is a major pest of ornamental palms in southern Europe and the Mediterranean and in date growing countries in the Middle East.

Management of any pest requires accurate detection and monitoring of its population, forecasting its dispersal and evaluating the success of eradication efforts. Preclusion of further spread of invasive pests requires tools for monitoring, especially at ports of entry and at new infestation foci. Early detection of the RPW infestation is particularly challenging as the pests develop deep inside the palm, well hidden from human eye. Particularly challenging are the situations in which not all the palms are accessible for individual assessment as common in urban areas, parks or in date palm plantations where the number of trees is too large to be monitored individually. Various methods and approaches were evaluated over the years for early detection of RPW infestations. The most obvious approach for infestation detection is visual examination of a tree. This method depends on the infestation stage, the site of infestation, palm height and species. For example, crown infestation by RPW is detectable as the palm crown loses its symmetry and inner fronds manifest chewing symptoms. This situation is common with Canary palms (*Phoenix canariensis*) and coconuts (*Cocos nucifera* L.) but rather rare in date palms (*P. dactylifera* L.). In date palm the infestation occurs mostly in the lower part of the stem; if offshoots are present, the symptoms often appear in them. The palm may appear healthy with no visible symptoms until inner cavities generated by the developing larvae overpower the tree robustness and it collapses. The cryptic nature of the weevil activity challenges visual detection at initial infestation stages. Other detection methods have been proposed to cope with the problem, including, chemo/olfactory sensing by dogs (Nakash et al., 2000; Suma et al., 2014), thermal imaging (Golomb et al., 2015), X-ray (Ma et al., 2012), thermal neutron imaging (Alghamdi, 2012), and more.

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Acoustic detection of RPW larvae activities was suggested based on distinct sounds reported from the pest-infected palms (Mankin et al., 2007; Soroker et al., 2004). The larvae, being large and active, produce chewing and moving sounds. These sounds, propagated through the fibrous material, can be captured by a suitable sensor, and are candidates for acoustical and vibrational detection and monitoring. The presence (or absence) of the RPW larvae was monitored in suspected coconut palm trees (Siriwardena et al., 2010); and in young date palms (Hetzroni et al., 2004; Soroker et al., 2004).

Typical RPW larva activity sounds like a train of clicks with strong energy between 0.4 and 8 kHz (Mankin et al., 2008; Herrick and Mankin, 2012). When a large number of large larvae reside inside palm tissue, then larval activity sounds can even be detected by trained expert even without special equipment. The detection is problematic at early infestation stages when the generated sound is too low to distinguish from the background. Even without external noise, palm internal environment is not quiet. Sounds are derived from other insect activities; or from the tree itself, such as air bubbles, water sipping or leaves blown even by a light draft.

Acoustic detection has been implemented to monitor a variety of pests including termites in wood (Scheffrahn et al., 1993), grubs in soil (Mankin et al., 2000) and adult insects and larvae in stored products (Mankin et al., 1997; Potamitis et al., 2009).

The incidental signals that small cryptic insects produce while moving and feeding can be very low in amplitude but still detectable (Mankin et al., 2011). Therefore, sensors' technology plays a significant role in capturing the larvae sounds. Various types of microphones can be used for acoustically detection of insects. The commonly used and reasonable priced sensors for insects that produce low frequencies sounds are the piezo electric transducers (Lampson et al., 2013; Potamitis et al., 2009; Schofield, 2011; Siriwardena et al., 2010). An accelerometer microphone attached to a cotton plant was successful in recording substrate-bore vibrational signals of stink bugs (Lampson et al., 2013).

Effectively attaching a sensitive microphone to the soft and fibrous tissue of the palm tree is a challenge (Mankin et al., 2011). A laser vibrometer can be used as non-tactile sensor. It was used to investigate sexual communication signals and communication traits transmitted between plant-eating insects as they propagated through the stem (Rodríguez et al., 2006). Laser vibrometer was also used to detect cryptic activity of a long horned beetle (*Anoplophora glabripennis*) and RPW, thus avoiding the problematic mounting of tactile sensor (Zorović and Čokl, 2015; Soroker et al., 2013). Recordings made from infested palms by digital laser exhibited a good signal-to-noise ratio, comparable or superior to other acoustic methods tested in previous studies (Mankin et al., 2011). Currently the cost of a single laser vibrometer makes it yet impractical for wide commercial application.

An acoustic probe inserted 10 cm into the palm's stem was proposed as a bioacoustics sensor for early detection of the red palm weevil. The detection was based on the acoustic intensity around 2.25 KHz. It was reported to detect infestation of two-week-old larvae under controlled environment, avoiding natural ambient noises (Gutiérrez et al., 2010). Others inserted a fixed nail/screw into the trunk and attached the microphone magnetically to it (Herrick and Mankin, 2012; Hetzroni, 2012; Jalinas et al., 2015).

A study by Pinhas et al. (2008) evaluated human labelling of audio clips of RPW infested trees and found that the human detection might be unreliable, depending on the listener. 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 activities of RPW larvae. Hussein et al. (2010) indicated 94% detection of RPW in cut infested trunk in quarantine, in absence of any other apparent inhabitants. Sounds of the RPW larvae were automatically discriminated from noise with up to 98.8% accuracy using Gaussian mixture model (GMM) as the classification method and mel-frequency cepstral coefficients as features, augmented with techniques adopted from speech recognition domain namely 'text-independent speaker identification' (Pinhas et al., 2008). Others reported 99.1% and 100% accuracy in sound detection of RPW and the rice weevil respectively using GMM classification using dominant frequency and 23 linear frequency cepstral coefficients as features (Potamitis et al., 2009). On the other hand, Lampson et al. (2013) implemented generalized method of moments and probabilistic neural network on extracted spectral features to classify stink bug sounds signals.

This work aimed to evaluate the practical aspects of using acoustic monitoring of young palm trees to determine RPW infestation. Specifically to estimate (a) how early larvae infestation can be detected and, (b) the consistency of the observer/machine determination on the infestation status over time. Measuring systems are characterized by measures such as sensitivity and accuracy. These can be controlled by adjusting the device configuration by setting threshold to the sensory output. The settings are aimed to optimal results. In our case, we aim to maximize system sensitivity while compromising on accuracy, i.e. to maximize detection of infested trees, with the cost of some false-positive classification. We present an approach for systematic setting the thresholds for the human evaluation and machine detection of RPW using acoustics.

2. Materials and methods

2.1. Controlled experiments in quarantine facility

Five experiments were conducted from 2012 to 2014 in a quarantine net house facility at Eden Research Station, Ma'ayanot regional council, Israel (32.27°N, 35.29°E) (Table 1). In each experiment, young palms were infested with RPW and compared to control

Table 1
Summary of controlled RPW infestations and acoustic detection experiments conducted between 2013 and 2014 at Eden Research Station.

Set	Palm species	Number of palms (control)	Date of inoculation	Date of tree dissection
#1	*P. canariensis*	12 (0)	21-Feb-2013	27-Jun-2013
#2	*P. canariensis*	12 (4)	18-Jul-2013	2-Sep-2013
#3	*P. dactylifera*	12 (4)	15-Sep-2013	21-Nov-2013
#4	*P. dactylifera*	15 (5)	14-Apr-2014	30-Jul-2014
#5	*P. dactylifera*	14 (4)	7-Aug-2014	21-Oct-2014