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4pAB3. Eavesdropping on coconut rhinoceros beetles, red palm weevils, Asian longhorned beetles, and other invasive travelers

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As global trade increases, invasive insects inflict increasing economic damage to agriculture and urban landscapes in the United States yearly, despite a sophisticated array of interception methods and quarantine programs designed to exclude their entry. Insects that are hidden inside soil, wood, or stored products are difficult to detect visually but often can be identified acoustically because they produce 3-30-ms, 200-5 000-Hz impulses that are temporally grouped or patterned together in short bursts. Detection and analysis of these sound bursts enables scouts or inspectors to determine that insects are present and sometimes to identify the presence of a particular target species. Here is discussed some of the most successful acoustic methods that have been developed to detect and monitor hidden insect infestations. Acoustic instruments are currently available for use in rapid surveys and for long-term monitoring of infestations. They have been useful particularly for detection of termites, coconut rhinoceros beetles, red palm weevils and Asian longhorned beetles in wood, white grubs and Diaprepes root weevil in soil, and stored product insects. 9 1616

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INTRODUCTION

Acoustic monitoring typically has different objectives for invertebrate insects than for cetaceans, pinnipeds, birds, amphibians, and other vertebrates. Mitigation of damage to the animals being monitored (Guan 2011), assessment of biodiversity (Frommolt et al. 2008) or management of conservation areas (Lammers et al. 2008) frequently are goals of vertebrate monitoring. These concerns have been addressed in several insect monitoring studies (Forrest 1988, Chesmore and Ohya 2004), but more often the goal has been to reduce insect-caused economic damage to crops (Mankin et al. 2009), ornamental plants, golf courses, or trees (Zhang et al. 2003, Mankin and Moore 2010), or stored products (Hagstrum et al. 1996), to simultaneously monitor and reduce populations of mosquitoes (Ikeshoji et al. 1985, Ikeshoji and Yap 1990, Silver 2008) or midges (Hirabayashi and Nakamoto 2001), or to detect invasive species (Mankin et al. 2006, Mankin et al. 2011). Also, the technical challenges of monitoring small insects can be considerably different from the challenges of monitoring large vertebrates whose sounds can be detected over long distances in air or water. A few insect species, notably crickets and cicadas, produce loud communicatory signals that can be detected by microphones over long distances (Walker 1988, 1996). However, many important questions in insect acoustic monitoring involve detection of weak incidental sounds (examples of which can be found at http://www.ars.usda.gov/pandp/docs.htm?docid=10919) in wood or other substrates that strongly modify and attenuate the signal, restricting its range and interpretability. This report considers some of the challenges involved in acoustic monitoring of weak, incidental sounds and provides some examples where monitoring has been used successfully to detect hidden infestations of longstanding pests and recently invasive insects. The monitoring and analysis of insect airborne communicatory signals has been considered in a number of other recent articles and books, e.g., Drosopoulos and Claridge (2006).

METHODS

The technology used to identify the sounds of targeted insects and discriminate them from non-target invertebrates and background sounds has evolved considerably since the beginnings of acoustic monitoring in the early 20th century (Mankin et al. 2011). Originally, the major goal was simply to increase sensitivity sufficiently to detect from a distance the weak incidental sounds that insects produce while moving and feeding. There were only a few exploratory attempts to acoustically monitor hidden insect infestations until the 1950s and 1960s, when the costs of manufacturing sensitive microphones, accelerometers, and piezoelectric film sensors decreased enough to enable widespread use of acoustic instruments. However, attempts to develop practical monitoring applications in agricultural and urban environments were hampered by significant contamination from background noise. Background noise is almost always a concern in acoustic monitoring studies, but is particularly problematic with insects that produce sounds of very low energy. To reduce problems of background noise, researchers conducted their experiments in noise-shielded environments whenever possible, and also filtered out low-frequency signals below 1-2 kHz in applications where the insect-produced signals contained high-frequency components (Hagstrum et al. 1996). Where ultrasonic sensors could be placed within 2-5 cm of infested grain kernels, the filter could be set above audible ranges because the spectral range of insect biting sounds extends up to 40 kHz and higher (Shade et al.

1990). Ultrasonic signals from insects in wood can be detected from distances of 5 cm up to ca. 1 m, depending on the sizes and numbers of active insects (Scheffrahn et al. 1993, Lemaster et al. 1997).

Insect movement and feeding sounds typically occur as short bursts (trains) of 3-30-ms impulses with characteristic spectral features or profiles (Mankin et al. 2009). In several studies, it has been possible to develop spectral profiles of impulses produced by the target insect that can be used in distinguishing the insect sounds from background noise. The use of spectral profiles in wood and other plant structures, however, is complicated by structural attenuation and resonances that reduce the identifiability of the signal as it passes through the substrate (Mankin et al. 2008).

Many insect acoustic monitoring applications require not just detection of weak signals and their discrimination from low-frequency noise but would benefit from more powerful signal identification and discrimination methods, for example in environments where nontarget species are present that produce signals similar in frequency to the target insect. One approach that has achieved moderate success incorporates analysis of temporal features into the signal discrimination process (Mankin et al. 2009, Mankin and Moore 2010). It also has been possible to consider microphone, vibration sensor, and visual signals together in distinguishing among sounds of different species (Mankin et al. 2010).

RESULTS AND DISCUSSION

Commercially, some of the more successful insect acoustic monitoring activities have been with termites (e.g., Indrayani et al. 2007), and several companies distribute termite acoustic detection instruments (Mankin et al. 2011). A popular use of such instruments is for pest control managers to check whether previously identified infestations have been eliminated. In these cases, monitoring is performed at regular intervals over a 1-5-year period or longer. Long-term acoustic monitoring of stored-product insects in grain bins has been shown to be technically successful (Hagstrum et al. 1996) but it has not come into widespread use, primarily due to issues of cost (Mankin et al. 2011). There also has been interest in surveying for infestation in grain samples extracted from shipments. However, the use of acoustic methods in such surveys is often difficult because of high levels of low-frequency background noise in shipping environments.

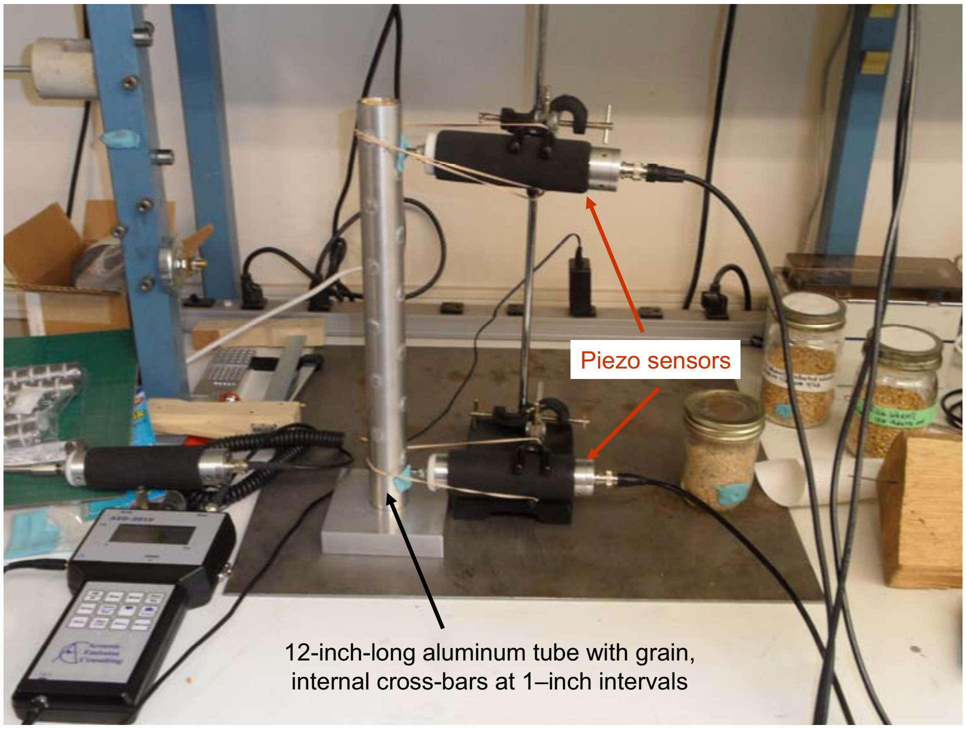

FIGURE 1. Grain tube setup for detection of rice weevils moving and feeding in grain kernels.

Potentially, the problem of background noise could be minimized by filtering out signals below 20 kHz and ensuring that the entire sample is within a few cm of a sensor. To consider the feasibility of this approach, a device was constructed recently by inserting cross-bars into a 12-inch-long by 1-inch diameter aluminum tube, spaced at 1-inch intervals (Fig. 1). Piezoelectric sensors (AED-2010, AEC Consulting, Inc., Fair Oaks, CA) were placed at each end to detect sounds from an infestation of rice weevil larvae, *Sitophilus oryzae* (L.), feeding internally in wheat kernels. The tube was filled half-way with uncontaminated grain and then with two inches of infested grain from a colony of rice weevils maintained in the laboratory, followed by four inches of uncontaminated grain. The signals were amplified 40 dB and high-pass filtered at 20 kHz using an AET-5500 instrument with customized software (AEC Consulting, Inc., Fair Oaks, CA). The initial times of sounds exceeding a 0.2 V threshold were monitored for 1-min periods simultaneously from each sensor. The locations of the sounds within the tube were calculated based on which sensor first detected a sound and the time differences between detections at the two sensors. A histogram of a typical 1-min record is shown in Fig. 2. The peaks of the histogram correlate well with the locations of infested grain kernels. This test was conducted in an office in a commercial district with a moderate amount of traffic, pedestrian, and conversational noise. There were no special precautions needed to eliminate background noise. It can be concluded that the use of such devices would enable grain samples to be surveyed without the need for extensive noise reduction precautions and the distribution of sounds along the grain tube could help determine whether the sample was uninfested, lightly infested, or heavily infested (Shuman et al. 1993).

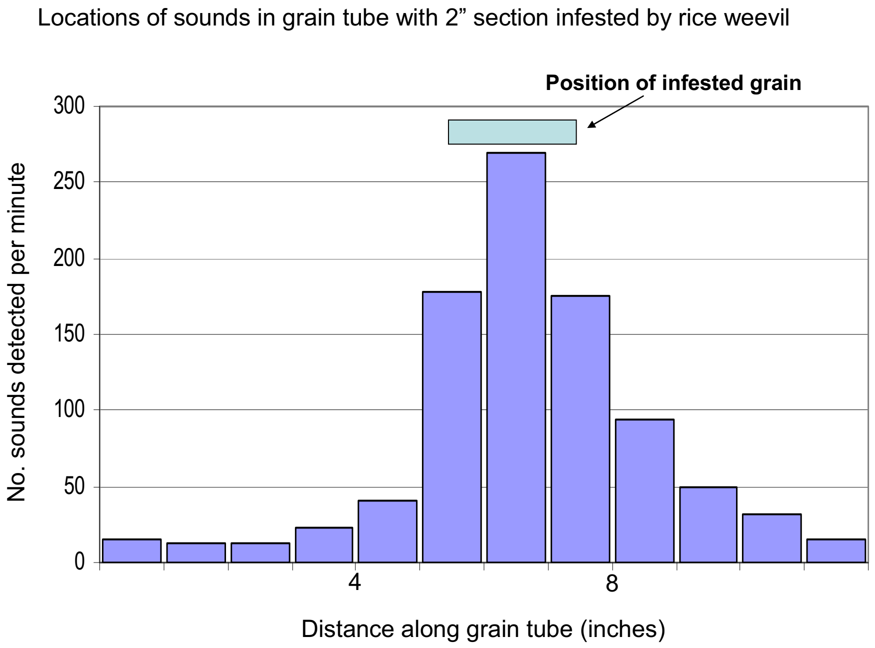

FIGURE 2. Histogram of sound rate in rice-weevil-infested kernels between the 6-8-inch position in a 12-inch-long aluminum tube loaded with grain.

A recent focus of acoustic monitoring has been to determine the range of infestation of invasive species in crop and ornamental trees. The Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky), was discovered in New York in 1997 (Mankin et al. 2008). Its range has been expanding slowly through the Northeast US. The coconut rhinoceros beetle, *Oryctes rhinoceros* (L.), was discovered in a resort area of Guam in 2007 (Mankin and Moore 2010) and has since expanded to cover much of the island. The red palm weevil, *Rhynchophorus ferrugineus* (Olivier), was discovered in Curacao and Aruba in 2009, and is a threat to palm trees in the Caribbean region (Mankin et al. 2011). Acoustic instruments have been used in monitoring programs against these insects, primarily as research tools that complemented pheromone trapping studies. In these cases, long term monitoring has not been as strong a focus as simple detection because a tree typically is immediately treated or chipped when the infestation is identified.

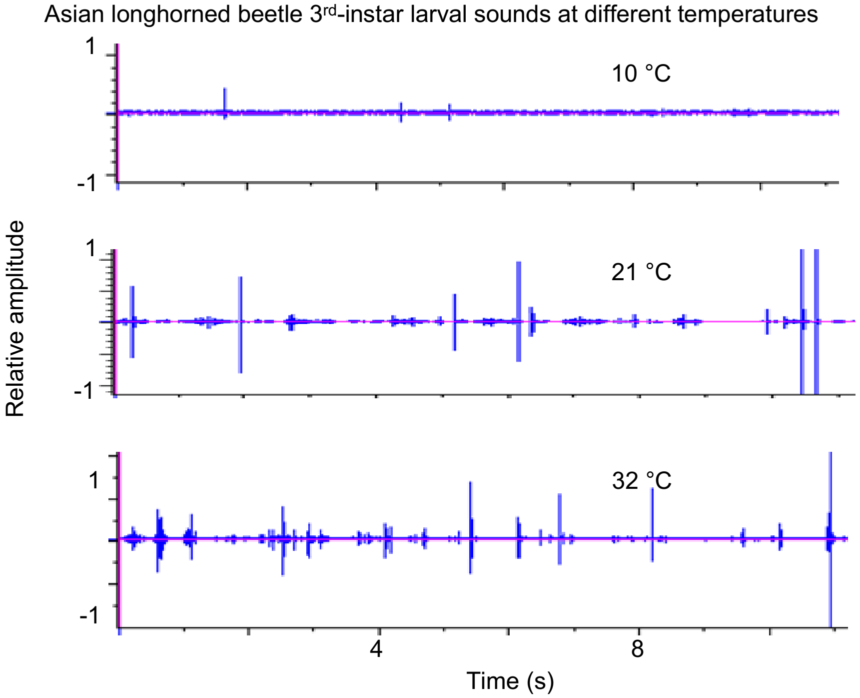

Figure 3. Oscillograms of 11-s records of sounds produced by 3^{rd}-instar Asian longhorned beetle larvae in 30-cm sections of red maple tree trunks held at 10, 21, and 32 °C.

One of the complicating factors that occurs more often in passive acoustic monitoring of insects than in monitoring of warm-blooded animals is that the rate of sound production is temperature-dependent, which reduces the efficacy of monitoring when temperatures fall below ca. 10 °C. An example of this is seen in Fig. 3, which displays signals from 3^{rd}-instar Asian longhorned beetle larvae at temperatures between 10 and 32 °C. The recording conditions were as described in Mankin et al. (2008). Fewer and weaker sounds are produced at 10 °C, which makes the larvae more difficult to detect over long distances. This is less of a problem in tropical and subtropical regions than in cool or cold climates. For this and other reasons, multimodal acoustic, visual, and habitat monitoring may be more effective for insects than acoustic monitoring alone.

Neither long-term acoustic monitoring of insects nor rapid sampling has been widely adopted as tools for integrated pest management until now, but there is considerable potential that their usage will increase in the next few years. Instruments like iPods or IPads, smart phones, and other communication and data storage devices are becoming more common and more affordable, and acoustic and piezoelectric sensors may become available soon as inexpensive options to purchase with such equipment. Continuing increases in global trade and transportation over time have greatly increased the need to detect hidden insect infestations (Pimentel et al 2005, Cocquempot et al 2010, http://www.invasivespeciesinfo.gov, http://www.cabi.org/isc/), and in many cases acoustic detection, or the use of multimodal detection systems is the best option for intercepting invasive species. The problem of invasive species is particularly acute in Florida and California, both of which are important agricultural regions. Finally, there are many important biological and ecological questions about the distribution and behavior of internal tree-feeding or subterranean insects that cannot be addressed easily without recourse to acoustic monitoring technology.

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