Review

Applications of acoustics in insect pest management

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Abstract

Acoustic technology has been applied for many years in studies of insect communication and in the monitoring of calling-insect population levels, geographic distributions and species diversity, as well as in the detection of cryptic insects in soil, wood, container crops and stored products. Acoustic devices of various sizes and power levels have been used successfully to trap insect pests that exhibit phonotaxis or other orientation behaviours, including mosquitoes, midges, mole crickets, field crickets, moths, cockroaches and Tephritid fruit flies. The attractiveness of traps depends on the behaviour, physiological state and age of the target insect, and varies with several environmental factors, including temperature and light level. Widespread adoption of acoustics for trapping has been limited by the costs of instrumentation and the relatively small segments of insect populations (e.g. mate-seeking adults of a limited age-range) that are attracted to a sound source, but trapping effectiveness often can be improved by adding swarm markers, chemical attractants or black lights, and by precisely timing temporal and frequency patterns to match the natural communication signals. There remains potential for using ultrasonic bat-cry signals to disrupt behaviour of night-flying insects, but ultrasonic signals have little effect on insects that are not normally preyed upon by bats. Potential areas for growth in the use of acoustic technology in pest management include the production of signals that disrupt vibrational communication, particularly in the Hemiptera, and the development of control treatments that combine pheromones and precisely patterned sonic or vibrational signals.

Keywords: Sound, Vibration, Ultrasound, Attraction, Trap, Phonotaxis

Review Methodology: Searches were performed in CAB Abstracts, Agricola, WorldWideScience.org and Google using keywords search terms (acoustic, insect, trap), names of researchers who have participated in acoustic and vibrational studies with insects. In addition, the author's personal library on acoustics, vibration, mosquitoes and fruit flies was inspected.

Introduction

Acoustic recording and playback technologies have been employed for insect detection and monitoring since the early 1900s [1] and the study of acoustic behaviour has developed into one of the prominent areas of insect ethology [2–5]. To consider applications for insect pest management, acoustic studies have been conducted to attract and trap insects [6, 7], and to manipulate their behaviours or interrupt intraspecific communication using either sound [8] or vibrational signals transmitted within host plants [9].

Traps using sound to attract insects were first reported in 1949 in studies where male *Anopheles albimanus* Wiedemann mosquitoes were captured in experiments with loudspeakers [10, 11]. Subsequently, acoustic methods were developed in field and laboratory studies to trap other mosquitoes [12–16], Chironomid midges [17–20], *Scapteriscus* spp. mole crickets [7, 21], gryllid field crickets and their tachinid parasitoids [22, 23], *Achroia* and *Galleria* moths [24, 25], *Blattella germanica* (L.) cockroaches [26] and tephritid fruit flies [27–29]. In addition, chemosterilization of acoustically attracted male *Culex quinquefasciatus* Say was conducted with moderate success [30], and male *Aedes albopictus* (Skuse) populations were reduced 76% by attraction to loudspeakers producing 400 Hz tones at the centre of insecticide-treated black polyethylene sheets [31].

In several studies, acoustic traps have been deployed not just to capture, sterilize, or kill insects, but to collect live specimens for biological studies [32, 33] and biological control programmes [34, 35]. Acoustic methods also have been used in surveys to monitor insect diversity [36, 37], population levels [38–40] and geographic distributions [41].

Given the urgent need of regulatory agencies and pest managers to obtain improved tools to detect and manage growing numbers of invasive insect species, e.g. [42–44], it is worthwhile to reflect on the current usage of acoustic technology in integrated pest management programmes, as well as the potential for additional applications in the future. Recent reviews on the evolution and function of insect auditory systems [45] and the physiological, behavioural, ecological and evolutionary context of insect communication [46], and several recent studies on mosquito audition and mating behaviour [47–54] and parasitoid acoustic organs [55] provide helpful background information for this discussion.

Currently Available Sound and Vibration Production Technology

Sonic sources of different dimensions and power levels have been tested in trapping studies, population surveys and behavioural manipulation bioassays, including general-purpose loudspeakers [7, 15], large piezoplastic sheets on foam boards [14], acoustic lasers [28], small tweeters [55] and even tuning forks [15]. Harmoniums [56] and MP3-player speakers [57, 58] have been used to produce airborne sounds that excited vibrations within plants or other substrates containing targeted insects. Caged insects [22, 59], tethered flying insects [48], electrodynamic shakers [60] and piezoceramic actuators [61] have been used to produce sounds and vibrations in behavioural manipulation studies. The speakers with large dimensions and the acoustic laser were constructed to broadcast long-range, loud (>100 dB at 1 m) signals, based on findings that increased signal levels resulted in increased signal attractiveness and trap capture rates [62, 63]. Speakers with small dimensions have been used to produce spatially divergent sound fields to facilitate directional orientation [15, 55, 64, 65]. Some of the signals produced have been playbacks of original recordings [10, 57, 64], others have been synthesized [8, 14, 24, 66, 67]. In several studies [21, 49, 52], the responses to live or recorded signals were compared with responses to synthesized signals.

Relatively high costs of broadcasting over large areas compared with the costs for chemical attractants and pesticides have hampered development of acoustic technology for insect management until now. Frequency-dependent attenuation reduces the effective range of airborne and structural vibration signals greater than 100–200 Hz [1, 60, 68]. High-amplitude speakers can extend the range of sonic broadcasts, but sufficiently powerful energy sources have not always been readily available in the field [6, 7].

Attraction and Trapping Devices

Insects of different species attracted to sound have been trapped by a variety of devices, including electrically charged screens [10, 11, 69], fans or vacuums [64] with collecting bags or cones with nets [66], adhesive cylinders [12, 70–72] and boards [14], funnel and bucket traps [73], or wood-and-screen silt traps [74]. The preferred trap-type depends partly on the size of the insect and its locomotory behaviours, i.e., flight or walking up or down a surface, preferences for crevices or holes, rough or smooth surfaces, etc. [75–78]. Frequently the trap captures are strongly affected by moonlight levels, wind and other factors [16]. In addition, the attractiveness of a trap is context-dependent [7, 22, 58], varying over time and over different segments of the population. For example, the calling sound of a male cricket can attract females, but at high intensities it can inhibit female locomotion or cause other males to move away [61].

The rates of captures in traps often are improved significantly by adding black cloth or other swarm markers, black light or other visual attractants [69, 79], or chemical attractants, depending on the target insect [7, 77, 78]. In the case of mosquitoes, live hamsters and dry ice were used to attract females in addition to the males that were attracted by sound [67].

The sound sources and traps currently in use are mature technology, not likely to change in the near future, but potential avenues for cost-reductions and for enhancements of the effectiveness of behavioural manipulations may be found in the design and implementation of controllers that set beginning and ending times and other temporal patterns of sound production to match the patterns of the targeted species [7]. Also, incorporation of automated counting and identification of the captured or detected insects [40, 80–82] into trapping and monitoring systems may improve their effectiveness in field experiments and integrated pest management programmes. Automated counting and identification is of benefit particularly in environments where servicing of traps might be difficult or dangerous, or when trapping data need to be collected in a timely manner.

Repulsion/Exclusion, Interference with Communication and Other Potential Applications of Acoustic Signals

It has been well documented that many species of insects subject to predation by bats will dive to the ground or move away when they detect ultrasonic signals that resemble echolocation calls [5, 7, 83]. Studies of ultrasonic signals on several moth pest species were conducted [84–87]. In the latter study [87], a light trap containing an ultrasonic speaker was placed in a maize field containing *Heliothis zea* (Boddie) and *Ostrinia nubilalis* (Hübner). The speaker delivered 1 ms, 25 kHz pulses at rates of 1–10 /s, simulating a range of pulse rates and durations emitted during echolocating cries by local insectivorous bats [88]. In this field study [87], high pulse rates decreased light-trap catches more effectively than low pulse rates, and the *O. nubilalis* were affected more strongly than *H. zea*. The results from these and related studies suggested that the effects of habituation and sound shadows rendered ultrasonic repellent signals ineffective for reducing oviposition or for reducing economic damage. It was proposed that the effects of habituation might be reduced by: (1) reducing the signal intensity, (2) presenting the pulses at unpredictable intervals, (3) varying the pulse duration irregularly, or (4) moving the signal source or imparting apparent motion to the signal source [88]. Thus, it may be instructive to revisit ultrasonic treatments in the future for crops where sound shadows can be minimized.

It is important to note also that capability to detect ultrasound to ultrasonic signals has evolved primarily in insects that are preyed upon by bats. Consequently, it is not surprising that none of the popularly marketed ultrasonic repellers has ever been shown to be cost-effective against insects such as cockroaches, mosquitoes, fleas and dragonflies that typically are not bat prey [89–92].

Potential applications of acoustic or vibrational signals for trapping of hemipteran insects or behavioural manipulation of their communication [56, 93–96], as well as for repelling ants or otherwise interfering with their colony-maintenance activities [58] have been considered but not yet implemented in field environments. In addition, there is potential for behavioural manipulation of predator–prey interactions [97] and acoustic mimicry [98]. Finally, several studies have been conducted with insects that use both sound and pheromone during courtship [24, 25, 99–103], as well as on insects that exhibit increased sensitivity to acoustic or olfactory stimuli after pre-exposure to the alternate stimulus [104, 105].

The precise control of timing and frequency of signals enabled by modern computer technology has considerable potential to enhance the trapping efficiency and effectiveness of behavioural manipulations in the future. Precise control of timing can be of value in the disruption of vibrational communication of duetting insects [106], especially pests such as *Diaphorina citri* (Kuwayama), the Asian citrus psyllid [107]. Similarly, there is potential that dynamic control of broadcast frequency may enhance capture efficiency of mosquitoes [49–54].

Conclusions

Until now, acoustic technology has an uneven record of success in insect pest management applications. The range of acoustic stimuli is limited in comparison with the transmission distances of pheromones and other chemical attractants. The responses to attractive or repellent acoustic stimuli habituate rapidly and are variable among different segments of a given target species.

As with pheromone technology, however, acoustic methods have proven useful in a number of insect management applications, particularly for trapping of mosquitoes and midges, and enterprising entomologists are likely to develop additional beneficial uses of acoustic technology for insect management in the next few decades. Certainly, acoustic and vibrational signals can serve both long- and short-range functions, and the signals can be patterned easily to transmit several different signals using the same signalling organs and receptors, as has been demonstrated by the observed diversity of cricket acoustical communication [108]. It has been proposed that a diversity of airborne sound signals [46] and structural vibration signals [60, 109] remain to be discovered in insects. Modern digital signal processing technology now enables broadcast of a diversity of sonic and vibrational signal frequencies of different temporal patterns for a wide range of yet undiscovered, customizable insect behavioural management opportunities.

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