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# SONIC DETERRENTS IN ANIMAL DAMAGE CONTROL: A REVIEW OF DEVICE TESTS AND EFFECTIVENESS

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Sonic devices are promoted as scientifically sound, humane, inexpensive, and simple to operate. The manufacture and sale of sonic devices intended to control damage by animals is a large industry, which included 51 manufacturers of ultrasonic devices and sales of $17 million in the United States in 1982 (Mix 1984). Consumer spending on sonic devices is increasing (Mix 1984), but the legality of selling untested devices is being questioned, and some companies in the United States have been ordered to refund consumers who purchased ineffective devices (W. D. Fitzwater. 1987. Natl. Anim. Damage Control Assoc., The Probe 71: 7).

Frings and Frings (1967:397) noted, "For every one of the noise-producing devices, there are experts offering it as the best available for bird control, and at the same time others finding it of low value." Their statement continues to accurately reflect the situation. Few experiments have been designed to test sonic devices and most publications on this subject describe field trials or demonstrations, rather than adequately controlled and replicated experiments.

Our purposes are to review the mechanisms by which sonic devices may affect animals, review published evaluations and identify effective tests, discuss design requirements for effective tests of sonic devices, and draw conclusions about the efficacy of sonic devices for animal damage control.

## PERFORMANCE TESTS OF SONIC REPELLENTS

Sound waves are longitudinal mechanical waves. Loudness or intensity of sound, usually measured in decibels (dB), varies inversely with the square of the distance from the source, although sound shadows may form behind solid objects. Short-wave, high frequencies above about 20,000 Hz are called ultrasound and are inaudible to people, although some animals such as dogs, bats, and rodents can hear well into the ultrasonic range (Frings and Frings 1967). Long-wave, low frequencies <20 Hz are called infrasound and are also inaudible to people. There is no evidence that ultrasound or infrasound have unique properties making them more likely to repel animals than audible sound. White noise is a random mix of all frequencies and usually sounds like a hiss to people. Signals used in animal communication usually have distinctive patterns of frequency, amplitude, and duration. Sounds are alleged to repel animals by several mechanisms: pain; fear; communication "jamming"; disorientation; audiogenic seizure; internal thermal effects; alarm or distress mimics; and ultrasound.

After a time, most animals adjust and ignore a new sound, a process called habituation. This observation has important implications when assessing the value of any acoustic stimulus, because initial responses are likely to be transient, and the duration and frequency of data collection must be sensitive to this effect.

Many uncontrolled, unreplicated field trials have been conducted on the effects of applied control measures on free-ranging animals. These demonstrations can be of some value for

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inferring whether a particular device or technique warrants further assessment, but are unable to indicate its efficacy, because changes observed may be due to the effects of site or time, rather than treatment. Inferential studies lack the power of controlled, replicated experiments and are an inefficient use of research resources (Ingram 1977). However, repeated observations from many sites or trials, all inferring that a particular device or method has a consistent effect, can be convincing.

### *Pain*

Audible sound above approximately 130 dB and infrasonic or ultrasonic sound >140 dB cause pain and sometimes sickness in vertebrates (Kryter 1970, Pinel 1972, Shumake et al. 1982, Georg 1985, Beuter and Weiss 1986). However, Campbell and Bloom (1965) found that sound intensities capable of causing physiological damage to rats (*Rattus norvegicus*) were less aversive than mild electric shocks. Some animals habituate to extremely loud sounds, as evidenced by European starlings (*Sturnus vulgaris*) observed feeding where jet aircraft created sound levels >130 dB (Boudreau 1968*a*).

Except for explosive bangs, it is technically difficult and expensive to produce and radiate sound >130 dB (Beuter and Weiss 1986). In areas where produce is stored, or where crops or trees are grown, physical features cause uneven distribution of sound. Audible sound at high intensities is likely to be a nuisance to people, and the use of pain for animal control may produce objections related to animal welfare. For these reasons, sound at pain-inducing intensities currently has little potential for pest control.

### *Biosonic Devices*

During the 1950's and 1960's there were numerous field trials in which broadcasts of recorded distress or alarm calls were used to drive birds from agricultural fields, orchards, and roosts (Frings and Frings 1963). This technique is called the use of biosonics or bioacoustics. Species inferred to be successfully repelled by distress or alarm call broadcasts include (1) gulls (Laridae) at dumps, factories, on the seashore (Frings et al. 1955), in fields (Bremond et al. 1968) and airfields (Brough 1967); (2) Canada geese (*Branta canadensis*) at campgrounds (Mott and Timbrook 1988); (3) starlings in roosts (Frings and Jumber 1954, Pearson et al. 1967, Brough 1969) and in orchards and vineyards (Summers 1985, Feare 1989); (4) house sparrows (*Passer domesticus*) in a millet field (Boudreau 1968*a*); and (5) flying foxes (*Pteropus* species) in orchards (Hall and Richards 1987). Underwater broadcasts of killer whale (*Orcinus orca*) vocalizations have been inferred to repel grey whales (*Eschrichtius robustus*) (Cummings and Thompson 1971), beluga whales (*Delphinapterus leucas*) (Fish and Vania 1971), and jackass penguins (*Spheniscus demersus*) (Frost et al. 1975), but not cape fur seals (*Arctocephalus pusillus*) (Shaughnessy et al. 1981). Martin and Martin (1984) tested 3 types of biosonic devices on cormorants, gulls, and pigeons on pier towers and inferred none of the devices reduced bird numbers.

Some designed laboratory and enclosure experiments have been conducted to test rates of habituation and relative aversiveness of various recorded calls. Thompson et al. (1968*a*,*b*; 1979) tested cardiac and operant behavioral responses of wild-caught starlings to various sounds in acoustic chambers. They found that distress calls caused a significantly greater increase in heart rate than escape calls, drug-induced calls, feeding calls, or a human voice. Furthermore, exposure to 3 times as many applications of the distress call than the other sounds was required before the birds habituated. They also found that distress and alarm calls were more aversive to starlings than sounds produced by an Av-Alarm® device, and that light intensity and group size affected aversiveness. Taped distress calls were more aversive to starlings than pure tones of equivalent amplitude. Langowski et al. (1969) showed that the scare effect induced by a starling distress call on captive starlings was greater than that induced by a pure tone. Similarly, Cole et al. (1983) and Johnson et al. (1985) found distress calls had a greater scare effect on captive starlings than either a pure tone or white noise, and that the distress call was less prone to habituation than the other sounds. Sprock et al. (1967) found that a wild rat spent more time in a control chamber than in a sound chamber in which a recorded distress call of a rat being fed to a skunk was being played. They inferred that the distress call showed promise as a means of controlling rats.

Only a few well-designed experiments have been conducted in the field to test the efficacy of broadcast alarm and distress calls. Naef-Daenzer (1983) conducted a field test on crow damage to cornfields using 3 treatments: crow distress calls, suspended dead crow bodies, and a control. Her study site consisted of 36 1-ha fields divided into groups of 3, and the fields in each of these triplets were within 2 km of each other. She randomly assigned 1 of the 3 treatments to each of 3 fields in a triplet. Fields where taped distress calls were played received significantly ($P < 0.05$) less damage than the other 2 treatments, which were not significantly different from each other.

Spanier (1980) tested 3 treatments on a number of night herons (*Nycticorax nycticorax*) at a fishpond: recorded distress calls, recorded gas gun, and a control. He alternated these treatments 19 times through each night and counted birds through binoculars at the beginning and end of each broadcast or control session. The recorded gas gun was effective initially, but there was complete habituation after 6 nights exposure. More than 80% of herons left the pond when distress calls were played, and no habituation was observed after 6 months.

These studies provide conclusive evidence that alarm or distress calls have a repellent effect on many bird species and may have promise for flying foxes and whales. This research also indicates that alarm and distress calls are more resistant to habituation than other sounds.

Busnel and Giban (1968), Boudreau (1968*b*) and Bremond (1980) suggested that it might be possible to isolate common elements from a range of species' alarm and distress calls that trigger dispersal. This information could then be used to synthesize a "super-signal," which would act as a stronger stimulus than natural signals and would affect a wider range of species. We found no evidence that these signals have or can be produced.

Although the efficacy of biosonics is not well documented, we agree with Schmidt and Johnson (1983) that use of biosonics has potential in vertebrate pest control. People using sounds based on animal vocalizations must have a certain degree of expertise and motivation to be successful. Most calls are species-specific, so a pest controller needs to be able to identify species. Future research could be directed towards more appropriately designed experiments to test the efficacy of this technique on a greater range of species and to determine the best methods of application.

### ***Nonbiosonic Devices***

Most sonic pest control devices rely on fear or perceived danger avoidance for their effect (Frings and Frings 1967, Vaudry 1979, Weber 1979, Wright 1982). Such devices include a variety of bangers, crackers, clangers, poppers, bombers, sirens, and electronic noises.

The following field trials provide inferential evidence about the effectiveness of fear-inducing nonbiosonic sounds. Stephen (1961) inferred that automatic acetylene exploders slightly reduced damage to preharvest grain crops by wildfowl on the Canadian prairies. Beuter and Weiss (1986) inferred that audible sound was aversive to gulls (Laridae) in roosting and feeding areas, but that ultrasound and infrasound were not. Holcomb (1976) inferred that an Av-Alarm® device reduced the numbers of red-billed quelea (*Quelea quelea*) and red bishops (*Euplectes orix*) and grain loss in rice fields. Pfeifer and Goos (1982) inferred that gas exploders prevented coyote predation on lambs for an average of 31 days. DeCalesta and Hayes (1979) inferred that shell crackers repelled starlings from blueberry fields over 30 days with no habituation.

Woronecki (1988) inferred that an audible electronic sound device did not reduce pigeon numbers in a vacant building. Martin and Martin (1984) inferred propane cannons reduced cormorant, gull, and pigeon numbers on pier towers for 13–45 days. Wilson and McKillop (1986) inferred that a sonic device was only mildly aversive to European rabbits (*Oryctolagus cuniculus*) in a grass enclosure and the effect lasted for only 1 week. Shaughnessy et al. (1981) inferred that firecrackers were ineffective in reducing disturbance by cape fur seals (*Arctocephalus pusillus*) at purse-seine nets.

Linhart (1984) examined the effect of sirens and strobe lights on lamb predation by coyotes (*Canis latrans*). In year 1, routine control measures including shooting were used. In year 2, routine control measures were stopped and only sirens and strobe lights were used. Five areas were tested each year. The number of lambs killed by coyotes was reduced by 44–95% in year 2. Because control and treatment effects were confounded with time, there is no way to assess seasonal variation, and it is not possible to conclude that reductions in lamb losses were caused by the use of sirens. Linhart et al. (1984) placed sound- and light-producing devices in fields with sheep after 5 coyote kills had been recorded. The predation rate declined and they inferred that the devices were effective. However, in the absence of experimental controls, it is not possible to conclude whether the result is an indication of device effectiveness or an artifact of temporal clumping in coyote predation on sheep.

Potvin and Bergeron (1981) tested the effects of acetylene cannons on levels of damage by red-winged blackbirds (*Agelaius phoeniceus*), common grackles (*Quiscalus quiscula*), and brown-headed cowbirds (*Molothrus ater*) in cornfields. There were 4 treatments on 4 sites: 2 guns synchronized; 2 guns desynchronized; 1 gun; and a control with no guns. Sites with 2 guns had less damage than sites with 0 or 1 gun. As there was no replication, there was no measure of experimental error. Therefore, it is not possible to determine whether differences observed were due to a treatment or a site effect (Hurlbert 1984).

Stickley et al. (1972) tested the effects of propane exploders and the chemical repellant 4-aminopyridine on crop damage by red-winged blackbirds in 6 ripening cornfields. The experimental design was a 3 × 3 Latin square and both treatments and control were replicated 6 times. Each treatment was applied for 6 consecutive days. Field size ranged between 5 and 17 acres, and 2 exploders were placed in each field. Damage was monitored by comparing the length of damaged rows in sample corn ears. Damage in fields with exploders was 81% less than damage in control fields. This statistically significant difference clearly indicated the effectiveness of the exploders over the short treatment period. No attempt was made to test for habituation or to assess the cost-effectiveness of the treatment.

Cummings et al. (1986) examined the effect of a pop-up scarecrow and propane exploder on damage by red-winged blackbirds to 5 ripening sunflower fields. Exploders were turned on and off at intervals of 5 days over 20 days. In 3 fields, the mean level of damage when the 2 devices were on was 78% less than when they were off. But in the other 2 fields, where feeding blackbirds were well established, the average damage with the 2 devices operating was only 8 and 31% less than damage levels with the devices off. An economic analysis indicated that crop loss needed to exceed 18% before these devices became cost-effective, and only 1.2% of fields had such severe damage. The on/off design does not take into account any time lag or habituation in bird response, which may produce a biased estimate of the efficacy of these devices.

Conover (1984) tested responses of red-winged blackbirds and common grackles to propane exploders in 6 treatment fields, divided into halves, and set up with a single device in half of each field. Damage in the half fields with exploders, and in the half fields away from the exploders, was compared with damage in 6 control fields with no exploders. Damage was 77% less in the half fields with exploders than in the control fields ($P < 0.01$). Damage was 71% less in the far half of the fields with exploders than in the control fields ($P < 0.05$). There was no habituation over 4 weeks. This experiment has the potential to give an upwardly biased estimate of the effectiveness of the treatments, because experimental units were not independent. If the devices are effective in displacing birds from treated onto untreated units, an upwardly biased level of damage which is an artifact of device proximity will be recorded. Clearly, treated and control sites must be independent, a requirement that is difficult to meet because of the mobility of birds and larger mammals.

Bomford (1990) tested Hi-Tec Electronic Scarecrows® (Hi-Tec Pty. Ltd., Lismore, Australia), which emitted a complex audible and ultrasonic signal, on feeding flocks of starlings in a grassy field. She divided a 150-m radius circular study site into 12 equal segments. The central 50-m radius circle and alternate segments were designated as buffer zones, and the remaining 6 segments were alternately designated to be treated with the electronic signal or to be untreated controls. In each of the 3 treated segments a speaker pointed toward the outer margin and the 3 untreated segments were screened from the signal. After 25 days of free-feeding, the device was switched on and numbers of starlings and rates of food removal were counted daily. The sound treatment had no effect on bird numbers or food removal during 2 weeks of treatment. As in the previous study, Bomford's experimental units were not independent, so if the device had worked there could have been upward bias of any measure of effectiveness. Hence her experimental design was suitable to test whether the device worked or not, but her results could not have been used to estimate levels of damage reduction.

Spanier (1980) conducted a designed experiment, as previously described, which showed that recorded gas gun broadcasts only caused night herons to leave a fish pond for up to 6 nights. After this period the birds became completely habituated.

Several experiments have compared the aversiveness of different sounds and examined habituation of animals in laboratories or enclosures. The main limitation of these experiments is the restricted applicability of their findings to free-ranging animals (Beck and Stein 1979). The main findings from these experiments follow.

Thompson et al. (1979) found that sounds from an Av-Alarm® device or pure tones were less aversive than taped distress or alarm sounds to starlings in acoustic chambers. Cole et al. (1983) and Johnson et al. (1985) compared the scaring effect of pure tone, white noise, and a taped distress call on captive wild-caught starlings. Pure tone had little effect, whereas white noise and the distress call caused a similar initial response. The distress call had a greater ($P < 0.05$) scaring effect than white noise after 10 presentations, indicating more rapid habituation to white noise. Myers (1967) tested the response of rats in boxes to acoustic stimuli. He found white noise was aversive at 85 dB and pure tones were aversive at 105 dB but also produced immobility responses in rats.

Langowski et al. (1969) used conditioning experiments to show that a scare effect induced by a starling distress call was much greater than that produced by a pure tone at the same decibel intensity. They also found louder sounds were more aversive than quieter sounds and adult starlings were scared more easily than juveniles.

The conclusions that can be drawn from these laboratory and field trials are: (1) loud sounds are more aversive than quiet sounds; (2) sounds with a wide frequency range are more aversive than pure tones; (3) adult birds are more easily scared than juveniles; and (4) all species habituated to nearly all sounds tested.

Consequently, the value of bangers, clangers, poppers, bombers, sirens, and most electronic noises on the birds and mammals tested is almost entirely limited to short-term control. The best effects are obtained when (1) sound is presented at random intervals; (2) a range of different sounds are used; (3) the sound source is moved frequently; (4) sounds are supported by additional methods, such as distress calls or visual devices; and (5) sounds are reinforced by real danger, such as shooting. Because of these complexities, the success of sound deterrents is largely a function of the skill and motivation of the operator.

### *"Jamming" Communication*

Sounds that block the reception of communication calls have been suggested as a means of pest control, and some field trials have been conducted (Crummet 1971; Stewart 1974; Knight and Robinson 1978*a,b*; Callaghan 1980; Rooke 1983). No designed experiments have successfully demonstrated the efficacy of communication jamming as a successful method for pest control in the field. Further field research is needed to assess the potential of this technique before reliable claims can be made (Brett 1979).

### *Ultrasound*

High-intensity ultrasound (sound frequencies ≥20 kHz) is often emitted by pest control devices, and all modes of action which we have discussed have been suggested to account for its supposed aversive effects (Shumake et al. 1984). In addition, it is sometimes implied that ultrasound has special properties that make it more aversive than audible sound. There is no evidence for this. With increasing frequency, sounds dissipate more rapidly, require more energy to produce, and are more likely to produce sound shadows. Mix (1984) reviewed research that largely discredited the use of ultrasound for practical insect control. Wright (1982) and Beuter and Weiss (1986) suggested that behavioral experiments provide no evidence that ultrasound can be heard by, or is meaningful to, birds. Even for pest vertebrates such as rodents, bats, and dogs which can hear ultrasound, there is controversy over its efficacy for control. Hurley and Fenton (1980) tested 2 devices on little brown bats (*Myotis lucifugus*) and inferred neither device was effective. Blackshaw et al. (1990) tested 7 ultrasonic devices on 15 domestic dogs held on a lead at 1 m distance in an open area. Six of the devices, with signal intensities of 60–118 dB at 1 m and frequencies between 7–45 kHz, were inferred to have no aversive effects. One device, with a signal of 120 dB at 1 m and a frequency sweep between 5 and 55 kHz, was inferred to be aversive. These authors did not test for habituation.

Many studies have rejected ultrasound as a practical means of rodent control (Sprock et al. 1967; Kent and Grossman 1968; Meehan 1976; Lavoie and Glahn 1977; Beck and Stein 1979; Lund and Lodal 1980, 1982, 1983, 1984, 1985; Shumake et al. 1982; Lund 1984; Monro and Meehan 1987). These authors concluded that ultrasound either had no effect on target species, or had only a partial and transient effect. No authors presented evidence that ultrasound devices have practical application for pest control. Howard and Marsh (1985) reviewed the effects of ultrasound devices on rodents and found that ultrasound is not of value for practical rodent control. Shumake et al. (1984) outlined test protocols for evaluating ultrasonic rodent repellent devices.

Woronecki (1988) tested an ultrasound device on pigeons in a vacant building and inferred that it did not reduce pigeon numbers. Martin and Martin (1984) tested an ultrasonic device on cormorants, gulls, and pigeons on pier towers and inferred it did not reduce bird numbers. Beuter and Weiss (1986) inferred that ultrasound was not aversive to gulls in roosting and feeding areas. Meylan (1978) tested an ultrasonic device on greenfinches, and house and tree sparrows in a sunflower crop and inferred that it deterred birds from visiting the crop. Griffiths (1987) tested an ultrasound device on the house finch (*Carpodacus mexicanus*), dark-eyed junco (*Junco hyemalis*), white-breasted nuthatch (*Sitta carolinensis*), black-capped chickadee (*Parus atricapillus*), and blue jay (*Cyanocitta cristata*). He found the device had no significant effect on any species for either feeding time, seed consumption, or numbers of birds visiting the test sites.

Shumake et al. (1982) examined the influence of 3 ultrasound devices (20, 20–30, and 40 kHz) on the behavior and food intake of rats (*Rattus rattus*), using 3 sound chambers and a control chamber, each 2 m$^2$, with an enclosed area surrounding the chambers and connected by runways. One device was placed in each sound chamber. Three factors were tested, each at 2 levels: plentiful versus restricted food; native versus immigrant rats; and continuous versus discontinuous sound. The response variables measured were food consumption and photocell breaks. There was a decrease in food consumption compared with the control for all 3 devices when food was plentiful. When food was restricted, only the 20–30- and 40-kHz devices reduced food consumption.

Immigrant rats avoided both control chamber and sound chambers in Shumake et al.'s (1982) study. Consequently, the experiment was insensitive as a test of the effect of the devices on immigrant rats. This has important implications for other assessments of ultrasound that test animals in a new environment. The trial lasted only 10 days, but there was rapid habituation even over this period. For the 20-kHz device, food consumption was 20 g/day on day 2, but was 50 g/day by day 10, compared with 80–100 g/day for the control chamber. When sound intensity was reduced by 30 dB (equivalent to 10.7-m distance), all 3 devices were ineffective. This experiment indicated that ultrasound may have a partial and temporary repellent effect on rats at close quarters. Its effect may simply reflect rodent neophobia, rather than any special property of ultrasound. However, we have not found evidence that ultrasonic devices have value in practical animal damage control.

### *Other Effects*

Shumake et al. (1984) listed disorientation as 1 of the suggested aversive effects of ultrasound. We were unable to find evidence of sound-induced disorientation as a means of pest control.

Captive rodents exposed experimentally to particular patterns of high-frequency, high-intensity sound sometimes undergo audiogenic seizures. At the start of a seizure, the rodent runs around wildly, then collapses and either recovers or dies (Lehmann and Busnel 1963, Frings and Frings 1967, Sprock et al. 1967). Audiogenic seizures have not been induced in rodents in their natural environment. Because of problems caused by sound shadows and signal strength attenuation with distance, it is unlikely that audiogenic seizures could be produced reliably outside the laboratory, except at great expense and technical difficulty.

Loud sounds, either audible or ultrasonic, can kill insects and rodents under laboratory conditions by increasing their body temperature (Danner et al. 1964, Nelson and Seubert

1966, Frings and Frings 1967). These thermal effects would be difficult, expensive, and perhaps dangerous to produce for use on free-ranging animals and, therefore, seem unlikely to be of practical use in animal damage control.

## DISCUSSION

Effective testing of sonic repellents in animal damage control has lagged because most work has focused on short-term tests of commercially developed and marketed products. Evaluation of prototypes during the research and developmental process has been much less common. Most tests have been short-term and single purpose, posing simple and frequently superficial questions about efficacy of devices. Biologically and functionally diverse signals such as alarm and distress vocalizations, recorded audible sounds, and ultrasonic, infrasonic, and synthetic signals have been assessed in a single category. This has given a false impression of homogeneity and has resulted in the tendency for successes or failures of specific devices to be generalized to all devices.

Many experiments have lacked experimental controls, thus precluding conclusions about damage levels in the absence of devices being evaluated. Only weak inference can be drawn from unreplicated or uncontrolled studies. While such evidence can add weight to an assessment of device effectiveness if sufficient independent studies have similar findings, this is not an efficient approach to assessing effectiveness. A regression design, whereby damage is assessed in relation to increasing distance from a device, will confound site and treatment effects, unless both controls and replication are incorporated in the design. Experiments should not be conducted when constraints are such that it will not be possible to interpret the result.

"Before" is not a control on "after" in time-sequence experiments because treatment is confounded with time. Therefore, untreated control sites must be concurrently monitored in such experiments. Control and treatment sites do not need to be matched, but both must be replicated so that treatment and time effects can be separated in the statistical analysis. Confounding may occur in time sequence experiments if there is time lag or habituation in the response of animals to treatment.

Where experimental controls have been used, independence was often compromised by their proximity to treated areas. Because birds and larger mammals are highly mobile, any effect of a repellent device has potential to displace animals onto untreated areas, inadvertently enhancing any measure of treatment effect. This lack of independence between treated and untreated sites is a design problem that must be balanced against the need for homogeneity between sites. In general, however, replication is relatively economical and technically feasible in field experiments with sonic devices, and we encourage its application. Multiple replicates and full randomization seem the most appropriate solutions.

Pseudoreplication (Hurlbert 1984) has been used frequently in experiments testing the effectiveness of sonic devices. Pseudoreplication occurs if either treatments are not replicated (though samples may be) or replicates are not statistically independent and the data are analysed as though these conditions are met (Hurlbert 1984). For example, treatment "replicates" may be grouped together instead of being represented across the entire study site. This confounds site and treatment effects and defeats the purpose of replication.

Measures of the effect of devices were frequently poorly defined, inadequate, or inappropriate. While it may be appropriate to use a count of bird numbers or mammal activity levels to answer the simple question of effect or no effect, such data have limited use for drawing conclusions about damage reduction. Where possible, observer bias in recording response variables should be avoided by using recorders who do not know which treatment levels are applied at each site. In addition, the effects of sex and age class on responsiveness, habituation resulting from persistent exposure to the signal, and seasonal variation in behavior warrant consideration in experimental design. Finally, signal characteristics of the devices under study should be quantified so that direct comparisons can be made between devices.

## SUMMARY AND CONCLUSIONS

We reviewed the literature on tests of devices that use sound to control animal damage. Although numerous devices have been developed and assessed, many reported tests are inconclusive. We recognize the technical and economic difficulties inherent in conducting large-scale field experiments on a spatially and temporally variable factor like animal damage. However, future tests on sonic devices would be improved by: adequate experimental control and replication; avoidance of pseudoreplication; appropriate measures of device effect; and quantitative description of the sound produced.

In spite of the shortcomings of most past evaluations, sufficient tests that meet some degree of rigor in design and execution have been conducted to indicate that devices producing sounds other than communicative signals (alarm and distress) have no persistent effect on animals' space use or food intake. These devices provide, at best, short-term damage reduction. Biologically meaningful sounds (those used in specific communication) have not been fully assessed. Limited available evidence supports the short-term effectiveness of these devices in damage mitigation and in influencing space use, particularly by birds. However, there is also evidence of habituation to the signals with prolonged or frequent exposure.

Sonic pest control devices should be viewed with considerable skepticism by legislators, pest controllers, and consumers. Few conclusive tests have been conducted of their efficacy, and even those devices that work may not be cost-effective or may not represent the most effective solution to damage control. Ultrasonic devices do not meet the claims made for them. Broadcast distress or alarm calls show the most promise as a control technique, but these are usually species-specific, and birds habituate if calls are played frequently or over a long period.

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# DIFFERENTIATION OF FRESH FROM FROZEN-THAWED GAME MEAT BY ELECTROPHORESIS

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A procedure for the differentiation of fresh from frozen and thawed game meat is needed for wildlife law enforcement. The time of harvest of a game animal is sometimes in question, and some uncertainties concerning possible violations can be resolved by determining if the meat has been previously frozen.

Muscle tissues undergo changes during freezing including formation of ice crystals and rupture of plasma membranes; upon thawing there is release of water and associated soluble components (drip loss) from the muscle tissue (Love 1966). Quantitation of drip loss (Wierbicki et al. 1957, Love 1966, Fennema et al. 1973) and ultrastructural changes (Fennema et al. 1973, Bello et al. 1981) have been suggested as possible means of distinguishing between fresh and frozen-thawed meat. However, drip loss is extremely variable and is dependent upon conditions of freezing and thawing (Fennema et al. 1973, Jul 1984). Changes in muscle ultrastructure may or may not be altered by freezing (Field et al. 1989). Furthermore, ultrastructure postmortem might be altered by aging, extent of muscle fiber contraction, and shrinkage (Bello et al. 1981). Decompartmentalization or changes in distribution of specific enzymes associated with muscle mitochondria has formed the basis for the most reliable procedures to distinguish fresh from frozen-thawed meat. Gottesmann and Hamm (1982) described a technique to determine if meat had been previously frozen based on the release of the mitochondrial enzyme beta-hydroxyacyl CoA dehydrogenase (HADH) into the sarcoplasm (cytoplasm) of the muscle cell. The activity of HADH in the meat exudate was assayed spectrophotometrically. This procedure was used to differentiate fresh from frozen-thawed game meat (Morgan-Renk 1988). The liberation of the mitochondrial isoform of glutamic-oxaloacetic transaminase (aspartate aminotransferase, AAT; E.C. 2.6.1.1) has also been used to distinguish fresh from frozen-