Review of international research literature regarding the effectiveness of auditory bird scaring techniques and potential alternatives.

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1. Executive Summary

1. There is limited information available on the efficacy of auditory and alternative bird deterrent devices and guidance on best use. The use of gas cannons in particular has resulted in complaints of noise nuisance. Defra therefore commissioned Central Science Laboratory to review and evaluate the current state of knowledge in order to provide a sound scientific basis for policy decisions and guidance material.

2. A search of published information and the grey literature relating to bird deterrents, information held by CSL and consultation with individuals, manufacturers and distributors of deterrent devices, resulting in a collection of 456 documents.

3. Auditory techniques in general are thought to be relatively effective, although subject to habituation and hence of short-term benefit. Much of the information on noise is unpublished and not generally available. Artificial noises, ultrasonics and high intensity sound are either ineffective or unsafe.

4. Visual techniques range from extremely effective (human disturbance) to ineffective (most scarecrows). Effectiveness depends on how real a threat they are perceived to be (predators and their models) or how much they are perceived to interfere with movement (tapes and wires).

5. Chemical techniques are generally found to be very effective in laboratory and cage trials, but less effective in the field. They are also relatively expensive and are time-consuming and difficult to apply. Only two chemicals are licensed for use as bird repellents in the UK.

6. Exclusion techniques are usually extremely effective. Efficacy depends on the degree to which birds are excluded, but the greater the exclusion the more expensive. They therefore tend to be restricted to high value crops or costly damage.

7. Habitat modification techniques are generally considered to be effective and environmentally friendly, but are rarely investigated scientifically. It seems likely, however, that that they will be shown to be cost-effective in a variety of situations.

8. Lethal techniques are generally considered to enhance other scaring methods, though this remains largely untested. However, as a means of population control they can be less effective and costly. In the UK lethal methods are licensed by Defra under the Wildlife and Countryside Act (1981).

9. Combinations of techniques, used in an integrated control strategy, are considered to be more effective than techniques applied singly but combinations are rarely scientifically evaluated.

10. Areas for further work are identified and include updating the guidance on gas cannons, producing guidance on best practice in the prevention of damage to crops, creating an interactive web site on bird deterrent techniques for users and/or wildlife advisors. More work is needed on bio-acoustics, tapes and flags, habitat modification and combinations of techniques. Existing information on noise levels should be further evaluated, disseminated and expanded upon as required.

2. Introduction

Avian deterrents can be categorised into auditory, visual, chemical, exclusion, habitat modification and lethal. The use of bird scaring devices, particularly those based on auditory techniques, has led to complaints from the public, with the suggestion that non-noisy devices should be used as alternatives. However, there is limited scientific information available, both on the efficacy of the various products and techniques, as well as guidance on how they can best be deployed, both to maximise effectiveness and to minimise nuisance to neighbours. The true costs of bird damage, and the cost of deploying different control methods are also of relevance. Much of this information exists as consultancy reports to customers or as unpublished datasets. Therefore, there is a need to review and summarise the available information, as well as to collate examples of costs and benefits. Defra commissioned CSL to undertake this study in order to meet this need.

The results of properly designed and conducted experiments comparing the efficacy of the methods as well as investigating the noise levels produced, are needed in order to give sound scientific advice on the use of bird deterrents. A critical evaluation of the literature is therefore also needed in order to properly assess its relevance and reliability. The primary question to be asked of the data is: do the techniques reduce the levels of damage below that expected if they are not used. Secondly, is the level of damage reduction sufficient to offset the cost of using the techniques? And thirdly, do any deterrent categories or specific devices/techniques perform consistently more effectively than others? Particular attention will be paid to the noise nuisance aspect, a cost difficult to quantify.

By reviewing published information, grey literature, datasets and personal experience of specialists from around the world, it will be possible to ensure that any new guidance material (on auditory bird scarers or alternative methods) is based on current best practice. If alternative techniques to auditory bird scarers are to be recommended, then it is important that the reasons for this have a sound scientific basis. This study will review the current state of knowledge and identify areas where further work is needed, to ensure future research is targeted appropriately and duplication of effort avoided.

3. Aims

To collate and review the published and unpublished information on bird deterrents, to critically evaluate studies which attempt to scientifically assess the relative cost-effectiveness of the different techniques and to identify areas for further work in order to fill gaps in knowledge.

4. Methods

4.1 INFORMATION GATHERING

Information published in standard scientific journals was obtained by searching the following databases: INSPEC (provided by the Institution of Electrical Engineers), Biosis Previews, Agricola, SciSearch (provided by the Institute for Science Information), Dissertation Abstracts Online, Enviroline, CAB Abstracts, Env. Bib.

(provided by the International Academy at Santa Barbara), AGRIS, Pascal, Zoological Record Online, 2002 BIOSIS and GEOBASE (Elsevier Science). Central Science Laboratory's extensive collection of information relating to bird control, and CSL's official files, were also searched. Information available on the internet was obtained by using Google search engine, and by visiting web-sites listed in recent Bird Control and Birdstrike conference proceedings. The grey literature on bird deterrents was further investigated by searching the Defence Controlled databases and Open Literature databases. Scientists and organisations (both government and NGO) from around the world, and manufacturers and distributors of bird deterrent products, were approached directly by both post and e-mail. Table 1 lists the individuals and organisations contacted, and whether any reply had been received.

4.2 COLLATION

The information gathered was collated and summarised. For each study, the following information was extracted: the category of deterrent and type of device investigated, the country in which the work was conducted, whether it was a field trial, laboratory study or a review, whether the device/technique was felt to be effective and whether any cost/benefit analyses had been carried out.

4.3 REVIEW

For each technique, reasons or biological principles behind its use were described, along with any factors or practices that might determine its efficacy. Examples of effective use were described, along with any examples where its use was less successful. Any potential for noise nuisance was highlighted along with techniques for noise reduction.

4.4 EVALUATION

Replicated field trials (as opposed to 'one-off' studies) were then selected for evaluation. Unreplicated or 'pilot' trials, although they are an indication of the potential usefulness of the technique, provide only anecdotal evidence and are not considered further. Studies based on cage or pen trials with captive birds are also not considered, as such trials are designed to maximise expression of the deterrent effect. Results are often not repeated when controlled and replicated field trials are carried out: Avery *et al*. (1993).

In evaluating the selected studies, in order to be as objective as possible, the principles of meta-analysis were used. This is the quantitative synthesis, analysis and summary of a collection of studies (Hedges and Olkin 1985). The technique has recently been applied to ecological questions (Osenberg *et al.* 1999).

Table 2 describes the system used to rate the selected studies in terms of context, treatment, experimental design and cost/benefit analyses.

The *context* of the study was noted, in terms of the species of bird, the resource affected and the country in which the study took place. The results of studies carried out on species and resources present in the UK score higher as these techniques are more likely to be transferable to the UK agricultural environment compared to overseas studies on non-UK species. Studies scoring 0 may still be of relevance to this project, however, if they investigate novel techniques.

The techniques evaluated in the study (termed '*treatments*' within the experiment) were also noted and the rate of application considered in terms of the practicality of use and in relation to existing legislation or codes of practice. Results of studies using application rates that are impractical or greater than recommended (in the UK) are considered to be less transferable to the UK agricultural environment, and hence score less than studies using realistic application rates.

The *experimental design* was then examined. Studies with adequate levels of control and replication were given a higher score. This decision was made based on our experience as field ecologists, and is necessarily subjective, as is the subsequent decision we made on whether habituation and potentially confounding factors had been adequately addressed. Confounding factors include time, carry-over effects (for example studies in which treatments are applied sequentially) and scale effects (experimental plots are too small to prevent interference between treatments).

When considering the *cost/benefit* aspect, weight is given to those studies which actually measured the level of damage (as far as possible), rather than just inferred it from the numbers of birds present, and those studies which considered the full cost of the technique (for example by including labour).

Finally, the *results* of each study were summarised. Techniques which were considered effective (resulting in over 50% reduction in damage or number of birds) scored 2, those that were partially effective (resulting in up to 50% reduction in damage or birds) scored 1 and ineffective (no significant reduction in damage or number of birds) 0.

5. Results

After searching the published and grey information, and contacting the individuals and organisations listed in Table 1, 456 documents were gathered and collated. Table 3 lists these documents and summarises their contents.

5.1 REVIEW OF CURRENT STATE OF KNOWLEDGE

The review of avian deterrent techniques was divided into auditory methods (those most likely to cause a noise nuisance) and alternative methods. Alternative methods were further divided into visual, chemical, exclusion, habitat modification and lethal techniques.

5.1.1 Auditory Bird Deterrents

GAS CANNONS

Gas cannons (or 'exploders' in the USA) are mechanical devices that produce loud banging noises by igniting either acetylene or propane gas. Their scaring effect is probably related to the similarity of the noise to that of a shotgun. The unexpected bang produced causes a ‘startle’ reflex and promotes escape flight (Harris and Davis 1998). The gas cannon works by igniting the mixture of gas and air under pressure, with the frequency of detonation regulated either by adjusting the gas feed or with an automatic timing device. Most produce a single report of up to 130dB(A) (distance from source unknown), (BanCannons website) at regular intervals, but these intervals can be varied and some can produce double bangs, and rotators are available so that shots can be aimed in different directions. Prices for gas cannons range from £165 to £475 (Henly 1992), though costs vary depending on whether it is a single, double or multi-bang cannon, and other features such as rotators and electronic timers.

Gas cannons are commonly used to scare birds off agricultural crops, but have also been used at aquaculture operations and on aerodromes. However, their effectiveness is variable and is dependent upon the method of their deployment, the bird species involved and the availability of alternative feeding areas close by.

In a survey of Mississippi catfish farmers, 97 of 281 respondents used gas cannons, of which 9% said they were very effective, 51% somewhat effective and 40% not effective. The general consensus was that they were most effective when used in combination with other scaring techniques (Stickley and Andrews 1989). Broyer *et al.* (1993, cited in Parrott 2000) also found cannons to be effective on small fisheries. Propane cannons were the only acoustic device to scare cormorants from their roost on pier towers (Martin and Martin 1984), though they only relocated to another roosting site a short distance away.

In agricultural settings, acetylene exploders successfully reduced or stopped blackbird damage to ripening maize (Cardinell and Hayne 1944) and De Grazio (1961, cited in Potvin and Bergeron; 1964) found that blackbird damage to corn was reduced by 98%. Sugden (1976, cited in Harris and Davis 1998) indicated that gas cannons were useful for reducing waterfowl damage to grain crops.

However, other studies have shown that single gas cannons can be less effective in reducing bird damage. A single gas cannon, fired every two minutes offered no protection to a forage corn field from blackbirds (Potvin and Bergeron 1981), though two pivoting cannons with desynchronised detonations reduced losses by 73% and one double detonation synchronized cannon by 66%. On aerodromes, a number of trials have shown that gas cannons have no worthwhile effect and so are not recommended for bird control (Civil Aviation Authority 2002). Conniff (1991) reported that gas cannons eventually became perches for double-crested cormorants. It is clear that effectiveness varies with mode of deployment.

Habituation seems to be the main reason for their loss of effectiveness; a cannon firing repeatedly without any variation in timing or direction quickly loses its potential to scare birds. Moving the cannon every few days is recommended (NFU undated; Transport Canada 1994; Harris and Davis 1998; Gorenzel *et al.*1994, Inglis 1992), along with variable firing intervals (Harris and Davis 1998). British Columbia Ministry of Agriculture, Food and Fisheries (2002) recommend managing gas cannons differently as the crop grows. When bird numbers are low, firing frequency should also be kept low and only increased if bird numbers increase. Starting with a high frequency of firing encourages habituation, though at Calgary Airport, bird control staff have found that a shorter firing interval keeps the birds on edge and so are more easily dispersed (Brian Richmond 1998 pers. comm., cited in Harris and Davis 1998).

The area protected by a gas cannon can vary depending on the crop or habitat. Cardinell and Hayne (1944) state that one cannon could protect 4 hectares of maize from blackbirds, though the most effective protection was within 60 to 120 metres from the cannon. Transport Canada (1994) recommend one cannon for every four to 10 hectares for blackbirds based on the work by Potvin and Bergeron (1981), and for protection of crops from waterfowl, one cannon per 20 hectares. At aquaculture facilities, Gorenzel *et al.* (1994) suggest one cannon can cover 1.3-2 hectares, if reinforced with other techniques. On aerodromes, Transport Canada (1994) recommends a cannon every 50 metres along runways to disperse gulls. Thus by placing one cannon in too large an area of crop, effective protection will not be achieved throughout the whole area. In addition, the number required to cover a large area may be prohibitive. Placing a cannon within, and frequently moving it between hides used by shooters may prolong the scaring effects of both the shooting and the gas cannon (Inglis and Isaacson unpub. data, cited in Parrott 2000).

Apart from single and multi-detonation cannons, products are also available that combine visual and acoustic stimuli to scare birds. The 'Rotating Hunter' consists of two propane cannons and the metal silhouette of a person that swivels with the force of each shot. It is claimed that one device can protect 20 hectares of open farmland (Agri-SX, cited in Harris and Davis 1998). The 'Falcon Imitator' has a cannon that propels a fringed rubber disk up an eight-metre pole which then parachutes slowly back down the pole. This is said to imitate a falcon chasing a bird. According to the manufacturer, one device is effective within a 150-metre radius (Agri-SX, cited in Harris and Davis 1998). However, both these devices are more expensive than standard propane cannons and results from full testing of their effectiveness have not been found.

Although gas cannons can be effective bird scarers if the firing frequency and direction is varied, there is public concern with noise nuisance and their use close to residential areas. Inglis (1993) found that the intensity of sound output from gas cannons was highly variable, both between guns and between explosions of an individual device. Local conditions, such as wind direction and strength also affect the intensity of noise. Pointing cannons away from houses and constructing simple straw baffles around them allows them to be placed at approximately half the distance of cannons without baffles, with no increase in noise nuisance (Inglis 1993). In the UK, the National Farmers Union (undated) have produced a code of practice to give guidance on the use of bird scarers but particularly gas cannons, in order to maximise their effectiveness and reduce the possibility of causing disturbance to the public. Although not available on the Internet, copies can be obtained from local NFU offices.

PYROTECHNICS

Pyrotechnics include a wide variety of noise-producing cartridges usually fired from rockets or rope bangers, or on aerodromes from modified pistols or shotguns, which produce a loud bang and emit flashes of light. They include shellcrackers, screamer shells and whistling projectiles, exploding projectiles, bird bangers and flares. Cartridges are projected from a shotgun with a range of 45-90m, or pistol (range approximately 25m), and then explode. Bird scaring cartridges can produce noise levels of up to 160dB at varying ranges (Primetake Ltd. 1996) but both the cartridges and the gun require a firearms certificate (Moran Committee Joint Bird Group, undated).

Pyrotechnics have proved effective in dispersing birds at airports, landfill sites, agricultural crops and aquaculture facilities. At airports in the UK, shellcrackers fired from a modified pistol are the commonest means of dispersing birds (CAA 2002), as they allow the bird controller to have some directional control over birds in flight, so they can be steered away from runways. The scaring effect can be projected into areas beyond the bird controller’s reach, and amongst the flock. Transport Canada (1994) state that shellcrackers are effective in dispersing gulls, crows, starlings and waterfowl but are not useful for the dispersal of pigeons, though others have found pyrotechnics extremely effective against pigeons. Habituation can occur rapidly if shellcrackers are used frequently, but the scaring effect can be reinforced by using taped distress calls or by killing the occasional bird.

Baxter *et al*. (2002c) evaluated the effectiveness of bird-scaring rockets for dispersing birds from landfill sites. With a limit of four rockets per hour between dawn and dusk, success was variable; at one site gulls were scared from the landfill but remained in the surrounding area, though in significantly lower numbers than were observed before the start of the trial. These birds took advantage of staff breaks to return to feed. At a second trial, birds were almost completely controlled, well within the limit of four rockets an hour. It was concluded that pyrotechnics were highly effective at controlling birds at landfill sites, but the use of large numbers of rockets might be required, so reducing the cost-effectiveness of the technique. It was also noted that the use of pyrotechnics should be limited to sites away from residential areas to avoid causing a noise nuisance.

In a survey of Mississippi catfish farmers, 21 of 281 respondents regularly used pyrotechnics. Of these, 24% considered them to be ‘very effective’, 57% ‘somewhat effective’ and 19% ‘not effective’ (Stickley and Andrews 1989). Moerbeek *et al.* (1977) found them ineffective for the control of cormorants, though Andelt *et al.* (1997) found that 14 consecutive days of firing exploding and whistling projectiles at a fish-rearing unit reduced black-crowned night-herons by 91% and great blue herons by 73% for the next 22 nights. Although the cost of the pyrotechnics and labour were high it was considered less than the estimated cost of the potential fish losses.

Although pyrotechnics are considered effective against waterfowl (Greer and O’Connor 1994 cited in Reilly 1995; Transport Canada 1994; Aguilera *et al.* 1991), Fairaizl (1992) found their effectiveness highly variable; some flocks of Canada geese in urban areas required continuous harassment and usually returned within hours.

Screamer shells fired at crows coming into urban roost in California were temporarily effective, gaining a control rating of nine on a subjective scale of one to 10 (best). However, the birds flew in after firing had ceased and it was considered that the noise limited their use (Gornezel and Salmon 1992).

Rope-firecrackers are inexpensive, commercially available and require little manpower (Booth 1994). Fuses of the firecrackers are inserted through a 8 or 9.5 mm cotton rope. The rope is ignited and as it burns the firecrackers produce a series or loud explosions at approximately 20 minute intervals (Henly 1992). Their noise levels can be enhanced by placing them inside empty oils drums (P. Haynes pers. comm.). Weather conditions can affect the burning speed of the rope and there is also a danger of creating a fire hazard.

In summary, pyrotechnics are an extremely effective method of bird scaring though the effectiveness may be partly due to the presence of an active human operative. Thus, their use is a labour intensive method of bird scaring, and if they are used in large numbers they are not cost-effective (except on aerodromes) and birds will habituate to them. Habituation can be delayed by using pyrotechnics selectively, that is, infrequently and at close range. Mott and Timbrook (1988) concluded that the efficacy of harassment with pyrotechnics was partially dependent on availability of alternative feeding and loafing areas for birds. As the direction and intensity of firing can be controlled to suit the bird species and location, disturbance to non-target species can be minimised. However, their use is limited near residential areas due to the problems of public safety and of noise, and pyrotechnics should not be used in situations where there could be a fire hazard, such as near dry vegetation (Harris and Davis1998).

BIO-ACOUSTICS, ACOUSTICS, ULTRASONICS AND HIGH INTENSITY SOUND

Bio-acoustic deterrents are sonic devices that transmit sounds of biological relevance: recorded bird alarm and distress calls. In general, alarm calls are given when birds perceive danger, whilst distress calls are vocalised when birds are captured, restrained or injured. These calls are species-specific and can cause conspecifics to take flight. Alarm and distress calls, however, may also evoke a response in other species that are taxonomically related to the call-producing species (Baxter *et al*. 1999) or which closely associate with it. Responding to alarm/distress calls has a high survival value, therefore such biologically meaningful sounds are more repellent and more resistant to habituation than other sounds (Bomford & O'Brien 1990, Harris & Davis 1998). However reactions to distress calls can vary both with the species and the individual bird (Schmidt & Johnson 1983); in some groups such as gulls, alarm/distress calls initially act as an attractant with birds approaching the source, apparently to investigate, before flying away (Brough 1968).

A number of sonic devices and pre-recorded alarm and distress calls are now readily available commercially and such devices are widely used for bird control. Some devices can produce noise levels u to 110dB(A) (at six metres) and have a useful operating distance of 300 m (Scarecrow Bio-acoustic Systems website). In Haifa, Israel, more than 80% of visiting night herons (*Nycticorax nycticorax*) were frightened off trout ponds when recorded distress calls of juvenile and adult (combined) night herons were broadcast (Spanier 1980, cited in Kevan 1992). Baxter (2002c; undated) found that distress calls resulted in immediate and almost complete clearance of gulls and corvids (crows, rooks and jackdaws) from landfill sites, though the effects were short-term (3-6 weeks), and birds quickly returned when equipment broke down. In deterring waterbirds from areas of oil spills, biosonics were highly species-specific but worked particularly well on gulls and some herons, with slow habituation (Greer and O'Connor 1994, cited in Reilly 1995).

Bio-acoustics are seen as the most effective and cheapest ways of dispersing birds from airfields, once the equipment has been bought and staff trained (CAA 2002). Only distress calls are used as birds react to these in a characteristic and thus more predictable manner. The calls are broadcast for about 90 seconds from a stationary vehicle approximately 100 m from the target flock.

Static, free-standing systems can be used on smaller areas, though a louder volume may be needed to effectively cover the area (Booth 1983, cited in Kevan 1992), but constant exposure to a sound that originates from the same location can quickly encourage habituation as well as causing a noise nuisance to adjacent areas. Mobile, hand-held or vehicle mounted systems that can be used in response to a bird problem are deemed more effective (CAA 2002; Booth 1983, cited in Kevan 1992), though they will be more expensive due to the labour involved. Brough (1969) stated that bird recordings and broadcasts should be made with attention to accuracy, signal strength and clarity, as a reduction in any of these would degrade the calls from a recognizable signal to a meaningless noise, so lessening their effect. More recently however, digitally recorded, high quality calls are readily available. Some birds, like pigeons and Canada geese do not produce easily identifiable alarm and distress calls, and the use of calls from other species may not be totally effective. Research into this problem is ongoing (N. Horton pers. comm.).

Broadcasts of raptor calls have been used in attempts to deter pest species from, for example, airports (Harris & Davis 1998) based on the theory that playback of the call signals that a predator is close by. Raptors, however, hunt silently and so the use of recorded raptor calls has no clear biological basis for use in such circumstances. However, the playback of a peregrine falcon call dispersed gulls at Vancouver International Airport (Gunn 1973, cited in Harris and Davis 1998), although this was not properly controlled (i.e. compared to the effects of other auditory sources such as random noise).

Sonic systems that produce a variety of electronically-produced sounds are also commercially available. They can emit noise at levels up to 120dB(A) at one metre (BanCannons website, Harris and Davis 1998). The range of loud and sudden noises they produce can frighten birds but as they have no biological meaning the risk of habituation is great (Harris and Davis 1998). Sonic systems like the Phoenix Wailer also produce bird alarm and distress calls as well as electronic sounds up to 119 dB(A) at five metres, though the volume is adjustable for use near built up areas (Phoenix Deterrent Systems Ltd). With static systems, frequent changes in location and adjustments to the sounds can reduce habituation (Harris and Davis 1998).

There is no evidence that ultrasonic devices deter birds (Hamershock, undated). In fact, evidence indicates that most species of birds do not hear in the ultrasonic range (>20kHz) (Erickson *et al*. 1992, Harris & Davis 1998) and so there is no biological basis for their use. Haag-Wackernagel (2000) and Woronecki (1988) both found that pigeons were undeterred by an ultrasonic system.

High intensity sounds such as sonic booms, horns and air-raid sirens, at close range, can cause distress or pain, which will cause birds to leave. At greater distances, the sounds can cause startle reactions amongst birds, though for the sound to cover any distance, the sound level at its source would have to be of an extremely high intensity

(Harris and Davis 1998). Greer and O'Connor (1994, cited in Reilly 1995) found waterfowl quickly habituated to airhorns and Martin (1986) observed that after four to six weeks, barn owls were perching on the generating units of ultra-high intensity sounds. This technique can cause hearing damage and other human health effects and so cannot be recommended (Harris and Davis 1998).

Systems using bio-acoustics are the most effective sonic devices available as they act on the birds' instinct to avoid danger. Their effectiveness is determined by the use of species-specific calls and the availability of alternative areas to move to. Although such systems can be placed in a field on a random timer sequence, birds will quickly habituate to such a device if it is not frequently moved, and it may cause noise nuisance in adjacent areas. A manually-operated system that is used only when birds are present will be more expensive but will also be more effective and less likely to become a nuisance. With all systems, sound transmission will be influenced by ambient temperature, wind direction and reflections from surrounding features such as buildings, and such factors need to be taken into consideration when siting sonic devices (Scarecrow Bio-acoustic Systems website). As with most methods of bird control, an integrated approach using a variety of techniques is likely to be more effective and reduce habituation rates (Schmidt and Johnson 1983).

SCIENTIFIC EVALUATION OF AUDITORY TECHNIQUES

Of the documents listed in Table 3, 73 described studies based on replicated field trials, and these were selected for further evaluation. Table 4 lists the 28 selected studies investigating at least one auditory technique, sorted according to total score and experimental design (those with the highest score and best experimental design are at the top). Sixteen studies contained evidence that the devices were very effective, six partially effective and six ineffective. When only the six 'best' studies were considered, i.e. those with a high total score (>4) and a good experimental design, a similar picture emerged (half were very effective). Only four studies scored over five.

When the type of auditory device is considered, distress calls, pyrotechnics and shooting appear to be more effective than sonic devices, humming tapes or gas guns (Table 5). Sample sizes were small, so in the table, studies reporting the technique to be very effective (>50% reduction in damage or number of birds) were combined with those reporting partial effectiveness (up to 50% reduction).

NOISE NUISANCE

Noise is usually regarded as unwanted sound, that which is too loud, too intrusive, happens without warning or at the wrong time (DETR 2001). Environmental noise, particularly in rural areas, is of growing public concern as rural areas are no longer regarded as areas specifically for food production, but are valued as a recreational resource and a place of peace and tranquillity (Lines *et al.* 1994). Noise nuisance is covered by the UK Environmental Protection Act 1990 and the Noise and Statutory Nuisance Act 1993.

A National Noise Attitude Survey (NAS) was carried out in 1991 (for Defra) with the aim of sampling the population of England and Wales, to assess attitudes to environment noise in the home (BRE 2002a; 2002b). A sample of approximately

2550 people were interviewed and asked questions on eleven categories of environmental noise, including 'noise from farming or agriculture – tractors, farm machinery, bird scarers'. From this sample, 2373 questionnaires were correctly completed, and 90 (4%) reported hearing farming or agricultural noise. Of these 90 respondents, 21% reported being adversely affected though it is unknown if any mentioned bird scarers specifically. The survey was repeated in 1999 using the same noise categories. A total of 2534 valid questionnaires were received from 2550 interviews. One hundred and thirty-two respondents (5%) reported agricultural noise, of which 14% were adversely affected, though again, the number specifying bird scarers is unknown. In both years, only 1% of total respondents reported hearing and being adversely affected by farming and agricultural noise.

Lines *et al*. (1994) reported the results of two surveys (commissioned by the UK Ministry of Agriculture, Fisheries and Food, now Defra) investigating perceptions of noise nuisance in the countryside. One survey involved a postal questionnaire circulated to 5,000 people selected randomly from across the UK, but excluded towns which had more than 100,000 inhabitants and areas where the population density exceeded 4.5 people per hectare. Respondents were asked to report incidents occurring in the preceding two years, when they had found noise in the countryside annoying. They were also asked to describe the source of noise and how or why they found it annoying. The respondents revealed six major categories of noise nuisance; road traffic, domestic, aircraft, agricultural, recreational and industrial. The percentage of people reporting noise nuisance from agricultural sources was 8.3%, with 2.3% specifying bird scarers. The other survey was sent out to 200 of the 408 local authorities responsible for the non-metropolitan areas of the UK, and analysed noise complaints received by local government authorities in the preceding 12 months. This survey revealed a total of 9955 complaints received by 51 authorities. Acoustic scarers were the most frequent source of agricultural complaint accounting for 41% of the total complaints.

In 1992, the Birdscarers Anti Nuisance Group (BANG) surveyed all (331) District Councils in England and Wales and achieved a 49% response rate. One of the conclusions of the survey was that Environmental Health Officers would find an official code of practice and a licensing scheme useful in dealing with complaints.

It is clear that noise nuisance is a feature of gas guns and exploders in particular, but sonic devices and pyrotechnics may also cause a problem. It is frequently mentioned as one as one of the 'costs' of using such devices and is difficult to quantify. Conover (1984) investigated the comparative effectiveness of a chemical repellent, exploders and kite in reducing bird damage to maize. He pointed out that 'a major drawback with exploders is the annoyance they can cause neighbours', and in Connecticut, USA, their use was prohibited within 152 m of a residence.

In the UK, the use of gas guns is subject to a National Farmers Union voluntary code of practice. This states that cannons should not be fired during the hours of darkness or more than four times during any one daylight hour. It also states that they should be positioned a minimum distance of 200 m from 'sensitive' buildings and that absorbent or reflective baffles, such as straw bales, should be used to concentrate sound onto the crop and reduce noise nuisance in adjacent areas. A casual search of the Internet shows that these guidelines are not being followed; the 'Bourne Diary'

(Needle 1999) mentions explosions at the rate of more than 120 per hour and sometimes explosions during the night. In addition to the issue of noise nuisance, excessive explosion rates ignore recommended practice for maximizing the effectiveness of cannons and other auditory bird scarers.

Other countries also have an awareness of problems caused by audible bird scaring devices, with an increase in complaints made to local authorities. The Adelaide Hills, South Australia, is an important viticulture area where the noise nuisance from gas guns and other audible bird scarers is a recurring issue (Gilfillan 1999; Elliott 2000; Leydon undated). Environmental Noise Guidelines drawn up by the South Australian Environment Protection Authority (2002) state that for all audible bird scaring devices, namely gas guns and electronic/speaker devices, one device should cover 10 ha, with a maximum of six shots/hour. Devices should be a minimum of 200-300 m from residences and as in the UK, recommend that they face into the crop with reflective or absorbent baffles to concentrate the sound. Although devices can be used at night, before 7 am or after 8 pm they must not emit a noise level that exceeds 45dB in adjacent areas. The guidelines also recommend that local and state government develop and adopt a complaint management protocol.

The British Columbia Ministry of Agriculture, Food and Fisheries (2002) have produced a report on the use of audible bird scare devices, again prompted by the number of complaints received: 76 in 2001 of which 72 were about propane cannons, three for orchard pistols and one each for bird call devices and electronic noisemakers. Audible bird scarers are the most commonly used method of crop protection followed by bird netting and visual bird scarers. The report recommends that the following guidance be added to the Wildlife Damage Control guidelines: a firing frequency of no more than one firing per five minutes, a 150 m distance from neighbouring residences (100 m for birdcall and electronic noise devices) and that all devices operate only between 6 am and 8 pm. Blueberries, sweet cherries and grapes are the main crops and these can be protected by netting. The report also recommends funding-options be available to farmers for netting cropland, with priority going to farmers nearest urban/residential areas. Included in the report is a survey of regulations affecting the use of audible bird scaring devices in Ontario, the United States, Europe, New Zealand and Australia. From the responses, it is clear that regulations and guidance varies on a state (USA), district (New Zealand) and city (Netherlands) basis.

BANG and their Canadian equivalent, ‘Ban the Cannons’ advocate the use of silent bird scarers, but neither has investigated their relative effectiveness. The South Australian Environmental Noise Guidelines recommend that local and state government investigate using a cost/benefit approach bird scaring management techniques, including non-noise options such as netting.

5.1.2 Alternatives To Auditory Deterrents

Visual techniques

LASERS

As the demand for non-lethal, environmentally safe methods of bird scaring has increased, interest has grown in the use of lasers, particularly low-power lasers that work under low light conditions. The low power levels, accuracy over distance, silence and the ability to direct them on specific problem birds, makes laser devices an attractive alternative to other avian scaring devices. Birds are startled by the strong contrast between the ambient light and the laser beam. During low light conditions this technique is very selective, but at night the light beam is visible over a large distance and hence can cause non-selective disturbance. Unpublished data from trials on French airfields indicate that these devices are ineffective in bright daylight conditions, and the device worked best when shone in birds' eyes. Results of pilot trials undertaken on UK cormorants and goosanders support this effect (McKay *et al.* 1999).

Lasers have been tested in a number of countries. In France, a laser gun was used to disturb cormorants from a night roost (Troilliet pers. comm., cited in Boudewijn and Dirksen 1996). During cloudy weather the method worked well, with most of the birds scared away within 20 minutes, and treatment over consecutive evenings caused the temporary desertion of the roost. Cormorants appeared to be particularly sensitive to laser light. Similar results were obtained at a cormorant night-roost in the region of the Dombes, France. After using a laser gun for two nights, the night-roost was deserted for a week (Broyer 1995, cited in Boudewijn and Dirksen 1996).

Successful results were also achieved in America using the laser gun 'Avian Dissuader', costing US$900. The laser treatment cleared roosting crows from the Capitol complex within an hour (State Capitol Bureau 2001). The long-term success is not reported.

In Britain, laser light was tested against two cormorant night roosts (McKay *et al* 1999). At one site cormorant numbers were significantly reduced after seven consecutive days use and bird numbers did not return to normal until between 12 and 30 days later. At the other site, the laser gun was less effective with some birds failing to leave the roost. The laser also deterred goosanders though the effect lasted less than one day.

The laser gun used in this British study was a purpose-built device produced by Desman S.A.R.L. of France and cost £4633 (at 1996 prices). Training in its use by the manufacturer cost another £1056. There were some questions over safety of the device because although the company state that the laser was safe, they also advised that it should not be pointed at humans. The device has been tested for safety at the UK Government's Defence Evaluation and Research Agency (DERA), Farnborough, England and found to be safe if it was not pointed at an unprotected eye within a distance of 155 m (McKay *et al*. 1999). The safe distance was considerably reduced if viewed with binoculars.

The use of lasers can be an effective method of bird scaring, although there is some evidence to suggest some birds are laser-resistant (McKay *et al*. 1999). The equipment is expensive and specialised training is required, adding to the costs. As the effectiveness of the laser decreases with increasing light levels, it is likely to be most effective at dawn and dusk. Its usefulness may therefore be confined to night time roosts and feeding sites at dawn. As it is operated manually user costs at anti-social hours must also be taken into consideration. However, the ability to 'target' specific problem species may be useful at certain sites, such as areas of conservation interest, where disturbance of non-target species may be kept to a minimum.

DOGS

The control of birds and other wildlife such as deer through harassment by trained border collies has been used at aerodromes, golf courses and agricultural land (Castelli and Sleggs 2000). The dogs represent an actual, not perceived threat, and so elicit flight reactions. Habituation is unlikely as they can continually pursue and change their behaviour. Border collies are used as they are working dogs bred to herd animals and to avoid attack, and they respond well to whistle and verbal commands (Erwin 1999). A single border collie and its handler can keep an area of approximately 50 square kilometres free of larger birds and wildlife (Carter, undated) and although they are effective at deterring ground foraging birds such as waders and wildfowl, they are not so useful for species that spend most of their time flying or perching, such as raptors and swallows (Erwin 1999).

In 1999 Southwest Florida International Airport became the first commercial airport in the world to employ a border collie in an airfield wildlife control programme (Carter, undated). After the use of the collie, numbers and species of birds on the airport declined and most birds that remained congregated in a drainage ditch away from the runway. The number of bird strikes dropped to zero compared to 13 for the same period the previous year (Carter 2000). Several other airports and airbases have now started similar programmes.

At Dover Air Force Base, Delaware, bird strike damage to aircraft caused by birds has been reduced from an average of US $600,000 / year for the proceeding two years to US$24 000/year after the initiation of a bird control programme that included the use of border collies (Carter undated).

The use of dogs, however, is labour-intensive, as the dogs need to be constantly directed by a trained handler. The initial costs of implementing a border collie programme may be high with the purchase of dogs, training, plus food and veterinary bills, and they may be no more effective than a human bird-controller. In addition, safety is an issue on runways.

HUMAN SCARER

Human activity can disturb birds from specific areas either deliberately by direct harassment (Vickery & Summers 1992), or indirectly through, for example, leisure activities (Bell & Austin 1985, Owens 1976). Those sites where man is absent or rarely present, particularly on foot, such as airfields, are particularly attractive to birds. Human presence is a feature of many bird deterrent methods, and it should be appreciated that it is difficult to separate the effects of the device, e.g. pyrotechnics, from the effects of human presence.

The most basic and simple way of frightening birds involves standing in full view of the birds, preferably as a silhouette against the sky, and raising and lowering the arms in mock wing beats of about 25 per minute (Markgren 1960, cited in Wright 1969). This action is interpreted as mimicking the wing beats of a large raptor, and is recognised as an effective bird scaring technique on airfields (Civil Aviation Authority 2002), though it is stressed that 'flapping' too rapidly with bent arms does not work!

At fisheries, human activity related to routine daily maintenance has been shown to reduce the number of heron visits and could also delay the return of the birds (Draulans and Van Vessem 1985). Brown and Gratzek (1980, cited in Kevan 1992) also found that the timing of human activity was important, with activity around dawn and dusk, the preferred feeding times for herons, being more effective. Human disturbance was found to be the only consistently effective scaring technique in deterring cormorants *Phalacrocorax carbo* from aquaculture facilities (Boudewijn & Dirksen 1996).

The cost and effectiveness of employing a full-time human bird scarer to remove brent geese *Branta bernicla* from winter arable crops, was determined by Vickery and Summers (1992). The scarer, equipped with a four-wheel motorcycle for quick access to each field, worked a six-day week (the farmer scared on the seventh) from approximately dawn until dusk. The geese were scared off immediately the birds had landed with the occasional bird shot under licence. Throughout the two winters of the study, the birds showed no signs of habituating to the human scarer except when weather conditions were severe, and rarely attempted to return to the wheat fields from nearby grass fields. The human bird scarer was extremely effective in reducing bird damage to winter wheat, reducing crop losses to £2 - £3/hectare compared to £51 - £87/hectare using traditional visual and acoustic scaring techniques. The human scarer was costed at £17 - 33 / ha.

On Islay there have been two attempts to organise human scarers to reduce goose damage. In the first, the then Manpower Services Commission provided 16 people working part-time to scare the geese. However farmers felt that these scarers were uncoordinated and lacked commitment. A reduction in goose numbers in some scaring areas was recorded, but the scheme was judged too expensive to continue. On the second scheme, farmers were paid to carry out the scaring themselves. However, this proved even less effective as insufficient scaring was carried out or it lacked coordination. The payment became regarded as compensation rather than payment for a task and so the scheme was abandoned (National Goose Forum 1998).

Although the use of a dedicated human scarer is more expensive than traditional visual and acoustic methods, in terms of wages and equipment, these costs can be offset by the greater reduction in crop losses. Casual scaring caused by routine day-to day activities can also be effective. However, the success of this technique is dependent on alternative feeding areas being available.

SCARECROWS

Predator models, such as scarecrows, are common, traditional methods used in attempts to scare avian pests. They mimic the appearance of a predator and so cause birds to take flight to avoid potential predation (Harris and Davis 1998). Most scarecrows are human-shaped effigies, usually constructed from inexpensive materials; Knittle and Porter (1988) report that simple scarecrows made from black plastic bags attached to wooden stakes are effective at deterring waterfowl from grain fields, as long as the effigies are put out before the birds arrive.

In general, however, motionless devices either provide only short-term protection or are ineffective as the threat from them is only perceived rather than real. In a survey of hatchery managers in the United States only one of the 14 hatchery managers who commented on the effectiveness of various control techniques said that scarecrows had a high success rate. Six said they had no effect (Parkhurst *et al.* 1987). Some birds may even come to associate them with favourable conditions (Inglis 1980).

To maximise effectiveness devices should possess biological significance, appear life-like, be highly visible and their location changed frequently in order to extend the period of habituation (Vaudry 1979). The effectiveness of scarecrows may be enhanced if fitted with loose clothing and bright streamers that move and create noise in the wind (Vaudry 1979) - effectively becoming a moving visual.

Recently, several types of moving, inflatable human effigies have become commercially available. One of these, the Scarey Man® is marketed worldwide. Created by a Cambridgeshire farmer the Scarey Man® is a life-size plastic effigy powered by a 12 volt car battery, that inflates rapidly, emits a high pitched wail and may illuminate at night. Inflation occurs about every 18 minutes and lasts for 25 seconds. According to the Pest-Away Australia website, one Scarey Man® costs AU$1390.00 and can give up to 6 hectares of crop coverage. For smaller sites, the Scarey Boy is now available (Clarretts Ltd.).

Australian testimonials on the Pest-Away Australia website state that the use of Scarey Man® is effective at preventing crows from damaging melon crops. Andelt *et al*. (1997) tested it's effectiveness at deterring black-crowned night-herons (*Nycticorax nycticorax*) and great blue herons (*Ardea herodias)* from a fish rearing unit in Colorado. Two manikins were programmed to activate for 35-40 seconds every 9-10 minutes from about 1700 or 2045 through to 0800 hours in order to frighten birds during their peak feeding times. Numbers of birds were reduced only during the first four nights of the trial. After that time, numbers of both species increased significantly. Birds quickly habituated to the manikins and so Scarey Man® was deemed ineffective at scaring herons from the fish-rearing unit.

Stickley and King (1995) also used Scarey Man® to repel double-crested cormorants (*Phalacrocoax auritus*) from catfish ponds. Ten mannekins were deployed, an average of one for every 14 hectares of surface water. Cormorant numbers dropped during the first week of use, but by the 11th day it was felt they were beginning to lose their effectiveness. Despite trying to enhance its effect by placing hats and camouflage masks on the devices, changing their positions and substituting shooters for Scarey Man®, levels of birds could not be reduced further. Despite some habituation within two weeks, the overall conclusion was that Scarey Man® could only be recommended in cases where cormorant depredations were a serious problem.

Other animated scarecrows have met with varying success. Conniff (1991) describes a jack-in-a-box device with inflatable arms, revolving strobe lights and amplified sounds (130dB, distance unknown) of horns honking, people shouting, shotguns and birds screaming. This scarecrow was declared ‘ineffectual’ against cormorants.

Another device developed and tested by the Denver Wildlife Research Centre (Cummings *et al.* 1986) combined an inflatable plastic scarecrow with a propane exploder. Costing about US$900 (or US$14/0.4 hectares (1 acre) based on a ten year life for the unit), this was effective for deterring blackbirds from sunflowers in some fields; it was less effective in fields where the birds had an established feeding pattern.

Ultimately, however lifelike, under most circumstances scarecrows do not present a threat that is sufficiently alarming to birds (Inglis 1980). Over a period of time birds learn that effigies or models do not represent an actual threat and are no longer alarmed by them. To increase the threat and therefore the habituation time, it is recommended that these devices be reinforced with other sound-producing or visual deterrents. Ideally, for example, scarecrows should be periodically reinforced by human activity.

RAPTOR MODELS

The basis for this deterrent is mimicry of real predators and evocation of fear and avoidance in the target species. Most potential prey species react to predator models; the strength of the response, however, varies between species (Conover 1979), and in some cases raptor models can attract rather than repel birds as species like blackbirds and crows often mob owls or owl models (Conover 1983, cited in Harris and Davis 1998).

Model raptors fail to incorporate behavioural cues, which may be critical to the induction of fear and avoidance in the target species. Falcons which are “in the mood” to hunt are said to be “sharp set”; such bird are invariably hungry enough to fly at quarry. Although it is difficult for human observers to differentiate between a falcon when it is sharp set and conversely well fed, birds will mob a hawk more frequently when sharp set than when well fed. Thus, model raptors will be inherently less threatening and consequently less effective than live raptors (Inglis 1980).

In the USA, museum-mounted models of a sharp-shinned hawk *Accipiter striatus* and goshawk *Accipiter gentilis* both reduced the numbers of birds visiting feeding stations. Habituation to the models, however, was relatively quick with birds re-entering the feeding area after only 5-8 hours exposure (Conover 1979).

For some bird species the avoidance response to large avian predators appears to be, in part, a learned behaviour. Juvenile gray jays *Perisoreus canadensis* showed little response to a model great horned owl *Bubo virginianus*, whereas adult jays reacted intensely (Montevecchi & Maccarone 1987). Interestingly, with repeated exposure, juveniles developed a greater fear toward the model whereas adults habituated to the decoy.

As for scarecrows, movement can enhance scaring effectiveness. An animated crow-killing owl model was more effective in protecting vegetable plots from crows than an unanimated model (Conover 1985). This model consisted of a plastic owl model with a plastic crow model in its talons that either had wings that moved in the breeze or battery-powered wings that could move in the absence of wind. Both versions of this device reduced crop damage by 81%. The deterrent effect was maximised by combining movement with an implicit risk. No indication is given of how long the deterrent effect lasted.

In general, raptor models are inexpensive (£5-£25 for plastic owl models, Network Pest Control Systems Ltd.) and easy to deploy. Their effectiveness is increased if they are animated and if they are moved frequently. However, birds quickly learn that the model poses no threat and rapidly habituate to it.

CORPSES

An alternative use of models to deter birds has involved deploying replicas or actual dead specimens in a manner which signals danger to conspecifics. Initially birds often approach the corpse but usually leave when they see the unnatural position of the bird. This approach has been frequently used in attempts to deter gulls from airports (Harris & Davies 1998).

Suspended Corvid corpse

Some success has been achieved both with dead gulls and model gulls deployed in positions to mimic dead or injured birds. Stout and Schwab (1979) (citied in Schmidt & Johnson 1983) found that models had to be realistic to be effective, and Hardenberg (1965) (citied in Schmidt & Johnson 1983) reported that stuffed dead gulls that had wet and disordered plumage from having been out in the rain for several days had less of a frightening effect on live gulls.

Cattle egrets (*Bubulcus ibis*) shot at a heronry and placed in clear view around the roost repelled other egrets and prevented other birds from landing. After the dead birds were removed the flock landed immediately (Fellows and Paton 1988). However, dead crows suspended in a field of sprouting corn failed to reduce crow damage (Naef-Daenzer 1983).

Hunter (1974) found that painted metal models of wood pigeons with wings extended to display the white wing marks, reduced damage to cabbages, but only for about four weeks, after which the flock became habituated to the models. Crude woodpigeon silhouettes were not effective repellents, but real woodpigeon bodies with outstretched wings gave significant protection from bird damage over a nine week period. Pairs of wings and three-dimensional lifelike models were just as effective as corpses. However, corpses and pairs of wings had to be in good condition to remain effective (Inglis and Isaacson 1987).

Although this technique is inexpensive, its effectiveness varies under different circumstances and depends on, for example, frequently moving models (to prevent habituation), the availability of alternative sites (to which birds can relocate) or reinforcement with additional deterrent techniques such as pyrotechnics and alarm/distress calls.

BALLOONS

Balloons tethered in a crop are an inexpensive method of bird deterrence, but studies show that they are not very effective and birds quickly habituate to them. Blue balloons were used in an attempt to deter oystercatchers from a Naval airfield. The birds attacked the balloons and burst them (Wright 1969).

Toy balloons were also used to reduce damage to cherries and blueberries (Pearson 1958). Tied to branches of the trees, the balloons deterred starlings, but robins and Baltimore orioles were seen to continue feeding only a few feet away. Balloons were also found to be ineffective in deterring waterfowl from the sites of oil spills (Greer and O'Connor 1994, cited in Reilly 1995).

To increase the effectiveness of balloons, eyespots, consisting of a circular pattern that resembles the general appearance of vertebrate eyes, can be printed on the side. These eyes mimic the eyes of large raptors, but may also mimic the eyes of conspecifics, which is alarming as many avian species have frontal threat displays in which the eyes are prominent (Inglis 1980). Two circular eyespots arranged horizontally, each containing concentric rings of bright colour appear to be the most alarming. Those that have a three-dimensional appearance may enhance the effect, and large eyespots are better than small ones (Inglis 1980).

At present there are a number of different designs commercially available and may either bear a single pair of eyes on one side or multiple eyespots encircling the entire balloon. Studies indicate that the deterrent effect of eyespot balloons varies between bird species, the eyespot design and with the mode of presentation. In New Zealand, numbers of house sparrows *Passer domesticus* visiting a bird-feeding table were significantly reduced by deployment of both a commercially available balloon and a homemade device (eyes painted on a beach ball) (McLennan *et al*. 1995). The commercial device had a greater deterrent effect than the beach ball. The effect of both devices decreased with distance and was negligible at 40m. The deterrent effect increased when reinforced with a rotating light and playback of alarm calls. With continuous use, however, the deterrent effect declined and ceased after nine days.

McLennan *et al.* (1995) also evaluated eyespot balls as a bird deterrent in vineyards. In the first three weeks the balls repelled 90% of all birds except song thrushes, which had started to ignore them in the second week. Their deterrent effect had almost ceased after four weeks, but by this stage the grapes had ripened and become increasingly attractive to the birds. It could not be determined whether the balls failed because the birds had habituated to them or because the lure of food overcame the deterrent effect.

McNamara *et al.* (2002) found that scare-eye balloons failed to protect the plastic film surrounding bales of silage from bird damage, though 'eyes' painted onto the black plastic reduced damage by 65% compared to control bales.

Although easy to set up and move around, balloons can be easily damaged in high winds and can deteriorate in sunlight leading to a loss of helium and thus height. They also need to be regularly checked to ensure they cannot break free from their moorings and present a hazard to aircraft. In the UK, the flying of balloons is governed by the Air Navigation Order, which states that without the written permission of the Civil Aviation Authority, a tethered balloon can not be flown at a height of more than 60 m or within 5 km of any aerodrome (CAA 2002). Their effectiveness at scaring birds appears to be dependent on the species concerned and effects are only short-term.

KITES

Kites and kite-hawks work as mobile predator models, which birds perceive as a threat. The kites bear an image of a soaring raptor and are tethered to the ground. Conover (1983, cited in Harris and Davis 1998) tested four designs of hawk-kites, but none effectively deterred birds from feeding on corn. To be effective, kite-hawks need to be 'flown' beneath helium balloons in order to possess sufficient 'threatening' movement (Conover 1984). When this was done, the kites became more effective at scaring birds from the cornfields.

Other studies have found kite-hawks to be ineffective or are quickly habituated to (Inglis 1980). Hothem and Dehaven (1982) tested a hawk-kite resembling an immature golden eagle, suspended from a helium balloon. Although there was a slight decrease in percent of grapes damaged, it was effective only over a very small area, and damage increased elsewhere in the vineyard.

Helium-filled bird scaring kites have been deployed between dawn and dusk at landfill sites. Numbers of gulls, corvids and starlings on sites remained relatively unchanged and there was little evidence that birds were deterred from the sites (Baxter 2002c; undated).

Like balloons, kites and hawk-kites can be damaged by strong winds and may be difficult to keep up in the air when wind speeds exceed 8 km/hr (Hotherm and Dehaven 1982). As they pose no real threat to birds, do not behave like raptors and remain visible for long periods of time, birds quickly habituate to them. They are effective only over a small area and for a short period of time. As with balloons, their use in the UK is governed by the Air Navigation Order, requiring the written permission of the CAA for kites within 5 km of an aerodrome or at a height of more than 60 m.

FALCONRY

The success of this method of bird control is based on the fact that many birds have a natural fear of falcons and hawks as predators, so their presence in the area encourages problem species to disperse. The natural reaction of most prey species is to form a flock and attempt to fly above the falcon. If this fails, they will attempt to fly for cover and leave the area (Transport Canada, undated).

The species of falcons and hawks used depend on the bird pests present. They should preferably be a bird predator of the pest bird species as occasional kills will reinforce the perception of danger (Grubb 1977, cited in Erickson *et al.* 1990). The peregrine falcon (*Falco peregrinus*) and the goshawk (*Accipiter gentiles*) are most often used (Erikson *et al*. 1990). Raptor use is mainly limited to airports where the risk of birdstrikes is high and a variety of measures are taken to ensure aircraft safety, though in the UK, falcons are also frequently used to deter birds from landfill sites (Baxter 2002c).

When using falconry for bird control on airfields, the raptor must be clearly visible to discourage target birds from entering the area and to chase away birds already present. Actual capturing or killing of a bird is not the object (Roeper 2001). Falconry is an expensive method of bird control as the birds require special care and training and a specialist handler, and often a number of falcons must be provided to operate at different times of the day. For many aerodromes the additional time and expenditure cannot be justified (CAA 2002). However, falconry is popular with the public as it is environmentally friendly and considered humane as the target birds are not killed but merely chased from the area (Dolbeer 1998), though the most effective falconry does involve the occasional killing of the prey species.

Roeper (2001) analysed the mean number of bird strikes reported per 100 landings and 100 departures at Travis Air Force Base, California, before and after the introduction of a falconry programme. His results indicated that falconry reduced the number of strikes and also reduced the severity of strikes in terms of mean dollar costs of aircraft damage. However, these cost savings appeared to be less than the cost of the falconry programme. He recommended that research be continued to determine when habituation to the falcons occurred and to determine which species of birds were not deterred by the falcons.

Successful bird control using falconry was achieved on military air bases at Istres, France. Between 1979 and 1983, the numbers of bird strikes were reduced from 16 to zero (Briot 1984). Dolbeer (1998) evaluated the effectiveness of shooting and falconry for bird control at JFK International Airport, New York. The study indicated that shooting reduced bird strikes but falconry did not.

The use of falcons and hawks on landfill sites in the UK has been evaluated by Baxter (2000e; 2002c; undated), and has shown varying success. Numbers of scavenging gulls and corvids were reduced when falcons were flown, particularly from dawn to dusk, though poor weather conditions when the birds could not be flown allowed the gulls and corvids to return to feed. Hawks (red-tailed hawk and Harris hawk) were less successful. These raptors generally take ground prey like rabbits when hunting, so their interest in pursuing corvids and gulls was minimal (Baxter, undated). Habituation to the hawks occurred quickly and within four weeks gulls and corvids resumed feeding at the landfill.

Although expensive and time consuming, falconry has the potential to remove hazardous birds from areas of land more quickly than can be achieved using conventional bird control methods, and they can also extend their influence into surrounding land where access may be restricted. However, other bird-scaring methods are often equally or more effective and economical (Erickson *et al.* 1990). Falcons appear to be more successful than hawks at bird control due to differences in prey species. Like many other control techniques, poor visibility and bad weather restricts use, and the birds must be flown regularly to sustain their effectiveness.

RADIO-CONTROLLED AIRCRAFT

Radio-controlled model aircraft have been used to scare or 'haze' bird pests since the early 1980s, mainly over airfields (Smith *et al.* 1999), but have also been used over agricultural areas, fisheries and landfill sites. This method has been shown to be very effective and birds habituate more slowly to a treatment in which they are being actively hazed. At Whiteman Air Force Base, Missouri, balsa wood radio-controlled aircraft are one of the primary bird harassment methods used to keep the airfield clear of raptors and other large birds, and they have also proved effective at dispersing the base's redwing blackbird roost (Hibler 1999).

Model aircraft have also been used to deter cormorants and herons from aquaculture facilities (Coniff 1991), though the aircraft should be used to haze the birds while they are still in the air, as birds already on the water are only encouraged to dive (Curtis *et al.* 1996). On larger land-based fish farms, flying one model aircraft for approximately every 100 hectares has been recommended (Littauer 1990). However, this method has been less successful with other water birds; model aircraft were totally ineffective in dispersing Canada geese from open water, though a coordinated effort with a radio-controlled boat was more successful (Carter 2000).

Using a falcon-shape aircraft or a conventionally shaped model aircraft painted with a raptor design may enhance the aversive effect (Ward 1975, Saul 1967, both cited in Harris and Davis 1998). Trials at Vancouver Airport successfully deterred gulls, ducks and geese while a conventionally shaped aircraft had no effect in previous trials. The rate of any habituation was not researched (Anon, undated).

Although an effective method of bird deterrent, using this technique is labour-intensive and requires skilled operators; at Whiteman AFB, training of model aircraft operators can take two months (Hibler 1999). Model aircraft cannot be used in inclement weather and it may be difficult to control the direction of bird dispersal, an important consideration on or near airfields. The use of the model aircraft may also create a flight safety issue, so their use is not recommended close to active runways.

LIGHTS

Flashing, rotating, strobe and searchlights are a novel stimulus to birds, which encourage an avoidance response (Harris and Davis 1998). Although a steady light source such as searchlights have been known to attract birds at night, particularly when it is cloudy or foggy (Harris and Davis 1998), strobe lights, revolving lights and amber barricade lights might be useful for deterring night-feeding birds such as herons at fisheries (Littauer 1990; Nomsen 1989 cited in Kevan 1992). The lights have a blinding effect which causes the birds to become confused and restricts their ability to fish (Salmon *et al.* 1986, cited in Kevan 1992). However, birds can quickly become habituated and black-crowned herons (*Nycticorax nycticor)* have been known to avoid the glare by landing with their backs to the lights (Kevan 1992).

Lawrence *et al.* (1975, cited in Harris and Davis 1998) reviewed strobe lights particularly in relation to their use on airfields, and concluded that strobe lights had some deterrent effect though they were more effective at deterring lapwings than gulls. Pilo *et al.* (1988) showed that birds such as kites, vultures and pigeons were affected by a high intensity strobe light, which could encourage them to take evasive action and move away. They also showed no habituation. Green and Bahr (1993) recommended a randomised selection of at least two strobe frequencies in order to deter a broader range of bird species. However, Theale (personal communication, cited in Feare 1985) investigated the use of strobe lights to drive house sparrows from the interior of buildings. In an experimental situation, such lights failed to disturb the birds feeding activities.

Numbers of night-feeding black-crowned night-herons and great blue herons at a trout hatchery were reduced by the use of bright rotation lights, but only by moving them a short distance to an unlit part of the hatchery. However, they caught fish just as effectively in both lit and unlit sections, so the lights had no effect on fish losses (Andelt *et al.* 1997). A floating solar-powered rotating beacon was successful in reducing the number of ducks visiting a sewerage pond by 90% (Read 1999). The device was most effective when rotating slowly and operated only during the night.

Although lights are easy to deploy and require very little maintenance, they should not be used where they might cause a visual nuisance to neighbouring properties. They may not be effective during daylight hours and their ability to scare birds at night varies with the bird species. Lights are best used with other deterrent methods.

MIRRORS/REFLECTORS

Mirrors and reflectors work on the principle that sudden bright flashes of light produce a startle response and drive the bird from an area. However, the response of free-living birds to mirrors has been investigated in only a handful of species.

Foraging by black-capped chickadees *Parus atricapillus* at feeding stations was depressed by the presentation of either a standard mirror or an aluminium foil covered mirror; feeding was depressed the most by the standard mirror (Censky & Ficken 1982). When placed in nesting territories mirrors evoked aggressive responses from blue grouse *Dendragapus obscurus* (Stirling 1968) and glaucous-winged gulls *Larus glaucesens* (mirror combined with playback of gull calls) (Stout *et al*. 1969).

Reflective objects have been reported as being effective in deterring raptors, such as sparrowhawks and goshawks, from game release pens. Experiments in Europe showed that large silvered balls were effective in protecting reared game and chickens from diurnal raptors, particularly sparrowhawks and goshawks (Mansfield 1954; Pfeiffer & Keil 1963, cited in Lloyd 1976). Various gamekeepers in the UK also advocate the use of reflective objects. Opportunistic trials using such suspended materials successfully ended sparrowhawk predation at three different release pens.

Mirrors and reflectors have also been found to be inexpensive but effective against waterfowl, gulls and some herons (Greer and O'Connor 1994 cited in Reilly 1995). However, although aluminium pie plates suspended on varying lengths of twine deterred some waterfowl species, ducks were regularly seen to swim within 4-5 m of the reflectors (Boag and Lewin 1980).

In a survey of 336 fish hatchery managers in eastern USA, eight reported using tin reflectors of which seven said they had limited or no success as a depredation control technique (Parkhurst *et al.* 1987). In the same survey only one manager used mirrors and that was unsuccessful. Mirrors placed inside nest-boxes did not deter starlings from nesting within (Seamans *et al.* 2001).

A device consisting of a rotating pyramid of mirrors has been recommended for preventing crow damage to seedling corn (Anon. 2002d). This device is available in the UK and the manufacturer claims it is effective over four hectares against pigeons, blackbirds, starlings and crows on a variety of crops, but no scientific research has been can carried out to substantiate these claims (Anon. 2000a).

Although easy and inexpensive to put up and easy to relocate, the effectiveness of mirrors and reflectors as a bird scaring technique is variable. As they are only effective when they reflect sunlight and so are useless before sunrise (Nakamura 1999), they are best combined with other methods of scaring.

TAPES

Tapes as a scaring device act as a combination of visual and exclusion deterrence. They are easy to erect and a wide selection of twines and tapes are readily available. Summers and Hillman (1990) used red fluorescent tape suspended from poles to protect fields of winter wheat from brent geese. Loss in grain yield was estimated at £50/hectare on an unprotected area, whereas the cost of the tape, its erection and dismantling and day-to-day maintenance cost £30/hectare making this a cost-effective method of bird-scaring. However, in a second trial when no untaped wheat was available the geese habituated to the tapes and landed between the rows; the attractiveness of the feeding area outweighed any deterrent effect of the tapes.

McKay and Parrott (2002) used a combination of hazard warning tape with twine to deter mute swans *Cygnus olor* from grazing oilseed rape. Although there was evidence that swan grazing was reduced during the first eight weeks, it was not effective in reducing the total amount of grazing over the four month long trial. In both studies the tape was susceptible to damage by wind, entailing extra labour for repairs. Further work to develop the technique is more promising: preliminary results indicate that a more durable material can reduce swan numbers on rape fields by over 50%.

Reflecting tape such as Mylar tape has been used in attempts to deter birds in a number of circumstances. The tape has a silver metal coating on one side that reflects sunlight and also produces a humming or crackling noise when moved by the wind. A variety of birds have been deterred by tape suspended in parallel rows over ripening crops (Bruggers *et al*. 1986). Dolbeer *et al*. (1986) found that reflecting tape stretched over agricultural crops deterred certain bird species but was ineffective against others; red-winged blackbirds, cowbirds and house sparrows were generally repelled but goldfinches and mourning doves showed little reaction.

Other studies have found reflective tape to be ineffective. Tobin *et al*. (1988) found that birds were not deterred from eating blueberries or from flying into taped plots, and Conover and Dolbeer (1989) found that tapes in cornfields did not reduce damage by red-winged blackbirds. In both cases the number and configuration of tape strands may have contributed to its ineffectiveness; leaving large spaces between rows of tapes allowed birds to avoid the tapes and enter the crop. Also, placing tapes along rows rather than perpendicular to them allowed birds easier access along the rows. Failing to tape the whole field can also allow the birds an entry point into the crop. However, close rows of tapes throughout a complete field can increase the costs, and even if bird damage is reduced the technique may not be cost-effective.

Although a close configuration of tapes may be successful in terms of crop protection, it can interfere with crop husbandry and increase costs in terms of labour and materials. In such situations, this technique is best suited to small areas of high value crops. Good maintenance of the tapes is essential in order to prevent them from becoming tangled in the crop, and to stop gaps resulting from broken tapes being exploited as entry points by birds. In general, tapes are useful for reducing bird numbers particularly if an alternative area for feeding is available.

FLAGS, RAGS AND STREAMERS

The placing of flags, usually made from old sacks, amongst a crop, is one of the simplest and cheapest forms of bird scaring. The movement of the flag or rag in the wind is perceived as a threat by birds, which then avoid the area. The effect of this perceived threat may be enhanced by partially hiding the flags. This technique was used to protect maize from red-winged blackbirds just before harvest. Rags tied between tall maize plants, so that the rags were partially concealed by the plants gave the illusion that someone, a possible predator, was hidden in the crop. This effectively protected the crop for up to 30 days after which there were signs of habituation (Cardinell and Hayne 1944).

On shorter or newly planted crops, it is not possible to hide flags within the vegetation. Transport Canada (1994) recommend the use of black flags made from 60x90 cm sheets of 3mm black plastic attached to 1.2 m posts to deter waterfowl. Black seems to be the most effective colour and flags of this size can easily be seen and may move well in the wind. It is recommended that one flag per hectare is enough to deter waterfowl from sites they have not actively been using, but where they are accustomed to feeding, four flags per hectare placed in an offset grid pattern work well.

Mason and Clark (1994) demonstrated that both black and white flags placed at a density of 2.47 flags/hectare reduced snow goose use of fields, based on counts of goose faeces, but did not deter geese completely. White flags placed at the same density in crop fields reduced goose numbers and even deterred geese from fields where they had been grazing for the previous few weeks (Mason *et al.* 1993). However, McKay and Parrott (2002) found that white flags placed at 25 m intervals in a regular grid were ineffective in reducing mute swan grazing on oil-seed rape.

Silver and red Mylar streamers can be used as an alternative to flags and were tested by Mason and Clark (1994). They were found to delay the onset of grazing by snow geese, compared to fields with no streamers or flags, but proved less effective in reducing goose use than either black or white flags. A number of scaring materials and methods for deterring roosting crows from trees were tested in California in 1991 and 1992. Mylar tape stripes of 0.6-0.9 m tied to branches were judged to be the most effective, scoring a control rating of 9.7 on a scale of 1 to 10 (best). However, it was time-consuming to apply, needed specialist equipment for tall trees and there was no overall area effect as the birds moved to adjacent untaped trees to roost (Gorenzel and Salmon 1992).

Mylar flags placed at a density of 300 flags/hectare did not deter herring gulls from a nesting colony but were more successful at a loafing area (Belant and Ickes 1997). The variation of this response was probably due to the availability of other loafing areas but not of suitable nesting colony areas.

In summary, flags, rags and streamers are a useful bird scaring technique, being cheap (Mylar streamers are more expensive), and easy to deploy. However, their success depends on alternative feeding, roosting or loafing sites being available nearby. Although not totally effective in completely eliminating bird pests, reducing numbers by dispersing birds over an area can reduce localised crop damage.

DYES/COLOURANTS

There is little research on the use of dyes to scare birds. Any deterrent effect may be as a reaction to a novel stimulus, or with association to a previous bad experience, such as bad tastes or polluted areas (Harris and Davis 1998).

A pool dyed greenish-yellow had a deterrent effect on waterfowl as long as 'dye-free' ponds were available nearby. However, the effect was only temporary and when all ponds were dyed, the coloured water had no deterrent effect at all (Richey 1964, cited in Harris and Davis 1998). Lipcius *et al.* (1980, cited in Harris and Davis 1998) tested water dyed a selection of colours on young mallards. Orange proved to be the most effective at delaying entry into the water and black was the least effective and possibly even attracted them.

The use of dye to protect fish farms has been suggested by Mott and Boyd (1995), as it increases water turbidity and reduces visibility. Dyes have reportedly been used on the Exeter Ship Canal in an effort to reduce fish losses to Great cormorants (H. McKay, pers. comm. – source undated newspaper article, cited in Parrott 2000). Its success is unknown.

Colour avoidance by birds could be an effective tool for reducing seed losses. In cage trials, red-winged blackbirds were presented with seeds in a variety of colours and feeding monitored (Avery *et al.* 1999). Blue was consistently the least preferred, though part of this was probably due to the novelty of blue seeds, so habituation would decrease the deterrent effect.

Dyes and colourants in water are easy to apply and require little maintenance and could be useful for deterring waterbirds. Their application as seed colourants would be more expensive, though costs would be incorporated into the price of the seed. However, success as a cost-effective method of bird control has yet to be proven.

SCIENTIFIC EVALUATION OF VISUAL TECHNIQUES

Of 73 selected studies (those using replicated field trials), 33 investigated at least one visual technique. These are listed in Table 6, sorted by total score and experimental design. Of these 33 studies, 17 contained evidence that the devices were very effective, 10 partially effective and six ineffective. When only the eight 'best' studies are considered, i.e. those with a high total score (>5) and a good experimental design, a similar picture emerges (half were very effective). Eleven studies scored over five.

When the type of device is considered, there does not appear to be a great difference in effectiveness. However, a small number of studies suggest that raptor models and human effigies appear to be more consistently effective than kites/balloons, tapes, and lines. Flags appear to be less effective.

Chemical techniques

TASTE REPELLENTS

Taste repellents can be divided into primary and secondary repellents. Primary repellents are agents that are avoided upon first exposure because they smell or taste offensive or cause irritation. Secondary repellents are not immediately offensive, but cause illness or an unpleasant experience following ingestion that the bird relates to the taste of the treated-food. In future encounters the bird will avoid the treated food.

Secondary repellents are usually regarded as the more effective form of deterrent. The majority of registered secondary repellents are derived from synthetic agrochemical pesticides. Primary repellents are usually derived from natural products including food and flavour ingredients (Sayre and Clark 2001). In the USA, such repellents are regarded as more environmentally safe and tend to be registered relatively quickly and cheaply, though they are considered to be less effective. In 1978, 16 bird control agents were registered by the US Environment Protection Agency, all of them secondary repellents; by 1998 this had reduced to 12 control agents, four secondary repellents and eight primary (Clark 1998). The use of all chemical repellents are regulated due to their toxicity and concerns about adverse effects on the environment (Sayre and Clark 2001).

At present, only two chemicals are registered for use in the UK as bird repellents by the Pesticide Safety Directorate of Defra (R. Watkins, pers. comm.). Ziram, product name AAprotect, is recommended against birds 'in all top fruit, field crops, forestry and ornamental specimens' (The UK Pesticide Guide 2002). In cage trials in Hawaii, ziram repelled red-vented bulbuls, and in further field tests, treated plots of dendrobium orchids also received lower levels of bird damage (Cummings *et al.* 1994). AAprotect applied at the recommended rate of 10kg/hectare failed to protect oilseed rape from mute swan damage after only four weeks. However, this was applied in only one application instead of the two recommended by the manufacturer. It was concluded that lack of persistence on the leaves probably contributed to the decline in repellency. A different formulation of ziram or a repeat spraying could be more effective (McKay and Parrott 2002).

Aluminium ammonium sulphate is marketed under several product names and can be used against birds in 'all top fruit, broad beans, bush fruit, cane fruit, carrots, forest nursery beds, forestry plantations, grassland, peas, spring field beans, strawberries, sugar beet, winter field beans, corms, flower bulbs seeds, flowerhead brassicas, leaf brassicas, winter barley, winter oats, winter wheat, oilseed rape, spring oilseed rape and winter oilseed rape' (The UK Pesticide Guide 2002). Synergised aluminium ammonium sulphate sprayed onto aerodrome grass failed to repel lapwings and gulls, even though the manufacturers' application rate was exceeded. Winter weather conditions and the availability of food had more influence on bird use of the grassland (Horton 1984).

A considerable amount of research has been carried out in the USA into the use of chemical taste repellents such as methyl-anthranilate (ReJeX-iT®), anthraquinone (Flight Control™) and methiocarb, with varying levels of success. Although registered and in use as bird repellents in the USA, they are not registered for use in the UK. Research into new repellents and new formulations of those already in use is ongoing.

Using taste repellents is expensive, with not only the cost of the chemical to cover a large area to consider but also the extra labour and time needed to apply it. Repeated vehicular access and extra tractor wheelings that may be required to effectively spray repellents could reduce yields (Inglis 1992). However, the use of taste repellents may be an economically viable option on small areas of crop where bird damage may be concentrated, such as field margins close to woodland.

BEHAVIOURAL REPELLENTS

Behavioural repellents or 'frightening agents' such as Avitrol® (4-aminopyridine) can be classed as toxicants rather than repellents as in large enough doses they are lethal (Harris and Davis 1998; Mason and Clark 1997). In sublethal doses they cause disorientation and erratic behaviour and birds often emit distress calls. This behaviour alarms other birds and causes them to fly away. If too high a dose is consumed, the bird will die (Harris and Davis 1998). The repellents are usually added to bait which can present a hazard to non-target birds.

Stickley *et al.* (1976) found that Avitrol® effectively reduced blackbird damage to field corn. They recorded 0.8% damage compared to 3.4% in untreated fields. The chemical also affected a few non-target birds (house sparrows). Avitrol® was also effective at reducing damage to ripening sunflowers from blackbirds (Besser and Guarino 1976) and has shown some use in dispersing gulls from airports (DeFusco and Nagy 1983, cited in Harris and Davis 1998). The US Air Force tested Avitrol® at seven air bases and found it to be effective against gulls, starlings, crows, pigeons and house sparrows (Seaman 1970, cited in Harris and Davis 1998).

Frightening agents work best in situations where there are large flocks of birds to respond to the erratic behaviour of a baited bird (Dolbeer *et al.* 1976, cited in Besser and Guarino 1976). Habituation can still occur; gulls rapidly learn to identify and avoid the kinds of bait food that causes distress to other members of the flock (Harris and Davis 1998). Substituting new baits can help to overcome this problem.

Avitrol® is not registered for use in the UK as a bird repellent.

Tactile repellents

Tactile repellents involve the use of sticking substances that discourage birds because of their 'tacky' feel. They can be applied as clay-based seed coatings, or as pastes and liquids on ledges and other roosting structures to deter settling birds.

Clay-based seed coatings become sticky when wet and have been found to be effective repellents under certain conditions. Decker *et al.* (1990) found that the estimated loss of clay-coated rice averaged 17% compared to 36.5% in plots with untreated seed. However, seed coatings are ineffective when bird numbers are high or when alternative food sources are unavailable (Avery pers. comm., cited in Mason and Clark 1997). Clay coatings also accumulate soil and detritius that provide camouflage from birds (Daneke and Decker 1988). Research has also been undertaken to develop seed coatings that increase seed handling time to such a degree that the seed is rejected by the bird. Clay-coated seeds that become sticky when wet have been found to be repellent to captive red-winged blackbirds (Daneke and Decker 1988).

Tactile repellents to deter perching contain polybutene and may contain other substances to induce a chemical reaction that gives the bird a mild 'hot foot' (Transport Canada 1994). They are easy but time consuming to apply as a paste, and although they are not weather resistant, can last up to a year in a sheltered area (Transport Canada 1994). They are known to be effective for controlling pigeons and have been used to prevent raptors from perching on antennas, but for smaller birds such as sparrows, they are less effective as they require only a small area for perching and may not come into contact with the repellent (Transport Canada 1994). Such 'hot foot' repellents are not licensed for use in the UK.

Scientific evaluation of chemical techniques

Of 73 selected studies (those using replicated field trials), 27 investigated at least one chemical technique. These are listed in Table 7, sorted by total score and experimental design. Of these 27 studies, 11 contained evidence that the chemicals were very effective, nine partially effective and seven ineffective. When only the five 'best' studies are considered, i.e. those with a high total score (>4) and a good experimental design, all consider the technique to be either very or partially effective. Five studies scored over five.

When the type of chemical is considered, methyl anthranilate appears to be more effective than methiocarb. Neither are licensed in the UK. Ziram, which is licensed, appeared to be very effective in two studies and ineffective in one.

Exclusion

Nets

The use of nets to cover crops and totally exclude birds is considered one of the most effective bird deterrents. It is widely used to deter fish-eating birds at aquaculture facilities (EIFAC 1988, Kevan 1992), but also to prevent birds from feeding on high value crops such as cherries, blueberries and grapes (Grun 1978, Biber and Meylan 1984, both cited in Harris and Davis 1998).

Results from a survey conducted by Parkhurst *et al*. (1987) of hatchery managers in the USA found that netting top screens placed over fishery ponds were one of the most effective methods of deterring all fish predators, including birds. In a series of trials in Africa to evaluate the efficacy of nets to prevent bird damage to ripening cereals, damage was less in netted areas than in uncovered sites in all trials (Bruggers and Ruelle 1982). Netting placed 1 m above and beside bales of plastic covered silage bales eliminated all bird damage to the plastic (McNamara *et al.* 2002).

Electric fencing, involving a two-strand system set approximately 30 cm from the water's edge has prevented herons and egrets from preying on fish (Littauer *et al.* 1997). The system may not be effective where the pond bottom slopes gradually from the bank as the birds can forage on the water side of the fence. Perimeter netting may discourage birds from walking into ponds to fish, and also discourage problem waterfowl such as Canada geese from leaving the water to graze on adjacent crops or grass.

The cost of completely enclosing a crop may be prohibitively expensive, especially compared to other deterrent methods, particularly on large sites; bird exclosures at landfills can cost £750,000 or more (Baxter 2002d), but is recommended by the UK Civil Aviation Authority as the primary system for bird deterrence at landfill sites near airports. The cost of enclosing a 40.5 hectare (100 acre) catfish farm was estimated to be approximately $1 million based on 1997 costs of $0.22/sq foot for materials alone, plus the cost of labour (Littauer *et al*. 1997). In some situations, costs may be reduced by laying the netting directly over the crop without the use of a supporting structure. This technique was used at Richard-Toll, Senegal (Bruggers and Ruelle 1982). Although protection was incomplete as birds could perch on and feed through the mesh of the net, damage to the crop was still reduced. With this method however, the net became tangled in the crop causing problems in removing it prior to harvest. The cost of a netting system depends on the area to be covered, the type of netting and the support system, and so may preclude their use in anything but the most valuable crops.

The use of netting can hamper access and interfere with routine daily maintenance. Reducing the level of exclosure to allow easier access may render the whole technique ineffective. For example, Martin (1986) found that hanging black polypropylene netting over the doorway of a storage building to prevent access by barn owls (*Tyto alba*) interfered with the movement of delivery vehicles. Shortening the nets to allow the vehicles to pass also allowed the owls to fly underneath.

Nets can be easily damaged by the wind or the build up of snow and ice, or displaced by stormy weather. Any rips or tears large enough to allow access to birds will be exploited (Littauer *et al.* 1997; Martin and Hagar 1990). McNamara *et al.* (2002) found that damage to plastic coated silage bales protected by netting only occurred when storms had disturbed the netting.

Netting, if properly installed, provides one of the most effective ways of preventing bird access to buildings. Its effectiveness though, is dependent on the correct mesh size being selected for the birds to be deterred, and on covering every gap or ledge that can be exploited by birds. When properly installed, netting is difficult to see and can be expected to last for several years.

However, netting may present a hazard to wildlife. Flying birds will generally 'bounce' off nets held taut by supports. Nets that are loose or which have deteriorated in condition can ensnare birds and can lead to their deaths. Thus, netting needs to be regularly checked and maintained to ensure its good condition and to release any trapped birds.

Acrylic fibres can provide an alternative to netting and are used in Europe to protect fruit trees and seedbeds by laying the fibres out as an irregular web-like mesh over the crop. They are less expensive to purchase and install but can easily be displaced by strong winds and birds will feed through the resulting openings. The fibres have to be removed before harvest, and the disentangling of the crop which will have grown through the fibres over the season may in itself lead to crop damage and losses (Bruggers and Ruelle 1982).

In summary, netting is readily available and can provide an effective barrier to exclude birds. However, its effectiveness is dependent on it being properly installed and maintained; on small areas this can easily be done but on larger sites, particularly on buildings, specialist skills and equipment are needed. It is not practical for large areas or where frequent access is required. Within agriculture, high costs may restrict its use to high-value crops.

WIRES

Overhead wires or lines strung over the area from which birds are to be excluded can be an effective deterrent, and a less expensive method than full exclusion. Many types of lines can be used but it is their spacing and height that appear to determine the bird species against which they are most effective.

Overhead lines or wires can deter most fish-eating birds if spacings are narrow enough. Polypropylene lines with spacings of 25.4 cm (10 inches) are used on some trout farms in the USA and are purported to exclude virtually all fish-eating birds. However, they are expensive over large areas (Littauer *et al.* 1997). Salmon *et al.* (1986, cited in Kevan 1992) recommended a spacing of overhead wires of 126 cm for gulls, 63 cm for mergansers and 31 cm for great blue herons. Placing netting along the sides of a pond where overhead wires were used, would also prevent birds gaining access from the sides. However Moerbeek *et al.* (1987, cited in Kevan 1992) found that while overhead wires deterred large groups of cormorants, they did not deter single birds that were able to land or go in between the wires. Gulls have been repelled from a fish hatchery by using monofilament lines 41 cm apart and 20 cm above the water (Ostergaard 1981). This spacing allowed routine maintenance to be undertaken and appeared to be working a year after its installation.

Overhead wires excluding birds from ponds

The costs of installing a wiring system can be much lower than for full netting exclosures. Littauer *et al.* (1997) estimated that small ponds up to 0.9 hectares (2.2 acres) could be wired for as little as $15/0.4 hectares (one acre) and needed about seven working hours of labour per hectare. Wiring larger areas becomes more expensive ($164/0.4 hectares for 3.7 hectares) because of the need for costlysupport systems. There is also the greater risk of the wiring interfering with the routine fishery activities.

Placing low wires along the edge of lakes is an alternative and less expensive method to overhead lines at fisheries. Two strands, one above the other at 20 cm and 35 cm above the ground can prevent herons reaching a feeding position on the bank (Meyer 1981), and only costs approximately £2 for a 30.5 x 9.1 metre (100 x 30 foot) pool. A chain of white polyethylene floats along the edges of the pond with a length of twine around the perimeter was found to be effective against great blue herons, as the herons would not go over the floats or feed in between them (Meyer 1981, cited in Kevan 1992). Wire, string or floating rope, in parallel or grid patterns, on or near pond surfaces have been partially effective in deterring cormorants by interfering with the long take-off distance that cormorants usually require. Again, the cost of wiring a larger pond, the physical constraints of spanning large distances and the interference with routine fishery practice limit their usefulness (Littauer *et al.* 1997).

Monofilament lines were used to protect plastic film surrounded silage bales from bird damage (McNamara *et al.* 2002). Lines with narrow spacings (0.5 m) were more successful than 2 m spacings, as they prevented rooks and jackdaws from flying between the lines, landing on the bales and damaging the plastic film.

On a larger scale, a system of 24.4 metre (80 foot) high wires at 3.05 metre (10 foot) intervals has been tested at an 89 hectare landfill site (Dolbeer *et al.*1988). The system reduced numbers of laughing gulls and excluded the larger herring and black-backed gulls. It was concluded that ensuring the wires were regularly separated at even height would prevent laughing gulls from exploiting some of the larger spaces between the wires and entering the landfill. An irregular criss-crossing of both monofilament lines and wires successfully deterred gulls from public places in Toronto, but were ineffective against rock doves (Blokpoel and Tessier 1984).

Monofilament lines positioned just above plants can protect agricultural crops such as row crops and bedded crops like strawberries. In the case of fruit trees and bushes, a series of lines placed in a tepee design from about 61 cm (2 feet) above the tree to the ground may also be effective (Knight 2000).

In summary, overhead lines can be successful at repelling bird pests but their success depends on the pattern of wire spacings and the bird species to be deterred. Wiring systems can be relatively inexpensive to install and need little labour to maintain, but like netting they need to be checked regularly for broken lines that will be exploited by bird pests. Although they have been used successfully on large-scale sites, they are probably more effective on relatively small open areas.

ANTI-PERCHING

Anti-perching devices prevent birds from perching, roosting and nesting on surfaces and ledges and involve wires, gels, coils or point systems. All either prevent physical access or else provide an unstable surface for perching. Installing a thin wire over the perch, which prevents the bird from landing is probably the simplest method. The wire should be low enough that the bird cannot stand under it, but also high enough to prevent the bird from straddling it (Johnson 2002). If a variety of bird species are to be deterred from the same perch, a series of wires at different heights should help to meet the above criteria for all species. White wires deterred pigeons from perching on stadium ledges (Andelt and Burnham 1993). Up to three lines were placed in front of the ledges and at different heights above the ledges. Short-term success was good.

Smooth strips fitted onto ledges at an angle of inclination greater than 45° prevent birds from perching on ledges (Andelt and Burnham 1993). Gels spread along ledges form an unstable surface for birds to land on. In the UK it is a legal requirement that the gel is ‘skinned’ immediately after application, so that the sticky gel is not exposed for the birds to get entangled in (Network-pest website). Coils of stainless steel and tensioned wires that go slack when birds settle on them, work on the same principle and although relatively expensive, are quick to install.

Point systems consist of strips of plastic or metal with thin, upward-pointing, stainless steel or plastic spikes in a variety of configurations, which are attached to ledges. The spikes present a physical barrier to prevent birds from landing. These systems are relatively expensive and although easy to install, they require checking occasionally in order to remove debris which may cover up the wires, reducing effectiveness. The tips of wire spikes are cut square, as sharpened tip systems, (which are used in the USA), are illegal for use in the UK (Turner 1998).

Electrical systems such as Avi-Away® consist of a cable running along the area to be protected that is attached to a control unit. When a bird lands on the cable it completes an electrical circuit and receives a mild shock. The manufacturers claim that any distress calls given by the bird help to disperse others (Transport Canada 1994). However, such electrical systems are illegal in the UK (Turner 1998).

All these designs may help to deter perching birds but their success is dependent on all perches being treated to discourage birds from the area.

SCIENTIFIC EVALUATION OF EXCLUSION TECHNIQUES

Of 73 selected studies (those using replicated field trials), five investigated at least one exclusion technique. These studies are listed in Table 8, sorted by total score and experimental design. In four studies, the techniques were found to be very effective and partially effective in the fifth study.

The study by McNamara *et al.* (2002) had a total score of six and used a good experimental design. They found that the use of netting and narrow wires was very effective in reducing bird damage to hay bales.

Habitat modification

VEGETATION MANAGEMENT

On airfields the areas between runways are usually covered with grass. This open environment can encourage feeding and resting by a number of bird species, which may become a hazard to aircraft. However, several studies have shown that the height of the sward can influence the species and number of birds present. Brough and Bridgeman (1980) found that birds such as lapwing, woodpigeon, rook, starling and gulls were fewer on long grass (15-20cm) than on short grass (5-10cm). However long grass may attract partridges and other ground-living species, and small mammal populations may also be encouraged by long grass, which, in turn, may attract predatory birds (Wright 1969). Maintaining a sward at this height may require careful management to ensure that the sward does not accumulate dead leaves and stems which are detrimental to the living tillers and which may constitute a fire hazard (Mead and Carter 1973). This ‘long-grass’ regime is now routinely used on airfields in the UK.

Plant species composition may also influence bird numbers. Omitting white clover from the grass sward can help to prevent flocks of woodpigeons, which find this an attractive food plant at certain times of the year (Wright 1968). Canada geese readily feed on areas of short grass and their droppings and aggressive behaviour can become a serious problem on amenity grassland. However, certain plants such as periwinkle (*Vinca* spp.), myrtle (*Myrtus* spp.), hosta (*Hosta* spp.) and ivy (*Hedera helix*) are avoided by geese and could be planted to reduce that area of forage, particularly close to water (French and Parkhurst 2001, Smith *et al.* 1999). Also, reducing the attractiveness of grass by reducing fertiliser use and so decreasing the nutritional quality of the forage can deter goose feeding (French and Parkhurst 2001, Smith *et al.* 1999).

Vegetation management techniques are likely to be expensive in the short-term during implementation, particularly if specialist equipment, such as that required for grass cutting on airfields, is required. However, such techniques may work out cost effective in the long-term with human input being limited to occasional maintenance. Unless alternative feeding or roosting areas are available, this technique is not likely to eliminate birds but can help to reduce numbers.

ALTERNATIVE FEEDING AREAS AND BAIT STATIONS

The theory behind alternative feeding areas (AFAs) and bait stations is to provide an area where the forage is of better quality than the site where damage is occurring (Owen 1990, cited in Smith *et al.*1999). The provision of AFAs is particularly important in the management of crop damage caused by the grazing of geese and other waterfowl.

In the UK, AFAs for geese are usually areas of grassland close to the birds' night roost and managed specifically to attract these birds (Owen 1977). However, such areas may not support all the birds, leading to increased damage to crops adjacent to the alternative feeding area. This problem may be reduced by creating a series of smaller feeding areas throughout the birds' feeding range. This dispersed refuge scheme was used by Scottish Natural Heritage (SNH) for pink-footed geese (*Anser brachyrhynchus*) at Loch of Strathberg, Aberdeenshire, between 1994 and 1997. Based on existing grass fields, AFAs were managed to attract the geese, by the earlier application of fertilizer, a reduction of disturbance and increased scaring from nearby crops. Over the four years of the scheme, the number of geese using the refuges increased and was judged a success in reducing conflict with local agriculture (Patterson 1999).

However, setting up an AFA by taking land out of agricultural production my lead to financial loss for farmers, although this depends on market prices of the crop concerned and the availability of payments from agri-environment schemes. Vickery and Edwards-Jones (1999) calculated the cost, based on 1996 prices, of establishing an AFA for dark-bellied brent geese (*Branta bernicla bernicla*) from set-aside (land previously under wheat). Despite the gain of an extra (Premium) payment and a reduction in crop damage, the cost of establishing the feeding area, loss of crop production on the land and the continuing of scaring on surrounding land to encourage the geese to use this new area, led to a loss of £192/hectare to the farmer.

In America, diversionary feeding programmes involve using bait stations to encourage birds, mainly waterfowl, away from commercial crops. Bait stations were first extensively used in California in the 1940s (Horn 1949, cited in Knittle and Porter 1988), with 45-60 tons of barley distributed annually to keep ducks away from commercial rice fields.

At the Lower Souris NWR in North Dakota, bait stations for mallard and pintail have been set up in the autumn harvest period, at natural feeding or loafing areas, to reduce damage to cereal fields (Hammond 1961). Scaring is still carried out to encourage birds to use the bait stations, where up to 20,000 birds have been counted. In 1961, the loss of grain to an area population of 125,000 birds during a 45 day harvest season may have been in excess of $100,000. The average feeding station costs were calculated as approximately $17,000 (Hammond 1961), showing that establishing bait stations was a cost-effective method of reducing bird damage.

In summary, the provision of alternative feeding areas and bait stations can be effective in reducing bird damage to crops. Both techniques can be costly to establish, sites need to be within the birds' normal feeding range and have to provide better forage than the crop to be protected. Disturbance must be kept to a minimum to prevent the birds from leaving, though scaring needs to be continued, not only on the vulnerable crop, but also other fields in the vicinity, to encourage the birds to favour these alternative areas.

LURE CROPS AND SACRIFICIAL CROPS

Lure and sacrificial crops are purposely provided as food in order to prevent birds damaging commercial crops. In the case of wildfowl in America, lure crops are generally fields of swathed or flooded grain left for geese to consume (Smith *et al.* 1999; Knittle and Porter 1988). In North Dakota between 1975 and 1980, lure crop plantings of barley and wheat were highly effective in reducing damage in several areas and produced an overall positive benefit to cost ratio of at least 2:1 (Knittle and Porter 1988). The value of birds as a hunting resource will also increase the benefit of this technique.

However, as with alternative feeding areas and bait stations, the success depends on the ability to scare birds from the vulnerable crops onto the lure crop, and with large concentrations of feeding waterfowl, a lure crop will become less attractive over time due to trampling and food depletion (Smith *et al.* 1999). Also, local bird pest density may increase as the birds are attracted to the abundance of food.

The use of sacrificial crops is based on the theory that overall bird damage to a commercial crop should be reduced by the same amounts as consumed in the decoy crop (Guarino 1984). In North Dakota blackbird damage to ripening sunflower was reduced by planting decoy sacrificial sunflowers. It was estimated that it cost approximately US$30/0.4 hectare (1 acre) to plant the decoy crops but 0.4 hectares of commercial crop eaten by birds was worth between US$100-150, saving about US$4-5 for every dollar spent (Guarino 1984).

Sacrificial 'crops' can also be used at fisheries where mixing valuable large fish stock with smaller fish may reduce losses to bird predators (EIFAC 1988, Lagler 1939, cited in Kevan 1992) and including another fish species can distract the predator and reduce loss of valuable fish. For commercial fisheries it has been suggested that higher overall fish densities, due to stocking buffer prey alongside commercial species, may serve as an increased attraction to predators (Elson 1962, Draulans 1987). To avoid this, the provision of buffer prey at alternative sites away from important fisheries was suggested as a preferred option (Utschick *et al*. 1982).

REMOVAL OF ROOST STRUCTURES

Removal of roost structures can be used to encourage birds to leave an area in which they are causing damage. Good and Johnson (1976) compared the use by blackbirds of roost trees that had been trimmed by removing one-third of the canopy, with trees left untouched. Groves of trimmed trees were completely abandoned whilst those of untrimmed trees were occupied as usual. However, a grove that contained both trimmed and untrimmed trees was also completely abandoned, indicating that even partial and less expensive alteration of a roost may have a beneficial effect.

Cattail marshes are used a roost sites by red-winged blackbirds, which cause severe damage to ripening sunflower and grain crops in America. It is recommended that these marshes be sprayed with glyphosate (Rodeo Aquatic Plant Herbicide) to reduce the density of the cattails and help to disperse the birds before vulnerable crops are planted in the vicinity (USDA 1997).

Long-term effectiveness of roost modification is likely to vary with the function of the site, i.e. breeding, night roosting or day loafing, and upon the distance to alternative sites in the locality. Practicality and cost depend upon the structures being used as the roost site; it may be possible to remove isolated trees or cover them with wires or netting, but lamp posts or pylons would need to be proofed with anti-perch devices. Other techniques such as bio-acoustics and laser light could be used in conjunction with physical methods to make roosts unattractive, although these additional methods are rarely successful on their own (Dumiege 1993; Broyer *et al.* 1993, both cited in McKay *et al.* 1999).

WATER SPRAY DEVICES

The Swedish Salmon Research Institute in Alvkarleby has developed a rotator device for protecting circular fish ponds from gulls and terns (Svensson 1976). The rotator has four arms that spray a mist of water over the tanks/ponds, providing shade by diffusing direct sunlight and possibly oxygenating the water. This spray of water reduces visibility and prevents birds from seeing the fish (Littauer 1990; Mills 1985 cited in Kevan 1992). Although useful on small, contained ponds, its use in protecting larger, irregular water bodies may be limited. There is no available literature to support its use for deterring wading or diving birds (Kevan 1992).

FOOD REMOVAL

This method of habitat modification is particularly important in urban areas and livestock farms. The abundance of food is the main attraction for pest species such as feral pigeon, collared dove, starling and Canada geese. Canada geese and feral pigeons are attracted to areas where people deliberately put food out for them. Plans to prevent the public from feeding birds, such as the pigeons in Trafalgar Square have met with opposition, but on a smaller and less well-publicised scale, requests that people do not feed pigeons, for example on railway stations, have met with some success (Feare 1985).

Modifying farm practices may help to reduce bird damage. Clearing up spilled grain, using bird-proof livestock feeders, feeding livestock indoors, liquid feeds or food with a large pellet size can all reduce feed losses and discourage bird pests (Feare and Wadsworth 1981, cited in Inglis 1985; Johnson and Glahn 1998).

SCIENTIFIC EVALUATION OF HABITAT MODIFICATION TECHNIQUES

Of 73 selected studies (those using replicated field trials), one investigated a habitat modification technique. This study is described in Table 9. McNamara *et al.* (2002) changed the position and orientation of bales of hay, and found that to be very effective in reducing bird damage to the plastic wrapping. This study scored six and used a good experimental design.

Lethal techniques

The principle mechanism for the legislative protection of wildlife in Great Britain is the Wildlife and Countryside Act (1981). Section 1 of the Act prohibits the intentional killing, injuring or taking of any wild bird and the taking, damaging or destroying of the nest or eggs. However, under section 16 of the Act, General Licences are issued which provide a mechanism for permitting actions that would otherwise be unlawful. A General Licence allows the killing of the following 13 agricultural pest species: carrion crow, collared dove, great blacked-back gull, lesser blacked-back gull, herring gull, jackdaw, jay, magpie, feral pigeon, rook, house sparrow, starling and woodpigeon. It permits the killing or taking of birds for the purposes of: 'preventing serious damage to livestock, crops, vegetables, fruit, growing timber, fisheries or inland waters' or for 'protecting any collection of wild birds' or for 'preserving public health or public air safety'. 'Killing or taking' includes taking, damaging or destruction of their nests or the taking or destruction of their eggs, where there is no other satisfactory solution. Unless otherwise stated the licence permits authorised persons to carry out the licensable act. An 'authorised person' is defined as the owner/occupier or any person authorised by the local authority or by listed officials. Further licences can be issued for the control of other bird species, for example, cormorants at fisheries. Control methods permitted are by shooting, a cage trap or net (hand-propelled). Defra policy is that shooting should be conducted in conjunction with non-lethal measures as part of an overall control strategy. The principle of shooting is to enhance non-lethal methods of deterrence and not as a deliberate means of population reduction. Some further alternative lethal techniques are permissible under Special Licence, such as the use of mist nets and stupefying baits.

SHOOTING

Shooting may be deployed as an avian deterrent using two different approaches: shooting to kill and shooting to scare.

Firstly, shooting may directly reduce numbers of pest birds through killing. The shooting of over 50,000 gulls at John F. Kennedy International Airport between 1991 and 1997, successfully reduced airstrikes by 76-89% (Dolbeer 1998; Dolbeer *et al.*1993, Dolbeer and Bucknall 1997, cited in Harris and Davis 1998). The birds were shot as they crossed the airfield on route to feeding areas, and the technique was successful at reducing the local nesting population of gulls but had no impact on the regional or national population (Dolbeer and Barras 2000). However shooting such large numbers of birds is not something that would normally be allowed or accepted.

In many circumstances, shooting may fail to reduce overall bird pest numbers as mortality is unlikely to exceed the recruitment rate from immigration and breeding (National Goose Forum 1998; Feare 1984). In addition, shooting may just remove the surplus birds that would have died of natural causes such as starvation or disease, without any reduction in the overall population size or associated problems (Murton, Westwood and Isaacson 1964, cited in Murton 1968). However, if bird problems are caused by small localized populations such as small groups of feral pigeons in buildings, shooting may be reasonably effective and long-lasting.

Alternatively, shooting may be used as a scaring strategy only, whereby birds are frightened away without attempts to kill; although a small number of birds may be killed with a view to enhance the scaring effect. Baxter (pers. comm.) investigated lethal shooting in combination with other techniques such as pyrotechnics as a means of reducing birds at landfill sites in England. They concluded that shooting a small percentage of the birds present was very effective in deterring birds from sites. In the UK, certain species may be shot under licence. Licensed shooting, however, should be part of a wider bird scaring programme; it is not intended as a means of population control.

It is generally accepted in bird control manuals that killing enhances the scaring effect of shooting (e.g. Transport Canada 1994, Civil Aviation Authority 2002). However, scientific evidence to substantiate this view is equivocal. Although increased wariness and dispersal by waterbirds in response to wildfowling have been well documented (Bell & Owen 1990; Madsen & Fox, 1995) no attempts have been made to differentiate between the disturbance effects of human activity and hunting mortality. Frederick *et al*. (1987) produced a multifactorial simulation model which attempted to describe the effects of alternative management schemes on the use of refuges by autumn-migrating snow geese *Anser c. caerulescens*. The main conclusion was that disturbance associated with hunting was more important in reducing population size, through early migration, than the direct effects of hunting mortality. The increased disturbance during shooting, caused by the retrieval of kills and injured birds may cause as much disturbance as the shot itself (Townshend and O'Conner 1993). This extra level of disturbance (rather than mortality itself) may deter birds from using a site. In a controlled, replicated field experiment shooting, both lethal and non-lethal, significantly reduced cormorant numbers by over 50% at fisheries, though it could not be shown whether killing enhanced the scaring effect of shooting (M^c^Kay *et al.* 1999).

The effectiveness of shooting depends on a number of factors: the target species, the site characteristics and the shooting regime. Sensitivity to shooting varies between species and between individuals within species (Bell & Owen 1990, Madsen 1998). For waterbirds, shooting has been shown to be more effective at smaller sites than large sites (Hughes 1996; M^c^Kay *et al.* 1999). The number of consecutive days shooting (Townshend & O'Connor 1993) and the number of shooting parties (Madsen 1993a,b) has also been shown to affect the magnitude of reduction in bird numbers.

In summary, shooting to kill under licence may have short-term advantages but its efficacy may be exaggerated through the immediate self-gratification to the shooter, who feels he is taking a positive action towards solving a bird problem (Kevan 1992). The success of the technique depends on the sensitivity of the target species, the physical characteristics of the site, the shooting strategy and the availability of alternative sites for the birds to move to, and these in turn affect the cost-effectiveness of shooting. .

EGG DESTRUCTION AND OILING

Egg destruction is used to reduce the local population of pest birds and in the UK it requires a licence from Defra. Eggs can be destroyed by several methods. Straight-forward egg removal can encourage re-laying unless the eggs are replaced by hard-boiled or wooden replicas (Baker *et al.* 1993). The pricking of eggs with a needle allows bacteria to enter the egg as well as desiccate its contents (French and Parkhurst

2001), but some pricked eggs may still hatch, and birds may abandon clutches to relay.

Egg oiling is a cheaper, more effective and more humane method of egg control. It involves coating the egg shells with oil such as liquid paraffin (Baker *et al.*1993). This stops air from passing through the shell to the embryo and prevents it from developing properly. Baker *et al.* (1993) tested this method on Canada geese and achieved a 100% success rate; none of the 231 treated eggs hatched. They also pricked some eggs and these too did not hatch, but they were incubated for significantly less time, allowing the adults to relay elsewhere.

This technique, using white mineral oil, was also effective on ring-billed and herring gull eggs, though some eggs (8-9%) sprayed early in incubation or sprayed with only a small quantity of oil late in incubation, did hatch (Christens and Blokpoel 1991). For total success, it was recommended that spraying should be undertaken three times during incubation. Although this should be more effective it is more labour-intensive and so less cost-effective.

The sole use of egg destruction is unlikely to reduce a local population in the long-term. It is a time-consuming process as all nests have to be located and treated, and this may be hindered by problems of access. The timing of destruction is important and any reduction in a population caused by the loss of young birds may well be offset by immigration of new birds from nearby non-treated areas.

NEST DESTRUCTION

Nest destruction, like egg destruction, requires a licence in the UK. It is a time-consuming though relatively inexpensive control technique, and may help to control a local pest species. This technique was used to control double-crested cormorants in America, and reduce their negative impacts on the nesting habitats of other colonial waterbirds, as well as help to restore the fish community (Farquhar *et al.* 2000). During weekly visits nests on the ground were removed by hand and those in trees dislodged with a telescopic pole. The nesting material was scattered to discourage re-building. Since the nest removal programme began there has been no successful cormorant breeding in the area.

Ickes *et al.* (1998) recommended nest and egg removal for ground-nesting colonies of gulls but found that the technique was unlikely to reduce the number of nesting gulls in a given area, but it moved the problem as the gulls dispersed to recolonise other sites. Nest and egg removal and just egg removal were found to be equally effective but the former technique was approximately 60% more labour intensive. This made it more expensive.

In general, the use of other scaring methods in addition to nest disturbance and destruction is more likely to cause abandonment of an area by a bird pest species (Blokpoel and Tessier 1992, cited in Ickes *et al.* 1998).

SCIENTIFIC EVALUATION OF LETHAL TECHNIQUES

Of 73 selected studies (those using replicated field trials), eight investigated at least one lethal technique. These studies are listed in Table 10, sorted by total score and experimental design. Six of the studies found the technique to be very effective, one partially effective and one ineffective.

Egg oiling was found to be particularly effective (two studies); the others investigated lethal shooting. Only one of these studies scored over five. It should be noted that shooting may be undertaken as a means of population control or as a means of scaring, often by reinforcing or augmenting other scaring techniques and in practice it may be difficult to separate these two effects.

5.1.3 Major reviews of bird scaring techniques

Three major reports evaluating various bird-scaring techniques were used in compiling this review. All concern the use of bird scaring at airports, an area where effective bird scaring is essential and many techniques have been assessed in order to reduce the risks of bird strikes.

Transport Canada's Control Procedures Manual (1994) states that the effectiveness of any technique varies with the bird species and that habituation will eventually occur with any scaring technique that is not reinforced by a demonstration of actual danger. Constantly changing the appearance and location of the device should help to prevent rapid habituation. An effective bird control programme should involve the use of several techniques used in a random fashion. Auditory deterrents are extensively used to disperse birds on airfields and can be effective as long as the sound source is frequently moved. Visual deterrents are not particularly suitable for an airport situation and are not found to be particularly effective. Exclusion of a bird from a preferred habitat by using a physical barrier such as netting is an effective but costly means of deterrence. In general, control measures rely heavily on techniques that have short-term effectiveness and are inexpensive in the short run but give immediate results. The best long term control is achieved by managing the habitat (e.g. vegetation height).

The Civil Aviation Authority's Aerodrome Bird Control report (2002) stresses that man-operated scarers and man-based techniques are most effective. Free standing bird scarers and other devices such as gas cannons, noise generators and novel devices such as flags, tapes and windmills are only effective in the short term and are not recommended for use on aerodromes. Safe and effective chemical repellents have not been developed to a level where they can be recommended. Bird scaring cartridges (pyrotechnics) are the commonest means of dispersing birds from aerodromes in the UK though there are important safety issues to be considered with their use. Broadcasting distress calls is effective, and in the long term, the cheapest way to deter birds. Falconry is a quick way of dispersing birds but is time consuming and expensive. Habitat management, particularly by maintaining grass at 150-200 mm is particularly useful, and reduces bird numbers to a level where they can be dispersed using other scaring techniques. This report was based on a review by CSL/AWM (unpub.) in which the authors: give advice on the use of distress calls (inc. products, equipment and positioning), review visual scarers, bird scaring cartridges, gas guns and other methods, concentrating on falconry and shooting.

Harris & Davis (1998) in a report to Transport Canada, found there were few comprehensive, objective, properly designed, quantitative studies on bird deterrents. They admit that as a result of this, their approach is necessarily subjective. They found that often a product on its own is largely ineffective because of habituation, but can be an effective part of a multi-product/method approach. They note that many of the least effective techniques are based on novelty, and although there may be biological basis to many of these products, any effects are short-lived. Techniques that mimic known threats to birds, e.g. scarecrows and hawk kites, tend to be stronger and longer-lived; the period of effectiveness is related to the realism of the model. They conclude that killing birds is only of short-term benefit. After reviewing the information available, they recommend the use of Habitat Modification (tall grass and the use of physical barriers to exclude birds from critical areas) and Active Bird Control (using pyrotechnics, falconry, distress and alarm calls and shooting). They recommend that the following techniques are NOT used on airports: high intensity sound, microwaves, lasers (because of concerns for human safety), ultrasound (because it is ineffective), aircraft hazing, smoke (because they are impractical), magnets, lights, dyes, aircraft engine noise, and infrasound (because of insufficient research). Limited recommendation is given to gas cannons, rotating sonic devices, synthetic noises and most visual deterrents, due to rapid habituation. They suggest that further work is needed to (a) independently test new and expensive products, (b) investigate habitat modification techniques (c) improve information dissemination.

5.2 EVALUATION OF SELECTED STUDIES

Of the documents listed in Table 3, 73 studies were judged to be replicated field trials, and were evaluated using the meta-analysis approach. In the appendix, Tables A1 – A5 contain the information extracted from these documents which was used to evaluate them using the scoring system described previously.

Each study was given a total score depending on its context, treatment, experimental design and cost-benefit analysis. Only 15% of the studies were on species and crops common in the UK. Half the studies were carried out on either UK species or on UK crops. The intensity of treatments used was practical and legal (in the UK) in 38% of the studies evaluated, but either impractically high or illegal in 49% of studies. Inadequacies included using chemicals not licensed in the UK, or detonation frequencies above the recommended rate for gas cannons (NFU guidelines). The experimental design was judged to be good in 36% of studies and poor in 18% of studies (the remainder were intermediate). Inadequacies included no appropriate control, insufficient replication, non-random allocation of treatments, trial not long enough to detect habituation and plots not large enough to prevent interference between treatments. A full cost-benefit analysis was carried out in 30% of the studies evaluated. Half the studies did not consider it at all.

Of the 73 studies evaluated, 28 investigated at least one auditory technique, 33 visual, 27 chemical, one habitat modification, five exclusion and eight lethal (Tables 4 – 10). Results on the effectiveness of devices in each category have been included in the preceding sections of this report. The following compares the different categories.

Figure 1 shows the relative effectiveness of the different deterrent categories. Habitat modification, lethal techniques and exclusion appear to be more consistently effective than auditory, visual or chemical techniques. However, the number of studies investigating habitat modification and exclusion, in particular, are extremely small (one and five respectively).

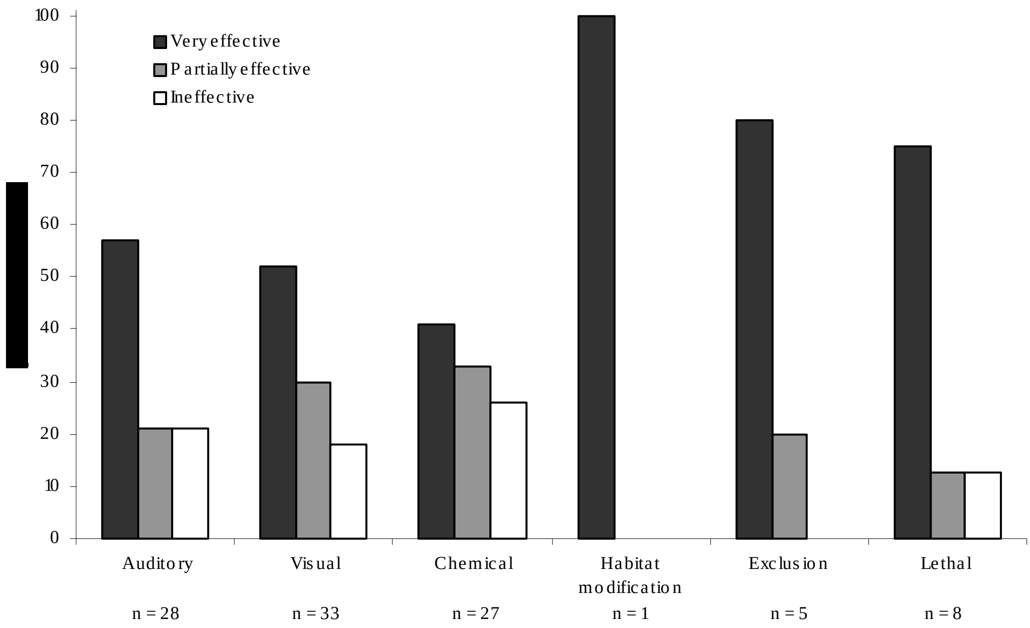

Figure 2: The relative effectiveness of deterrents of different categories, as found in 73 replicated field studies.

Very effective: >50% reduction in damage or number of birds.
Partially effective: up to 50% reduction in damage or numbers of birds.
Ineffective: no significant reduction in damage or number of birds.

Information used in cost-benefit analyses of the different techniques is summarised in Table 11. Not all studies which scored highly in this area, are included, as some measured damage but did not cost it. It appears that, in general, in terms of cost-effectiveness exclusion is the most costly deterrent, followed by chemical techniques. Visual and auditory deterrents tend to be less expensive.

6. Discussion

A search of published information and the grey literature relating to bird deterrents, the extensive information held by CSL and consultation with individuals, manufacturers and distributors of deterrent devices, resulted in a collection of 456 documents. Information from these studies was extracted and collated into a table, and used to review the current state of knowledge. Studies involving replicated field trials (73 studies) were evaluated in order to assess the extent to which the results can be extrapolated to the UK situation, and to compare the performance of the different deterrent techniques. For the purposes of this review, deterrents were categorised into: auditory, visual, chemical, habitat modification, exclusion and lethal.

In our review, we found that auditory techniques (gas cannons, pyrotechnics and bio-acoustics) are thought to be relatively effective, although subject to habituation and hence of short-term benefit. As such, they are usually only recommended as part of an integrated control strategy. Noise nuisance is also an important consideration, and can be reduced by modifying the way in which the devices are used. Little information is available on the noise levels produced, and much of this is unpublished and not generally available. Artificial noises (sonic devices), ultrasonics and high intensity sound are either ineffective or unsafe. In our evaluation of replicated field studies, we found that compared to the other categories, studies which investigated auditory techniques tended to have a lower total score, mainly because they did not use species/crops common in the UK. Distress calls, pyrotechnics and shooting appeared to be more effective than sonic devices, humming tapes or gas guns.

Visual techniques (lasers, dogs, human disturbance, scarecrows, raptor models, corpses, balloons, kites, falconry, radio-controlled aircraft, lights, mirrors/reflectors, tapes, flags/rags and streamers and dyes/colourants) are thought to be of varied effectiveness ranging from extremely effective (human disturbance) to ineffective (most scarecrows). Their effectiveness depends on how real a threat they are perceived to be (e.g. predators and their models) or how much they are perceived to interfere with movement (e.g. tapes and wires). In our evaluation of replicated field studies, we found that compared to the other categories, studies investigating visual techniques were more transferable to the UK situation (higher total score), although they tended to have poorer experimental design.

Chemical techniques (taste, behavioural and tactile repellents) are generally found to be very effective in laboratory and cage trials, but less effective in the field due to practical problems such as persistence (the chemical soon washes off). Our review also suggested that these techniques are relatively expensive and time-consuming and difficult to apply; several applications may be required, involving repeated access to fields during wet winter conditions. The greatest barrier to their use is legislation; only two chemicals are licensed for use as bird repellents in the UK (ziram and aluminium ammonium sulphate). In our evaluation of replicated field studies, we found that compared to the other categories, results of studies investigating chemical techniques were not as transferable to the UK situation (low total score), mainly because the majority use species/crops not common in the UK, and test chemicals not registered in the UK. Chemical techniques appear to be less consistently effective than auditory or visual techniques.

Exclusion techniques (nets, closely spaced wires, anti-perching devices) are generally considered to be extremely effective in the studies we reviewed. Effectiveness depends on the degree to which birds are excluded (e.g. closer spacing between wires). However, the greater the exclusion the more expensive the technique. For this reason it tends to be restricted to high value crops such as blueberries and commercially farmed fish. Compared to most other categories, replicated field studies are rare. However, results of the few studies that have been carried out are transferable to the UK situation (high total score) and are well-designed.

In our review, habitat modification techniques (vegetation management, alternative feeding areas and bait stations, lure and sacrificial crops, removal of roost structures, water spray devices and food removal) are generally considered to be effective and environmentally friendly. Because the techniques must be tailored to the damage/species context, they tend not to be investigated by replicated field trials, but by one-off demonstration studies. Also, as particular chemicals, materials or devices tend not to be used, there may be less interest in evaluating them from a commercial viewpoint. However, vegetation management appears to be extremely effective at reducing numbers of birds at airports and it seems likely that habitat modification will be shown to be cost-effective in other situations.

Lethal techniques used for population control, rather than to augment scaring, (shooting, egg destruction and oiling and nest destruction) are generally considered to be less effective in the studies we reviewed. This is because the level of mortality achieved rarely exceeds immigration and breeding rates. The large effort needed to do this makes this technique relatively expensive, and in addition, it is unlikely to be publicly acceptable. In the UK lethal methods are regulated under the Wildlife and Countryside Act (1981), and licences are required from Defra. However, killing may enhance or reinforce other scaring techniques, and licences may be granted for this purpose. Relatively few studies attempt to evaluate lethal techniques using replicated field trials. We found in our evaluation that compared to the other categories, these studies tend to have a lower total score, mainly because they use poor experimental design and do not consider cost/benefits. In contrast to the general review, lethal techniques were found to be more consistently effective than auditory, visual or chemical. However, it is not clear whether their effectiveness depended on the effect of killing or scaring birds.

Combinations of techniques, used in an integrated control strategy, are considered in the studies we reviewed to be more effective than techniques applied singly. Studies which investigate combinations of techniques are often concerned more with practical implementation than with scientific evaluation (for example the landfill studies by Baxter *et al*.). This is a necessary stage in the development of a bird deterrent technique. Cost-benefit analyses should also be carried out at this stage, and the perceptions and practical concerns of users of these deterrents, and neighbours, taken into consideration. This is particularly important where noise nuisance is concerned, but may also be an issue with other techniques which may impact on the countryside.

7. Conclusions

Auditory bird deterrents such as gas cannons tend to be of short-term benefit due to rapid habituation, and their effectiveness varies widely depending on how they are used. They are perceived to be relatively cheap, portable and labour-free (i.e. automatic) compared to other techniques (N. Horton, pers. comm.). However, the available evidence suggests that to achieve maximum effectiveness, they should be intensively maintained and monitored. Our evaluation of the literature suggests that a variety of techniques could potentially provide cost-effective noise-free alternatives. Moreover, an integrated management strategy will be more effective than an auditory device used on its own. Improved guidance is therefore required. We suggest that a lack of knowledge of the cost-effectiveness of alternatives contributes to gas cannons being widely used. There is a similar lack of knowledge concerning gas cannons.

Further work is needed on promising techniques to fill the gaps in knowledge, and also more effort is required to disseminate relevant information.

8. Gaps in knowledge

- Noise levels of auditory devices. Re-evaluate the early CSL experimental work on auditory devices and noise nuisance, with the aim of possible publication or making the information more generally available (at the time this work was done, peer-reviewed journals would not consider it for publication due to lack of interest in the subject, I. Inglis, pers. comm.). Consider further experimental work.

- The cost-effectiveness of bio-acoustic techniques, using well-designed field experiments, on birds/crops relevant to the UK.

- Well-designed field experiments to test silent bird deterrents, on birds/crops relevant to the UK. Brightly coloured tape attached to a grid of stakes is currently being developed as a means of deterring mute swans from winter crops, by CSL (funded by Defra European Wildlife Division). Results are promising.

- Studies investigating the cost-effectiveness of habitat modification & exclusion techniques, using well-designed field experiments on crops and birds relevant to the UK.

- An evaluation of combinations of techniques in integrated control strategies.

- An evaluation of bird deterrent studies which use cage and laboratory trials, and consider investigating promising techniques using well-designed field trials on crops/birds relevant to the UK.

- Investigation of the use of lethal shooting as a bird deterrent.

9. Recommendations for further work

- Produce improved guidance in the use of gas cannons, including limitations to effectiveness, best-practice and cost-effective alternatives.
- In the longer term, produce guidance on best-practice in managing bird damage to crops, with emphasis on minimising nuisance to neighbours.
- Design, create and manage a database on bird deterrents, to be freely available to users over the internet. A previous database with this aim (put together by Ian Inglis) and the IENICA project run by CSL (a web-site on industrial crops and their applications) can be used as models.

10. Additional references

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11. Tables

Table 1. List of individuals and organisations selected for consultation and their reactions.

X replied, and provided information
0 replied, but unable to provide information
- did not reply, although e-mail appeared to have been successfully sent

People contacted	Organisation	
G. Austin	British Trust for Ornithology	-
S. Baker	Rural Development Service, Defra	0
K. Ballinger	Arkion Life Scinces/Flight Control, DE	X
C. Bennett	Birscarers Anti Nuisance Group	X
T. Boudewijn	Bureau Waardenburg, the Netherlands	-
S. Boyle	Bird-X Inc., Chicago	X
J. Burton	Bird Gard ABC, New Jersey	X
P. Butt	Rural Development Service, Defra	0
D. Carss	Centre for Ecology and Hydrology	-
P. Cranswick	Wildfowl and Wetlands Trust	-
C. Dutton	Nixalite of America Inc.	0
C. Feare	WildWings Bird Management	0
R. Furness	University of Glasgow	-
D. Gibbs	Ban the Cannons, Canada	X
E. Gill	Rural Development Service, Defra	-
J. Holland	The Game Conservancy Trust	0
N. Horton	NH Bird Management	X
B. Hughes	Wildfowl and Wetlands Trust	0
I. Inglis	Central Science Laboratory	X
A. James	Bird-X Inc., Chicago	X
J. Madsen	Danmarks Miljoundersogelser	-
B. McKenzie	Keele Valley Landfill, Toronto	X
G. Merchant	The Pigeon Control Advisory Group	X
T. Morris	RSPB	-
J. Packer	ADAS	0
M. Rehfisch	British Trust for Ornithology	0
R. Robinson	British Trust for Ornithology	-
B. Rochard	Airfield Wildlife Management Limited	X
I. Russell	The Centre for Environment, Fisheries and Aquaculture	-
R. Sage	The Game Conservancy Trust	-
G. Turner	Network Pest Control Systems Limited	X
J. Vickery	British Trust for Ornithology	0
R. Watkins	Central Science Laboratory	X
T. Milsom	Central Science Laboratory	X
	ADPI Enterprises Inc, Philadelphia	-
	Agricultural Supply Inc, California	-
	Allsopp Helikites Bird Control, Hampshire	-
	BASH Inc., Colorado	-
	Becker Underwood, IA	-
	Bird.B.Gone, California	-
	Clickairport, Bournemouth	-
	Conwed Plastics, Minneapolis	-
	Cornell Laboratory of Ornithology	-
	Gas Gun Corporation, Australia	-
	Geo-Maine Inc, Florida	-
	Goosedog.com, California	-
	H.C. Shaw Co., California	-
	J.A. Cissel Manufacturing Company, New Jersey	-
	M.J. Flynn, New York	-
	Margo Supplies Ltd, Canada	-
	National Netting Inc, GA	-
	Nylon Net Co., Tennessee	-
	Pest-Away Australia	-

People contacted	Organisation	
	Phoenix Agritech, Canada	-
	Pisces Industries, California	-
	Precise Flight, OR	-
	Reed-Joseph International Company, USA	-
	Reva Plastic, New York	-
	Scarecrow Bio-Acoustic Systems, East Sussex	-
	Sinco Inc, CT	-
	Sutton Ag Enterprises Inc, California	-
	Weitech Inc, OR	-
	Wildlife Control Center, USA	-
	Wildlife Control Technology Inc, California	-
	Winfield Solutions, Canada	-

Table 2. System used to evaluate scientific bird scaring studies.

Criteria	Score	Description
Context	0	Non-UK studies on species and resources which are not common in the UK
	1	Non-UK studies on species or resources which are common in the UK
	2	Studies on species and resources relevant to the UK
Treatment	0	Treatments applied at unrealistic levels of intensity or using techniques not legal or recommended in the UK
	1	Some treatments applied at unrealistic levels or using techniques not legal or recommended in the UK
	2	All treatments applied at practical, legal and recommended levels (relevant to the UK)
Experimental Design	0	Lacks adequate control and/or sufficient replication.
	1	Has control and replication, but does not adequately address habituation, or is confounded by other factors.
	2	Has adequate control, replication and addresses confounding factors.
Cost/benefit Analysis	0	Costs and benefits not measured.
	1	Costs and/or benefits partially measured
	2	Cost/benefit analysis carried out in full.

12. Glossary

Bio-acoustics	Sounds such as alarm or distress calls that have a biological relevance to a pest bird species. The playing of such calls indicate the presence of a potential predator and can encourage other birds to leave the area.
Conspecifics	Birds of the same species.
Corvids	Collective name for members of the crow family: carrion crows, rooks, jackdaws, ravens and magpies.
Deterrent	An object or action that scares birds.
Falcons	Birds of prey with long, pointed wings that typically catch prey by diving on it from above.
Free-living	Wild or non-captive birds.
Habituation	The action of becoming accustomed to a deterrent technique due to persistent exposure, so that it no longer has a scaring affect.
Hawks	Birds of prey with short, rounded wings, that typically catch prey near to the ground after a short chase.
Monofilament line	Single strand line such as fishing line.
Pyrotechnics	Scaring techniques that use a variety of explosive devices that emit loud, banging noises and can also produce flashes of light.
Raptor	Bird of prey, including hawks and falcons.
Replicate	Repeat or exact copy of an experiment carried out in order to obtain a consistent result. Unreplicated experiments are carried out only once and are not repeated.
Ultrasonics	Sound with frequencies above 20,000 Hz, and therefore above the upper limit of human hearing.