Animal & Plant Health Agency

Annex 2: Wild Bird General Licence Review

A review of alternative non-lethal methods for mitigating damage by avian species listed under General Licences GL34-36 in England

Conducted by the National Wildlife Management Centre

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Contents

Executive Summary

- A review of published and grey literature relating to bird management was undertaken in order to evaluate the availability of non-lethal measures to mitigate the detrimental impacts of avian species listed under General Licences GL34-36.

- The current review built-on a previous extensive systematic review of avian management undertaken by the Animal and Plant Health Agency (then the Central Science laboratory) (Bishop *et al*. 2003), using the same methodology, focussing on developments during the intervening period.

- Auditory techniques in general are thought to be relatively effective, although subject to habituation and hence of short-term benefit. Artificial noises, ultrasonics and high intensity sound are either ineffective or unsafe.

- Visual techniques range from very effective to ineffective; also subject to habituation. Effectiveness depends on how real a threat they are perceived to be or how much they are perceived to interfere with movement.

- Combined audio-visual deterrents are more effective than either deployed singly. For example, life-like human effigies, alongside gas cannons and rope-bangers or pyrotechnics, reinforced with scaring by real humans has been effective in reducing crop damage.

- Effective deterrence requires a proactive approach which involves monitoring the birds' response to the ongoing deterrent strategy and modifying the approach when necessary.

- Audio-visual deterrent strategies have also been combined with diversionary feeding in a 'push-pull' strategy that deters birds from vulnerable crops onto areas of sacrificial crops.

- The use of lasers can be an effective method of bird scaring. For crop protection, automated lasers need to be sited with care to maximise the coverage of the area to be protected, taking into account field topography in order to minimise laser 'blind spots'.

- 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 one chemical is licensed for use as bird repellent in the UK.

- There is growing interest in using fertility control to manage wildlife and associated conflicts. However, in the UK, at the present time, no fertility control chemicals are licensed for use in wild birds.

- Exclusion techniques are usually extremely effective. For crop protection, 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.

- For wildlife conservation, nest-cages have been used effectively to reduce predation on ground-nesting birds. For livestock, lambing indoors or in poly-tunnels has been advocated.

- Habitat manipulation techniques are generally considered to be effective and environmentally friendly but are rarely investigated scientifically. These aim to mitigate the detrimental impacts of agricultural practices that have reduced the availability of suitable cover and food for birds, thereby helping to reduce predation and increase productivity of prey species.

- Crop practices have been advocated that reduce the attractiveness of crops, such as siting vulnerable crops away from woodland or near to human disturbance. For livestock (e.g. gamebirds) practice, stocking densities should be used that are below that which impact detrimentally on the habitat, thereby preserving important cover for wild birds.

- A recurring theme in wild bird management is an *integrated management strategy* (IMS) that combines relevant elements of these different categories of technique, ideally at a landscape-scale with cooperation between landowners. The actual nature of an IMS (i.e. techniques, intensity, timing and duration) will need to be developed to address the site-specific features and context of individual sites/areas.

- In urban environments restricting access to food and bird-proofing of buildings are the principal management tools. Improvements in urban waste management would reduce the availability of waste and discarded food, whilst addressing deliberate provisioning may be achieved through education and/or enforcement. Restricting access to food has been shown to reduce the abundance of feral pigeons.

- The development of a cost-effective bird management plan requires assessments of the economic value of the resource. This value then serves as a baseline against which the financial value realised through a reduction in damage achieved by implementing management measures can be assessed.

- A number of the techniques reviewed: audio-visual deterrents reinforced with human activity, automated lasers, exclusion, habitat modification and crop and livestock practices, can contribute to mitigating the impacts of species listed under General Licences GL34-36.

1. Introduction

There is a very extensive body of literature relating to the management and control of avian pest species, using lethal and/or non-lethal methods. Non-lethal techniques can be categorised into three different types of action:

Deterrents: prevent or reduce the utilisation of a vulnerable site or commodity by the target species, with no overt attempt to reduce the size of the overall population (other than potentially shooting a few individuals to aid scaring).

Population control: seeks to directly reduce the population (i.e. fertility control).

Manipulation measures: species are targeted indirectly through the resources they utilise (i.e. food source or habitat).

These three types of action can be further split into five categories of management techniques; *visual, auditory, chemical, exclusion, habitat manipulation and 'other' (e.g. livestock/crop management).*

The current review of nonlethal management measures (as an alternative to lethal control) builds on a previous extensive systematic review undertaken by Bishop *et al*. (2003). In their study, Bishop *et al*. (2003) reviewed published information and the grey literature relating to bird deterrents, information held by the Animal and Plant Health Agency (then the Central Science Laboratory) and consultation with individuals, manufacturers and distributors of deterrent devices; resulting in a collection of 456 documents.

Bishop *et al* (2003)

The findings of the Bishop *et al*. (2003) review are reproduced below:

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. Artificial noises (sonic devices), ultrasonics and high intensity sound are either ineffective or unsafe. 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 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).

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). These techniques can be 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 with test chemicals not registered for use in the UK.

Exclusion techniques (nets, closely spaced wires, anti-perching devices) are generally considered to be extremely effective. The degree of effectiveness depends on the extent 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.

Habitat manipulation 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. However, vegetation management appears to be extremely effective at reducing numbers of birds at airports and it seems likely that habitat manipulation will be shown to be cost-effective in other situations.

An *integrated control strategy* (i.e. using combinations of different techniques) are 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.

The ***current evaluation*** undertook a similar approach, focussing on the period 2004 to the present (2020); using the same methodology as Bishop *et al* (2003). The findings of the two reviews were then combined to provide an overview of the status of avian management techniques. The current review paid particular attention to any novel techniques that were either not available during the Bishop *et al* (2003) review, or which had undergone significant development post-2003; such as lasers and Unmanned Aerial Vehicles (UAVs) or drones.

2. Aims

To collate and review the published and unpublished information on bird management techniques post-2003, and to combine the findings with a previous systematic review (Bishop *et al*. 2003) in order to evaluate the availability and effectiveness of non-lethal methods, as alternatives to lethal control, for the management of avian species listed under General Licences GL34-36.

3. Methods

3.1 Information gathering

Information published in standard scientific journals was obtained by searching Web of Science and Google Scholar (Appendix 1: search terms). Additional literature was identified from APHA's previous research reports on wildlife conflicts involving reviews of management options for a range of native and invasive non-native avian species (INNS).

3.2 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 (Appendix 2 Table A1).

3.3 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.

3.4 Evaluation

Replicated field trials were then selected for evaluation. Unreplicated, 'pilot' trials or case studies, although they are an indication of the potential usefulness of a technique, provide only limited evidence; these were not considered further unless they involved a novel, recently improved technique, or an integrated approach (where replication is difficult). Studies based on cage or pen trials with captive birds were, generally, not considered further, 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).

The selected studies were rated in terms of context, treatment, experimental design and cost/benefit analyses; the system used is detailed in Appendix 2 Table A2; and the studies evaluated in Tables A3-A7.

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 situation in the UK compared to overseas studies on non-UK species. Studies scoring 0 may still be of relevance, 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 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, also 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.

4. Results

4.1 Auditory

Loud noises

Loud noises can be generated by gas cannons, pyrotechnics, rope-bangers, blank ammunition, or sound systems. Birds rapidly habituate to constant noise, rendering such deterrents ineffective. A number of systems randomly broadcast a variety of sounds in an attempt to minimise the effects of habituation. Whisson & Takekawa (2000) tested the Breco bird scarer – a hazing device that broadcasts a variety of high-intensity sounds at random. They found that this device was not effective for deterring waterfowl in the San Francisco Bay estuary. Soldatini *et al*. (2008) tested another hazing device – the Aviotek Bird Guard System, which generates random high-intensity sounds, at a refuse tip in Italy and found it was not effective at deterring gull species, with rapid habituation. Ronconi and Cassady (2006) tested a radar-activated system that fired propane cannons when incoming birds were detected, and found that this was more effective at deterring incoming birds than other methods, including human effigies and predator alarm calls.

Sonic systems produce a variety of electronically-produced sounds. 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). With static systems, frequent changes in location and adjustments to the sounds can reduce habituation (Harris and Davis 1998).

A combination of methods is often more effective than using one method alone. Auditory methods can be reinforced with visual methods and/or lethal control. Soldatini *et al*. (2008) tested the effects of people with pyrotechnics (which combines visual and auditory scaring) and found that it was the most effective of three tested methods at deterring gulls. Gulls did, however, become habituated, so that it was only effective for a short time. Cook *et al*. (2008) found that wailers were not an effective deterrent and that blank ammunition required the reinforcement of lethal control in order to deter gulls. Baxter and Allan (2007) also found that reinforcing the use of blank ammunition with lethal control led to greater effectiveness in deterring gulls, although it did not lead to greater effectiveness in deterring corvids.

Acoustic hailing device (AHD)

Acoustic hailing devices (AHD) are capable of emitting sound output at high enough volumes to cause physical discomfort at long distances and project this sound within a targetable narrow beam width (Schlichting *et al*. 2017). Trials of an AHD as a tool for dispersing free-ranging birds yielded variable results: partially effective in dispersing vultures and gulls; ineffective for dispersing blackbirds, diving ducks and coots (Schlichting *et al*. 2017).

Ultrasound

Jenni-Eiermann *et al*. (2014) tested an ultrasonic device (Cityguard CG2) and found that it had no effect on feral pigeons *Columba livia*. This is consistent with evidence that 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.

Distress calls

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. Delwiche *et al*. (2007) found that species-specific distress calls were effective in reducing damage caused by gulls and corvids, with savings of $12 and $25 per ha in treated areas. At three ring-billed gull *Larus delawarensis* roosts, presentation of a distress call resulted in a mean of 85% of gulls taking flight (Lecker *et al*. 2015). Cook *et al*. (2008) found that distress calls were initially effective but that birds quickly became habituated.

Predator calls

Ronconi and Cassady (2006) tested a radar-activated system that set off a mechanised peregrine effigy (visual) and played peregrine *Falco peregrinus* calls (auditory) when incoming birds were detected. They found that this was not an effective deterrent, likely because predators do not tend to call when hunting.

Sonic net

Mahjoub *et al*. (2015) tested a sonic net that broadcast a directional sound overlapping in frequency with European starling *Sturnus vulgaris* vocalisations and was contained in a specific area (creating a 'net'), hypothesising this would disrupt starling communication and deter them from using the area under the 'net'. Over three consecutive days, captive starling presence at a treated food patch was reduced by 46% compared to the same patch with no sonic net. Swaddle *et al*. (2016) tested a similar sonic net at an airfield and found it reduced the presence of a range of bird species in the treated area by 82%, with no apparent habituation during the four-week trial.

Radar-activated hazing system

Stevens *et al*. (2000) evaluated a radar-activated hazing system for the protection of waterfowl by deterring them from contaminated ponds at a power plant. The system comprised a marine radar, a sound system (generating a variety of animal distress calls), pyrotechnic launcher (using 'screamer' shells), and high-pressure aerosol sprayers (utilising methyl anthranilate). Following deployment of the system, waterfowl flights over two protected ponds and landings on the ponds were markedly lower compared to flights and landings on a control (unprotected) pond. Unlike automated timed interval deterrent systems, birds did not habituate to the demand-performance hazing system.

- Loud noises can have an immediate proximate effect in deterring birds, but this is short-lived as birds habituate. Habituation can be prolonged by varying the pattern of noise and its temporal and spatial delivery. Auditory methods can be reinforced with visual methods and/or lethal control. Auditory methods reinforced with visual methods and lethal control have been used to successfully reduce crop damage.

- Auditory systems using bioacoustics are often considered the most effective as they act on the birds' instinct to avoid danger. However reactions to distress calls can vary both with the species and the individual bird. Success requires high-quality recordings of suitable calls and specific calls changed frequently.

- More technical developments, such as a radar-activated system that detects approaching birds and fires propane cannons, and sonic nets have shown some promising results.

- Demand systems, that detect and respond in real time to bird movements, are more resistant to habituation compared to systems that utilise timed intervals (i.e. with or without the presence of birds).

4.2 Visual

Lasers

Low-powered lasers in the form of hand-held devices and automatic pattern tracking units have developed significantly over the past 20-odd years.

Hand-held laser (field)

A small-scale investigation tested whether low-powered hand-held lasers (a small 'laser-pointer' type and a larger, commercial 'bird-scaring' laser) could reduce woodpigeon *Columba palumbus* grazing on a field of winter cabbage (APHA 2018). Both lasers consistently lifted grazing woodpigeon flocks (up to 300 birds) off the field from up to a distance of 300m (small laser) to 350m (large laser). On exposure to the laser, woodpigeons typically lifted and re-landed in the field but progressively more distant to the source of the laser; after several exposures relocating to neighbouring fields or leaving the area completely.

The effect, however, was short-term with numbers of woodpigeons recorded on the field remaining largely unchanged through the five week treatment period (lasers deployed on 2-3 days per week at different times of the day, but focussing around early morning and late evening when the laser was most visible). The low-powered commercial hand-held laser costs in the order of £500; the smaller, laser-pointer cost in the order of £15.

Hand-held laser (waterbody)

In Canada, trials to deter waterbirds (ducks, geese and waders) from natural and man-made ponds, it was concluded that green lasers were more effective than violet lasers, responsiveness decreased with ambient light levels, more birds were more likely to respond in spring relative to fall, and in morning relative to evening (Cassidy 2015). The responsiveness of the birds(s) did not vary with the distance from the laser source, supporting the efficacy of lasers as bird deterrents over large spatial scales.

Laser scarecrow (field)

Laser scarecrows were effective in preventing European starlings and red-winged blackbirds *Agelaius phoeniceus* from feeding in fields of sweet corn (Brown 2017). Devices were deployed in commercial fields at multiple sites in Rhode Island and south-eastern Massachusetts, USA. Based on grower reports, they were more effective than scare guns (gas cannons) at preventing damage. The maximum bird damage reported by growers in a protected field was 5% compared to 40% to 100% in unprotected fields.

In a separate paired-plot, cross-over trial, the laser scarecrow significantly reduced bird damage - protected plots consistently had fewer damaged corn ears than the unprotected plots (Brown 2017). The birds {primarily starlings) did not appear to become habituated to the laser beam and avoided the fields even in full sunlight when the beam was not visible to human eyes.

No carry over effect was observed with birds resuming grazing in less than a day after the laser application had ceased. One constraint on laser effectiveness was the topography of the field. If the laser was blocked by a rise or shielded portion of the field, the birds would aggregate and feed in the unprotected area (also observed in APHA 2018). The relative height of crop and laser beam appeared to be important; the beam needed to clear the crop yet be low enough to be aversive to the birds.

Hand-held laser (roost dispersal - field)

A low-powered hand-held laser was effective at dispersing woodpigeons from a traditional night roost (230-300 birds) (APHA 2018). The laser was deployed from a distance of 180m around dusk on five consecutive evenings during the treatment phase. Complete dispersal was achieved by the end of five consecutive evenings of deployment of the laser; the effect of the laser appeared to increase incrementally over the five evenings. On consecutive evenings fewer birds attempted to enter the roost. It is presumed that dispersed birds relocated to a neighbouring alternative roost.

During the period of roost dispersal the numbers of woodpigeons on fields within a radius of 1km of the treatment roost, on the following day, increased by 25% - but this was a markedly lower increase than in an equivalent area around the control roost, where woodpigeon numbers increased by 87%. It is possible, therefore, that dispersal of the woodpigeons to alternative roost sites, influenced their choice of feeding site and, to a degree, supressed the build-up of birds grazing on fields in the area neighbouring the treatment roost compared to the control roost.

Due to confounding variables, however, other factors cannot be discounted. Although the area around both treatment and control roost was predominantly similar (ploughed soil), there were differences in crop cover that may have influenced relative numbers of woodpigeons in the two areas (although both areas included crops at stages known to attract woodpigeons).

The effect of the roost dispersal was short-term, however, with numbers in the roost showing full recovery over a five day post-treatment period. This highlights the need for subsequent periodic reinforcement of the deterrent through further deployment once birds start to reuse the roost (APHA 2018).

In field trials in the USA, two different low-powered lasers were consistently effective in reducing numbers of double-crested cormorants *Phalacrocorax auritus* in night roosts by at least 90% after 1-3 evenings of deployment. The cormorants, however, returned to the roost after one week (Glahn *et al*. 2001).

Tripod-mounted (roost dispersal – water body)

Successful deterrence of a roost of several thousand gulls from a large waterbody was achieved using laser deterrents (Baxter 2007). Without exception, on deployment of the laser, gulls were successfully dispersed and their overnight return was completely prevented by regular overnight deployments. Laser use did not, however, prevent birds returning on subsequent afternoons to attempt to roost. Complete deterrence of gulls from the site would require either longer term use of lasers, or deployment in conjunction with conventional techniques to disturb birds on arrival during daylight hours to prevent them landing in the first place.

Automated laser (field)

The effectiveness of an automated laser at deterring woodpigeons was tested in a cross-over experiment on two fields of autumn-sown sprouts (APHA 2018). Field 1 was treated with the laser and the second field (Field 2) left untreated (control). After four weeks the laser treatment was switched between fields and the trial run for another four weeks. Over the initial four-week period, crop damage increased, from pre-treatment, on both fields but was markedly lower on the laser-treated field (+9%) than on the control field (+89%). Switching of the laser between fields reversed these trends – crop damage decreased markedly on the now protected Field 2 (previously control) (-74%) and increased on the now unprotected Field 1 (previously laser-treated) (+33%).

The results are consistent with a deterrent effect of the automated laser. Some caution is required, however, due to confounding variables - oilseed rape and peas in fields neighbouring Field 1 may have contributed to attracting woodpigeons away from this field. As observed by Brown (2017) field topography could result in laser ‘blind-spots’ in which woodpigeons would continue to aggregate and graze; which occurred in Field 2.

In captive trials, Canada geese *Branta Ccanadensis* have also been deterred from plots by a motion-activated laser hazing system (Werner & Clark 2006).

- The use of low-powered lasers can be an effective method of bird deterrence including for the reduction of crop damage.
- As the effectiveness of the laser decreases with increasing light levels, it is likely to be most effective during low ambient light conditions; although deterrence under full sunlight has been recorded.
- Automated equipment, however, is expensive and specialised training is required, adding to the costs.
- Automated lasers need to be sited with care to maximise the coverage of the area to be protected, taking into account field topography (to minimise laser 'blind-spots') and nearby habitation.

UAVs (drones)

The designs and applications of small Unmanned Aircraft Vehicles (UAVs), or 'drones', has undergone a remarkable development; and is being applied to an increasing range of ecological tasks, including the monitoring and management of wildlife.

In a review of animals' responses to UAVs, it was found that the reaction of wildlife (birds and mammals) depended on both the attributes of the UAV (flight pattern, engine type and aircraft size) and the characteristics of the animals (type of animal, life-history stage, and level of aggregation) (Mulero-Pazmany *et al*. 2017). The strongest reactions were associated with: target-oriented flight patterns, larger UAV, and noisier engines (fuel-powered); animals during the non-breeding period and in large groups; and birds compared to other taxa. Within birds, the probability of a response tended to be higher in flightless and large flying birds than in smaller flying birds, while the intensity of the response was higher in flying-birds (large and small) than for flightless birds. The review, however, evaluated the effect of UAVs from the perspective of inadvertent anthropogenic disturbance rather than in the context of deliberate wildlife control.

In more recent trials, in Lincolnshire, England, there was no evidence that a quadcopter drone had anything other than a very short term deterrent effect on grazing woodpigeons (APHA 2018). On each occasion that the drone was flown toward a flock of grazing woodpigeons (20-160 birds) the birds flew away from the field into nearby treeline (median distance flown 300m). On all occasions (n=37 over 3 consecutive days), however the woodpigeons returned to the field within a relatively short time (median <20 minutes). The repeated disturbance of the woodpigeons did not have an overall effect on woodpigeon activity on the field. The numbers of woodpigeons and the percentage of time spent on the treatment field showed a similar pattern to that observed on a separate control field (no drone flights). The trial highlighted limitations in the practicality of using a drone as a deterrent against grazing woodpigeons. The drone was not able to be flown in strong winds and sub-zero temperatures drained the batteries preventing its use.

In Prosser, Washington, USA, a large multi-rotor UAS (Matrice M600 Pro) was flown over a 3.75 acre plot of wine grapes for approximately five hours during peak bird activity in the morning and evening, supported by a Phantom 3 Standard during the battery swapping of Matrice M600 Pro (Bhusal *et al*. 2018). Six days of UAS flights and eight days of control observation (no UAS flight) alternated in an interval of two days, for a total of a 14-day trial. The number of birds entering the field was 50% lower on days when UAVs were flown (500 birds) compared to control days (1,000 birds).

UAV systems involving bird detection sensors and UAVs armed with audio and chemical spray applications have been investigated (Ampatzidis *et al*. 2015) but are at the development stage only.

- UAVs can have an immediate proximate effect in deterring birds but this is short-lived. The larger and most capable drones are expensive and require a skilled operator.

- Due to battery drainage, flights are relatively short; requiring frequent battery changes. If constant presence of a UAV is required then the deployment of a second drone is necessary during battery change-over in the first drone.

- Severe weather (strong winds or sub-zero temperature) can significantly limit drone functionality or performance.

Scarecrows/human effigies

To maximise the effectiveness of scarecrows, 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; Shivik 2004). 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.

A successful example of the latter approach was used as part of a crane-agricultural damage management programme to successfully deter Eurasian cranes *Grus grus* (a protected species) from fields of crops in the Hula Valley, Israel (Nemtzov & Galili 2006). Life-size human effigies dressed in yellow hooded rain-suits and a facial-mask (each holding a mimic of a shotgun) were placed in a seated position (approximately one scarecrow per 5 ha) and were periodically reinforced by a human dressed identically. Any cranes entering the field would be scared off by the 'human-scarecrow' firing pyrotechnic ammunition towards them. As part of the wider crane management programme all landowners in the Hula Valley cooperated, so that whenever any farm workers were engaged in bird scaring activity (chasing or shooting pyrotechnics) they wore yellow hooded rain-suits. In addition to scaring, alternative feeding areas were established for the cranes to feed. Analysis showed that the entire crane-agriculture management program was cost-effective for the farmers, since losses due to crane damage were reduced to almost nothing.

In Lincolnshire, England, life-like mannequins (shop dummies), reinforced with a gas cannon, rope-bangers and a live marksman (dressed identically to the mannequins) reduced woodpigeon damage to fields of brassica crops; with a decrease of -30% to -38% from pre-treatment levels in damage compared to an increase of +27% to +43% on control fields (median decrease in damage of 58%) (APHA 2018).

In the APHA (2018) study, the median cost of deployment of reinforced deterrents was £30/ha over a 10-week period. The cycle from planting to harvest in the trial fields was around 11-12 weeks, so crops were protected for the majority of their growing period. Costs do not include staff-time for initial deployment of mannequins, gas cannon and rope-bangers. Average yield and farm gate price (2016) of the crops under consideration were: calabrese 9.7 tonnes per ha and £512 per tonne; cauliflower: 9.2 tonnes per ha and £579 per tonne (Defra data). Hence, a saving of 1% in loss of yield (equivalent to £50/ha and £54/ha respectively) exceeded the costs of deploying reinforced deterrents.

In a previous study (APHA 2014) involving a limited phone-based consultation exercise, growers' estimates of the economic loss associated with woodpigeon crop damage ranged from £125/ha for OSR, £250/ha for peas and £330-£1,250/ha for brassicas. These costs exceed (in the case of brassica markedly so) the costs of deploying the reinforced deterrent system described.

- Life-like mannequins/scarecrows periodically reinforced with the actions of identically dressed humans have been used successfully to deter birds and reduce crop damage, using either a non-lethal approach (firing pyrotechnics) to deter the protected Eurasian crane and lethal approach (live rounds to kill a small number of birds to reinforce scaring) to deter woodpigeons; the latter also deployed auditory reinforcement with gas cannons and rope-bangers.

Dead bird effigies

An alternative use of effigies 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).

Dead ring-billed gulls and herring gulls *Larus argentatus* were deployed as effigies at landfills, a nesting colony and a containment disposal facility (CDF) next to an airport (Seamans *et al*. 2007), with mixed results. At landfills, results varied with distance to the active dumping area and time of year – gulls were deterred for shorter periods (hours to weeks) outside of winter and when effigies were placed on the active face. Effigies were not effective in nesting colonies. At the CDF (with reinforcement from pyrotechnics and lethal control) habituation occurred after two months. It was concluded that gull effigies could reduce gull presence under some circumstances but as part of an integrated control programme, rather than a stand-alone method.

Peterson and Colwell (2014) reinforced the presentation of raven *Corvus corax* effigies with a theatrical 'death scene' and playback of recorded gunshots and distress calls to evaluate the effect on corvids (ravens and American crows *Corvus brachyrhynchos*) in feeding areas (trial plots) established on a beach (used by snowy plovers *Charadrius nivosus* for breeding). Effigies significantly reduced average corvid abundance and incidence (observations with at least one corvid present), but the effect was only significant within a 50m zone of the effigy. In all cases, however, some, albeit fewer, corvids continued to occur on plots with effigies. It was concluded that the effectiveness of the technique as a deterrent to deter corvids and protect plover nests during the breeding season is limited. In addition, as the trials were of extremely short duration of only three treatment days, the effect of habituation was unknown.

- Studies have shown the effectiveness of dead bird effigies as a deterrent to vary between avian species and setting (Bishop *et al*. 2003); as a function of the level of desirability of the location and the availability of alternative areas (Seamans *et al*. 2007).

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 and smoke. They include shell-crackers, 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. Most species of birds immediately take flight in response. Best practice is to aim the shell so as to burst a few metres from the target birds (e.g. Anon. undated). Using 12-gauge blanks in amongst the more expensive pyrotechnic cartridges can reduce the costs of this technique.

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. 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 they are useless before sunrise (Nakamura 1997), they are best combined with other methods of scaring.

A device consisting of a rotating pyramid of mirrors has been recommended for deterring birds in a number of settings including the protection of crops. There is, however, little scientific research into the effectiveness of this device (or other mirrors/reflectors). In New Zealand, such a device had minimal effect on reduction in bird (mainly starling) damage to grapes, relative to an eye-spot balloon (Fukuda *et al*. 2008).

- Although easy and inexpensive to put up and easy to relocate, the effectiveness of mirrors and reflectors as a bird scaring technique is variable. They are best combined with other methods of scaring.

Lights

Blackwell & Bernhardt (2004) used captive birds in a flight cage to evaluate avoidance behaviour in response to an approaching ground-based vehicle exhibiting pulsing 250-W white aircraft landing lights. In experiments involving brown-headed cowbirds *Molothrus ater*, Canada geese, European starlings, herring gulls, and mourning doves *Zenaida macroura*, only cowbirds exhibited a response to the landing lights, but not consistently.

- 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

High-visibility tape

Grazing by mute swans *Cygnus olor* can cause significant yield loss on individual fields of autumn-sown oilseed rape (OSR) (Parrott & Watola 2007). In field trials, mute swan usage of 12 fields of OSR was reduced by a median of 97% following the suspension of high-visibility tape in a herringbone pattern across the fields.

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).

In trials at landfill sites the number of scavenging gulls and corvids was reduced during all flights of falcons but this was not achieved during flights of hawks (Baxter & Robinson 2007). Both falcons and hawks failed to clear all birds all of the time due to the impracticality of continuously flying birds.

Steensma *et al*. (2016) compared deterrent techniques to protect against bird damage to fruit in North America and found that falconry fields showed less damage than non-falconry fields. Hawk-kites (i.e. kites designed to look like hawks) and kite falconry did not prevent damage. It was suggested that adding nest boxes and perches for predatory birds e.g. falcons may be a useful biodiversity-friendly control method. In contrast, in Southern Australia, kite-hawks were reported to be effective in reducing crop damage by little corellas *Cacatua sanguinea* (DEC 2007). The technique involved launching the kite each morning and then tethering it on 300-400m of line. The method is considered effective on paddocks up to 40ha.

- Although falconry has shown some promising results (mainly at airports) there are a number of issues that impact detrimentally on its effectiveness; the birds cannot be flown under certain weather conditions (strong winds, rain, fog) and when in moult; the birds' behaviour can sometimes be unpredictable; and the dependency on a trained falconer renders the techniques relatively expensive.

- With few exceptions, it has been necessary to deploy other scaring techniques in conjunction with falconry.

Dogs

The control of birds by trained border collies has been used at aerodromes, golf courses and agricultural land (Castelli & Sleggs 2000). The dogs represent an actual, not just 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).

In Ottawa, Canada, border collies have been used to scare Canada geese from 300ha of fields at an experimental farm used to develop new crops, including wheat, soybeans, barley, corn and other crops (http://o.canada.com/news/canadian-government-to-hire-dogs-to-scare-geese-away-from-experimental-farm/). The work involved two collies and a trained handler.

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.

An alternative method of using a dog is to allow the dog to roam freely in a pre-determined area that is delineated with an 'invisible' fence (Vercauteren *et al*. 2005). An invisible fence is an electronic system consisting of a buried wire that is energised by coded signals and an electronic shock collar. If the dog wearing the collar crosses the boundary a mild electric shock is delivered by the collar. The location of the boundary can be physically marked with flags to indicate to the dog the area in which it is free to roam. In the USA, dogs confined by an invisible electric fence successfully protected fields of fruit and vegetable from deer damage, whereas damage occurred in fields protected by traditional electric polytape fencing (Vercauteren *et al*. 2005).

4.3 Chemical

Repellents

These techniques can 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) and presentation of treated bait. Only one chemical is registered for use in the UK as a bird repellent by the Chemical Regulations Directorate. Aluminium ammonium sulphate is marketed under several product names and can be used in 'agricultural premises, on many different crops (The UK Pesticide Guide 2012).

Fungal deterrents

In, field trials, in New Zealand, a specialist *Neotyphodium* fungal endophyte, introduced to tall fescue grass reduced bird numbers at airfields (Pennell & Rolston 2013); and may have other applications. The endophyte causes post digestion feedback and acts as a secondary repellent.

Fertility control

There is growing interest in using fertility control to manage wildlife and associated conflicts (Massei & Cowan 2014). Nicarbazin is a bird-specific oral contraceptive which acts through interfering with egg production and reducing hatchability. It is registered in the USA for use with Canada geese and feral pigeons and in Italy to control urban populations of feral pigeons. The treatment is delivered to birds as a constituent of ready-to-use bait.

In captive trials, in the USA, pairs of nesting pigeons hatched 59% fewer eggs when supplied with Nicarbazin bait compared to a pre-treatment period (Avery *et al*. 2008). In a post-treatment phase, nestling production recovered to that during pre-treatment.

In Italy, the population size of colonies of feral pigeons treated with Nicarbazine decreased by a mean of 6-39% over periods of two to seven years. For the four cities in which counts were conducted at six-monthly intervals (two were counted annually) the reduction in numbers of pigeons in the first 18 months averaged 28-50%.

Elsewhere, evidence for population-level effects is equivocal; although this may be influenced by the necessity for Nicarbazin to be fed continuously before and during egg-laying to be effective (Massei & Cowan 2014).

A significant challenge in the application of fertility control is ensuring that only the target species is treated (Lambert *et al*. 2017), and in the case of Nicarbazin that delivery is persistent throughout the critical egg-production period. These criteria can be met far more easily for feral pigeons in an urban environment than in the case, for example, of woodpigeons in an agricultural setting.

- In the UK, at the present time, no fertility control chemicals are licensed for use in wild birds. Registration of Nicarbazin for use in the UK would be a lengthy and expensive process.

- In addition to an effective fertility agent is the requirement for the development of a delivery system that restricts delivery of the agent to the target species.

4.4 Exclusion

Netting

Tracey (2012) evaluated the efficacy of lethal and non-lethal methods to protect crops from bird damage in vineyards and orchards. Using data across 185 property-years, netting was found to be the most effective. However, some damage did occur under netting due to birds entering through holes or gaps in improperly installed netting or pecking of fruit through the netting.

Netting can be very effective but must deployed with due regard to animal welfare. Installers of exclusion netting must ensure the mesh size is appropriate and the netting adequately maintained to avoid entanglement of wild birds (Newcastle City Council 2018; Natural England 2019).

Wires/lines

Experiments on captive crows (large-billed crows *Corvus macrorhynchos* and carrion crows *Corvus corone*) showed that transparent nylon lines installed at 1m intervals (wingspan of crows) over the crop (sides of block were enclosed by windproof netting) was more effective than highly coloured visible wires in suppressing crow intrusions (Yoshida *et al*. 2019). The authors report the subsequent implementation of the method on two plots of pears by farmers, who reported a reduction in damage from approximately 10% in the previous year to 1% in both plots in the first year of installation.

In comparing metallic wire and matt black wire (strung at 2.5 m intervals over study plots), it was found that crows exhibited a higher risk of collision with the matt black wire (Honda 2012). Crows that collided with the wire were not injured and immediately flew away.

It was hypothesised that the lower visibility matt black wire incurs a higher risk of collision and thus has a greater deterrent effect on crows. Conversely, although not the subject of the study, Eastern turtle doves *Streptopelia orientalis* and rock doves *Columba livia* also visited the plots but fed immediately following a collision. It was hypothesised that the effectiveness of wires was dependent on the species style of flight (e.g. ability to hover) and collision risk awareness.

Cage exclosures / nest-cages

Cage exclosures were effective in protecting ground-nesting lapwing *Vanellus vanellus* and redshank *Tringa totanus* nests with protected nests having higher hatching success in both species (Isaksson *et al*. 2007). A major drawback, however, was increased predation on adult redshank: nine adults were depredated in 8 out of 37 protected nests, whereas only one adult was depredated in 31 unprotected nests. There was no adult predation at lapwing nests (n=190).

Increased predation on redshank was likely a consequence of the species' incubation behaviour, in which the brooding birds sits tight until the predator is at close distance. Isaksson *et al*. (2007) concluded that although next exclosures can be an effective technique to increase nesting success, caution needs to be exercised in their use for redshanks and other species with similar incubation behaviour.

A separate meta-analysis of 16 predator exclusion studies found predator exclusion using either exclusion fences or nest-cages resulted in a significant increase in hatching success of ground-nesting species (+92% and +98% respectively); nest cages had a greater positive effect (although the sample size was small) (Smith *et al*. 2010).

Boothby *et al*. (2019) found that adding standing canes to the area surrounding breeding Arctic terns *Sterna paradisaea* reduced predation attempts by large gulls, although it did not affect the probability of success of those attempts.

- The use of nets to cover resources and totally exclude birds is considered one of the most effective bird deterrents. The greater the degree of exclusion, however, the more expensive the technique is.

- The effectiveness of wires or lines to protect crops varies with a number of factors, including the spacing interval and visibility of the wires, and the flight style of the avian species.

- Predator exclusion using barrier fences or nest-cages have been shown to be effective in increasing the hatching success of ground-nesting birds.

4.5 Habitat manipulation

Habitat manipulation involves a wide range of activities aimed at modifying the environment to be less favourable to the pest species and/or more favourable to its predators and/or prey. The effects of habitat management and predation on nesting success interact, and understanding these interactions could facilitate habitat management interventions that have potential to reduce predation rates (Laidlaw *et al*. 2015). Scientific trials of methods such as these are rare, but they are likely to be more cost-effective than many other methods.

Vegetation

Pheasants *Phasianus colchicus* prefer shrubby areas: winter pheasant density within-site was positively influenced by the presence of a high proportion of shrubby cover (100–200 cm) (Robertson *et al*. 1993a) and breeding density within-site was related to the availability of woodland edges with high levels of shrubby cover (30–200 cm) (Robertson *et al*. 1993b).

The use of natural and artificial cover in poultry pens has been applied overseas. In the Heritage Turkey industry in the USA, the American Livestock Breeds

Conservancy advocates the provision of cover in pastures, in the form of trees or shrubs or shelters (Beranger 2007).

Nesting habitat

A long-term study at Berney Marshes, Kent (a 500 ha nature reserve) has shown that lapwing nest predation is lower when lapwing nesting densities are higher, when they nest in the centre of wet fields, and in close proximity to areas of tall vegetation that support small mammals (Laidlaw 2015). In addition, similar patterns of small mammal prey resources and small mammal abundance, and lapwing predation rates were observed between reserves and the wider countryside (Laidlaw *et al*. 2015). It was concluded that landscape management approaches used on reserves were also likely to be beneficial in the wider countryside; providing opportunities to create habitat that promotes colonisation by breeding waders and reduced levels of nest predation.

Woodpigeon nesting density varies between different habitats. Murton (1960) found that hedgerow supported the highest number of nests per acre and deciduous woodland the lowest. Inglis *et al*. (1994) investigated the breeding density of woodpigeons in hedges and woods of different size, shape and composition in order to provide advice on the type of woodland least favourable for nesting woodpigeons. Hedgerows (containing trees) had a significantly higher nest density than woods; small woods (<5ha) had higher nest densities than medium woods (5-10ha) which in turn had higher densities than large wood (>10ha); nest density increased with increase in the proportion of edge habitat of the wood.

In order to limit the growth in local woodpigeon numbers it was concluded that wherever possible to plant a single large woodland rather than many dispersed small woodland blocks. Extending existing woodland rather than creating new copses and shelterbelts would be the preferred option. The authors did stress, however, that whilst these actions would benefit limiting the local woodpigeon population, networks of woodlands linked by hedgerows represented important ecological networks beneficial to biodiversity.

Predator perches

Simple measures such as the addition of perches or nest sites for predatory birds may reduce the amount of damage caused by pest bird species. Peisley *et al*. (2017) found that adding artificial perches to vineyards in Australia reduced damage to grapevines from frugivorous birds around perches by more than 50%, by providing places for the more aggressive Australian magpie *Cracticus tibicen*. Kross *et al*. (2012) found that the introduction of New Zealand falcons *Falco novaeseelandiae* to vineyards in New Zealand led to a 95% reduction in the number of grapes removed by pest bird species compared to vineyards without falcons, and a 55% reduction in the number of grapes pecked.

Anti-perching devices

Seamans *et al*. (2007) tested anti-perching devices on captive birds and found that both anti-perching wire installed 5cm above a perch and BirdBlox (plastic anti-perching devices) were effective at deterring some bird species from perching. Haag-Wackernagel and Geigenfeind (2008) researched the structural properties of perches and openings that would be impossible for feral pigeons to use and found that restricting openings and ledges to a maximum width of 4cm would effectively prevent feral pigeons from using them. In addition, ensuring an incline of at least 25° for smooth materials, 35° for medium rough materials such as wood, and 50° for rough materials such as concrete, would prevent feral pigeons from perching. This information could be incorporated into the architecture of new buildings or could be used to modify existing structures.

Bird Free® Optical Gel is a product that is marketed as an anti-perching treatment. The gel is deployed in shallow saucers arranged in a sequence along a preferred perching substrate (e.g. ledge). Deterrence is claimed to be achieved through utilising the bird's visual spectrum (that includes ultraviolet) with the product giving the appearance of fire to the birds (so acting as a visual deterrent rather than a tactile one; although the concept of pigeons perceiving the gel as fire is unlikely – Stock and Wackernagel 2014). Anecdotal evidence suggest it is effective at discouraging pigeons from perching but this is in urbanised areas where there are many other options for perching.

A recent study, observed that a contact gel (67% less time on surface) and an optical gel (92% reduction in landings per day) both individually reduced feral pigeon usage of treated surfaces but failed to prove the claimed complete effectiveness (i.e. 100% reduction in usage) (Stock and Haag-Wackernagel 2014). The authors expressed concerns in respect to animal welfare and the potential for the extremely adhesive gel to glue birds' feathers together. Bird Free gel was also tested on feral pigeons by Gagliardo *et al*. (2020), who found that it completely abolished the presence of feral pigeons at a night roost, and significantly reduced their presence at day roosts for at least a year. In addition, it dissuaded pigeons from building nests at potential nest sites for at least three months.

Diversionary feeding

Planting sacrificial or decoy crops is a technique used to divert feeding flocks away from a susceptible crop. Decoy crops should be made available prior to the problem birds first arriving, as it is more difficult to shift birds to the sacrificial crops if they develop a pattern of feeding on the susceptible crops.

A review of diversionary feeding studies (targeted at birds and mammals) found that success varied greatly and further, more detailed, research is required (Kubasiewicz *et al*. 2015). The review revealed that studies frequently failed to report sufficient relevant information to permit an evaluation of effectiveness. Although diversionary feeding is considered an expensive option for management, detailed cost-effectiveness analyses are rarely conducted (Kubasiewicz *et al*. 2015).

Diversionary feeding of Eurasian kestrels *Falco tinnunculus* reduced predation rates by 47% and doubled productivity at a little tern *Sternula albifrons* colony in years when kestrels were fed compared to unfed years (Smart & Amar 2018).

Strips of kale are sometimes planted along the edges of fields for use by game birds; these also form valuable decoy crops for woodpigeons (Inglis & Haynes unpublished data). A sacrificial crop can be created along the edges of oilseed rape fields by sowing the rape at a lower density in these areas; woodpigeons prefer to forage in the less dense areas of the crop (Inglis & Isaacson unpublished data).

Decoy feeding programmes have to be carried out at sufficient intensity. In Australia, a preliminary trial involving the provisioning of 20 tonnes of oats to 4,000 long-billed corellas *Cacatua tenuirostris* was cost-effective in protecting commercial crops. In the following year, however, when local farmers took over control of the decoy feeding programme it failed. This was due to the farmers not being consistent or persistent enough with the provisioning regime to keep birds at the feeding site and away from the commercial crops (Alexander 1990, cited in Bomford & Sinclair 2002).

For large grazing birds factors such as food availability and quality, distance to roost site, crop type, field size, interspecific competition and disturbance risk generally influence field and thus damage risk across the agricultural landscape (Nilsson 2017). These factors can thereby potentially also inform managers where and when to allocate and priorities crop damage preventive measures. Based on these findings, Nilsson (2017) recommended a ‘push and pull’ strategy where undisturbed diversionary fields with high food availability in the vicinity of the roost sites can function as a ‘pull’ component to attract birds, in combination with scaring and occasionally hunting as a ‘push’ component to steer birds from damage-prone crops.

For woodpigeons, potential sacrificial crops largely fall into two groups – unharvested (poor quality, lack of a market) susceptible crops and alternative non-crop plants attractive to woodpigeons (e.g. clover) and grown specifically for them. Currently, in brassica growing areas there is little in the way of alternative, non-commercial crops and growers are considered unlikely to entertain growing a crop simply to feed woodpigeons. Unharvested, partially harvested (and abandoned) and harvested cuttings already serve as decoy crops for woodpigeons; and such fields often host significant numbers of feeding woodpigeons. The longer these fields are available the longer they decoy crops away from other vulnerable fields.

There is, however, a potential danger in providing supplementary food, which is that in the long-term it may lead to an increase in species-density, if the availability of food resources is limiting numbers. Supplementary food may also increase the survival rates of young birds and exacerbate the long-term problem.

Livestock practices

Livestock practices could be altered to reduce the exposure of vulnerable animals in certain areas or during critical periods (Shivik 2004, 2006). Close shepherding during the lambing period and/or the relocation of stock have been advocated. Moberly *et al*. (2003) identified indoor lambing as an important preventive measure against fox predation in Britain. It was recognised, however, that housing was costly and impractical for some sheep-management systems. In circumstances where indoor housing has been unavailable, lambing has taken place in temporary structures, such as poly-tunnels; one technique advocated to protect lambs from white-tailed eagles *Haliaetus albicilla* in Scotland (SNH 2004, 2006). It has been recognised that small improvements in sheep flock management may be far more beneficial to productivity than large-scale attempts to control predators (Davies 1999). The simplest and most effective method has been to place a shepherd with the flock during the lambing period. Extra shepherding would only be required for the eight week period over which lambing takes place, but would require skilled shepherds.

Corvids and gulls visit livestock premises principally for the readily available food resources. Reducing the availability of livestock food to birds will reduce the number of birds visiting the premises. Reduced availability may be achieved by selecting the most appropriate food type and delivery system to minimise spillage and wastage.

In respect to gamebirds, within pheasant release pens adequate cover of both herb and shrub layers was associated with lower predation rates, Lloyd (1976) considered the herb layer to be the most important. Adequate suitable cover within pens is essential to allow poults to develop their natural anti-predator behaviour and also provides protection by screening and/or physically protecting the birds. It has not been uncommon, however, for release pens to be stocked above recommended levels (Lloyd 1976; Allen *et al*. 2000; Sage *et al*. 2005) with detrimental consequences for the retention of sufficient vegetation.

It is recognised that the release of large numbers of pheasants into a pen over a long period can lead to changes in the ground flora, both in and around the pen. Outside of release pens, high pheasant densities may lead to altered habitats (Sage *et al*. 2005, 2009), declines of invertebrate abundance (Pressland 2009), spread of disease (Tompkins *et al*. 2001) and changes to farmland food webs (Bicknell *et al*. 2010). Over the period 1960–2014, there was a maintained increase in the density of pheasants released (Robertson *et al*. 2017).

Crop management

A programme to mitigate conflict between cranes and agriculture comprised a number of elements, including altering the timing of planting, pattern of harvesting and crop location to best avoid damage by cranes (Austin & Sundar 2018). In addition, crops would be rotated with alternative crops not attractive to cranes; and diversionary feeding fields placed near roost sites.

In a review of the limitations of population suppression of pest birds for protecting crops, Linz *et al* (2015) concluded that crop losses can potentially be mitigated through changes in agronomic practices, such as altering planting and harvesting schedules.

Restrict access to food

Reducing the availability of food for pest species is a management method that is especially likely to work in urban areas where direct or indirect feeding by people constitutes a major food resource for the target species.

Preventing or restricting access by pest birds (e.g. pigeons and gulls) to urban waste would both remove a source of food and reduce interactions between pest birds and the public. Improvements in urban waste management would involve reducing the availability of waste and discarded food, more secure storage of food waste in receptacles (bins and bags) and a more efficient waste collection schedule. To this end, a number of councils around the UK have undertaken trials of gull-proof bins and hessian gull-proof waste bags. The outcomes of these various trials are not known. Some types of existing ‘hooded’ refuse bin are not effective, with birds able to perch on top and extract rubbish through the open gaps once the bins are full. Bird-proof bins counteract this with the incorporation a hatch opening that completely seals of the bins’ contents from the outside.

Addressing the feeding of pest birds through accidental spillage of food and by deliberate provisioning may be achieved through education and enforcement.

Senar *et al*. (2016) were able to reduce the food available to feral pigeons in experimental areas in Barcelona through public education and found that the density of feral pigeons was reduced by 40% in those areas in just four months.

Bird proofing premises

Wire mesh can be used to block access to chimneys or any gaps in the building's structure. *Bristle strips* can be applied to the tops of doors to prevent access through any gap. *Heavy-duty polyvinyl chloride strips* may be suspended over entrances to restrict bird access through large doorways. *Netting systems* can be used to block off loafing and roosting sites and can also be used to enclose vulnerable areas entirely. Newcastle City Council (2018) guidance on netting for buildings states that netting must be installed on buildings outside the breeding season and must be properly installed and adequately maintained to avoid entanglement of birds.

4.6 Shooting to scare

Taking woodpigeons as an example, there are two aspects involved in shooting in respect to attempts to reduce crop damage. First is the action of shooting as a scaring technique to deter woodpigeons from fields of crops. Second, is the reduction in the numbers of woodpigeons available to graze those crops. Entwined in this is a potential 'conflict' between growers and shooters in regard to their respective functional and sporting interests. Shooters, for example, may prefer (or be constrained) to limit shooting to weekends and/or at times and locations most favourable to their convenience. Whereas, in order to maximise crop protection an alternative shooting strategy might be more appropriate.

The most common strategy with which shooting is undertaken (i.e. with concealed gunmen) is consistent with attempting to maximise the number of woodpigeons killed, rather than maximising the deterrent effect of shooting. This 'conflict' between the scaring effects of shooting and successfully killing woodpigeons is exemplified in Harradine and Reynolds (1997). The authors state '…*the low numbers shot in January to March reflect that during the winter woodpigeons form large flocks, particularly over oilseed rape crops, and, consequently are difficult to decoy. Furthermore, a large flock at this time is easily disturbed and scared away, with only limited opportunities for birds to be shot and is not rapidly replaced by another flock, since such flocks are relatively widely dispersed*…'.

To a large extent the crop protection value of shooting depends on it acting as a scaring mechanism (Murton *et al*. 1974). In examining the economics of woodpigeon damage to brassicae, Murton and Jones (1973) noted that although a gunman roving around fields was the least effective method of killing woodpigeons it was the most effective way of keeping birds off the crops.

- A variety of habitat manipulation methods have shown positive results in terms of rendering sensitive areas less attractive to avian pests (predator perches, crop management), reducing the availability of resources to pests (crop management, nest cages, bird-proofing, restricting access to food), attracting pests away from sensitive areas (diversionary feeding), and enhancing environmental requirements for prey species (appropriate vegetation and grassland wetness).

4.7 Integrated Measure

An integrated management strategy (IMS) involves the simultaneous and/or sequential use of a variety of different deterrent techniques (visual and auditory). The replacement of one deterrent device with another or the deployment of an additional device to supplement a first will prolong the habituation process. The presentation of multi-modal repellents is considered to be more effective through simultaneously working on different sensory systems (Lecker *et al*, 2015).

In south-western Australia, recommendations for controlling damage by Carnaby's cockatoo *Calyptorhynchus latirostris* and Baudin's cockatoo *Calyptorhynchus baudinii*, are to deploy gas guns in combination with motorcycle harassment and/or shooting to scare (using pyrotechnic shells), and to vary the combinations of treatments (DBCA 2017). It should be borne in mind that although combining treatments is more effective it will also be more costly (Tracey *et al*. 2007). It was recommended that deterrence should be initiated as soon as birds first begin foraging on a crop and not to allow the establishment of a foraging habit, otherwise birds will be more resistant to being deterred.

In England, audio-visual deterrents (life-like mannequins, gas cannon, rope bangers) reinforced with live shooting (shooters dressed identically to the mannequins) was effective at reducing woodpigeon grazing and crop damage on fields of brassica (broccoli and cauliflower) (APHA 2018). Treatment fields were consistently exposed to lower woodpigeon activity and experienced lower levels of grazing damage. At harvest, low levels of grazing damage were associated with larger crop head sizes and a higher percentage (+27%) of plants being harvested at first cut compared to high damage areas.

In addition to scaring devices, different categories of mitigation measure are also frequently applied in conjunction with deterrents. For example, the deployment of visual and auditory deterrents at the site of the vulnerable crop may be augmented by the provision of a sacrificial feeding area at a distance from the site – a 'push pull' strategy (Nilsson 2017). Scaring birds from a crop will be more effective if there are alternative foraging opportunities available.

Integrated management programmes have successfully mitigated the conflict between cranes and farmers in a number of countries, through the combination of scaring techniques, diversionary feeding and altering crop practices (Austin & Sundar 2018; Nemtzov & Gallili 2006).

5. Evaluation of studies

A total of 86 studies were reviewed (Table A2). Of these, 57 were selected for more detailed evaluation with respect to the context of the studies and the effectiveness of the techniques investigated (Tables A3-A7). These studies involved a total of 82 evaluations of techniques (some studies investigated a number of different devices/techniques).

A broad comparison of the relative effectiveness of the different categories of management measure (auditory, visual, chemical, exclusion, habitat management) indicated that chemical, exclusion and habitat modification tended to be more effective than auditory and visual deterrents used alone (Table 1).

For chemical, exclusion and habitat manipulation, 40-60% of evaluations were scored as very effective; whilst for both auditory and visual only 25% and 23% of evaluations were scored as very effective respectively. When auditory and visual deterrents were combined, however, 46% of evaluations were scored as very effective. Sample sizes, however, are relatively small for a number of categories.

Table 1. Relative distribution of scores for effectiveness for the different categories of avian management measure (auditory, visual, chemical, exclusion, habitat management). Scores from Tables A3-A7 involving 82 evaluations from 57 studies.

		Effectiveness		
Category	n	0	1	2
Auditory	16	5	7	4
Visual	35	12	15	8
Auditory-Visual	11	2	4	5
Chemical	5	1	2	2
Exclusion	5	1	1	3
Habitat manipulation	10	0	4	6

Effectiveness score: 2 = very effective (>50% reduction in damage or number of birds), 1 = partially effective (up to 50% reduction), 0 = ineffective (no significant reduction)

Chemical methods almost exclusively related to fertility control studies outside of the UK. These studies are not transferable to the UK, as at the present time, no fertility control chemicals are licensed for use in wild birds. Studies on exclusion methods (e.g. crop protection with netting and lines; protection of ground-nesting birds with nest-cages) were exclusively from overseas but as they involved shared species and circumstances are also applicable to the UK. Habitat manipulation studies were largely from overseas but did include a number of UK studies. All of the habitat manipulation studies (e.g. manipulation of food availability, vegetation management) were scored as at least partially effective. For auditory and visual deterrents (various devices used independently or more effectively when combined), although again most studies occurred overseas these categories included the largest UK component of any category. Overseas studies mostly involved species or groups of birds and circumstances shared with the UK. In all categories, relatively few studies undertook a cost-benefit analysis.

Bishop *et al*. (2003) also found that exclusion and habitat modification were relatively the most effective categories; again, however, with very small sample sizes for these categories. The disparity in sample sizes of studies between the categories, in both reviews, is a reflection of the relative practicalities of implementing, monitoring and evaluating their effects. In terms of application, however, exclusion and habitat modification measures will require significantly less day-to-day maintenance and will not suffer from the limitations of habituation inherent in more easily applied auditory and visual deterrents.

6. Discussion

Considering the previous Bishop *et al*. (2003) and current reviews there is evidence for a number of non-lethal methods to contribute to the mitigation of impacts imposed by avian species listed under General Licences GL34-36. To be most effective these techniques need to be deployed as part of an overall pest management programme, ideally at the landscape-level involving cooperation and coordination between neighbouring landowners.

Audio-visual deterrents

Traditional visual and auditory scaring techniques have been frequently deployed against pest birds; with varying degrees of deterrence and duration of their effectiveness being reported. Virtually all visual and auditory deterrents, used on their own, will gradually become less effective due to habituation. Most animals will exhibit fear or wariness towards any novel object placed in their environment and will avoid it. Dispersal can also be induced through a startle reflex as a result of the sudden presentation of visual or auditory stimuli. However, animals come to realise that the deterrent does not actually present a real threat and gradually ignore the stimulus (a process called habituation). Thus, for all visual and auditory deterrents any initial effectiveness will inevitably decline.

To maximise effectiveness, through prolonging the process of habituation, deterrents should:

(i) be as realistic as possible,
(ii) be temporally and spatially unpredictable,
(iii) present as real a threat as possible,
(iv) be presented as infrequently as possible whilst having an effect, and
(v) be reinforced or replaced with alternative type/s of devices.

To achieve this, effigies and scarecrows, for example, should be as physically lifelike as possible, moved frequently between different locations and reinforced with other stimuli; ideally by real humans dressed identically. Essentially, the more biologically meaningful a deterrent is the greater the period of habituation. For some circumstances, deterrents may only need to resist habituation for a relatively short, but critical period, such as during the lambing period. Another important factor in maximising effectiveness is to instigate deterrent measures as soon as the species of concern commences utilising a site, i.e. before a pattern of attendance is established. Once a pattern is established, the birds will be more difficult to deter.

Combinations of audio-visual deterrents are more effective than either used singly and have been successfully deployed to mitigate crop damage (e.g. Nemtzov & Galili 2006; APHA 2018). The use of lasers has been shown to be an effective method of bird scaring (e.g. Brown 2017; APHA 2018). Automated equipment, however, is expensive and specialised training is required, adding to the costs. Automated lasers need to be sited with care to maximise the coverage of the area to be protected, taking into account field topography, to avoid laser 'blind-spots' and any nearby habitation.

Exclusion techniques

Nets, covers, closely spaced wires are generally considered to be very effective. Effectiveness depends on the degree to which birds are excluded (e.g. closer spacing between wires); the closer that wires are installed the more they approximate to a net. Properly installed and maintained netting will provide complete protection for a crop and is often recommended as the only technique that is consistently effective in preventing bird damage. The greater the degree of exclusion, however, the more expensive the technique is. For this reason, netting tends to be restricted to high value crops.

APHA (2014) conducted a limited telephone consultation with growers that revealed that some individuals either prolonged the time over which coverings (e.g. fleece) were deployed in order to extend the period of protection from woodpigeons, or initiated the use of fleece where previously it had not been used. One potential area of crop protection that may have potential for development is the more extensive use of coverings, such as fleece and netting. Elsewhere, however, there were concerns amongst growers with the use of nets and other coverings as the micro-habitat beneath the cover can result in reductions in some aspects of produce quality (e.g. firmness and shelf-life) and the facilitation of disease.

For vulnerable avian prey species, nest-cage exclosures have been shown to reduce predation and increase productivity. Careful consideration has to be given, however, to the nesting behaviour of individual species, to ensure appropriate use.

Habitat manipulation

A major conservation concern in Britain is the widespread decline of populations of farmland birds (Newton 2004). The main drivers of population declines identified by Newton (2004) have been changes in agricultural practices: (i) the use of herbicides for controlling weeds, (ii) earlier ploughing of stubbles through a change from spring-sown to autumn-sown crops, (iii) land drainage and intensification of grassland management, and (iv) increase in stocking densities of livestock. Further changes have involved the removal of hedgerows and 'rough patches'.

Together these changes have reduced the availability of food and suitable cover for nesting and refuge from predators. Habitat manipulation to mitigate or reverse the effects of the detrimental impacts from agricultural practices, such as enhancing preferred nesting, feeding and refuge habitat, will be beneficial to numerous species of farmland birds.

For crop protection, habitat manipulation methods have shown positive results in terms of rendering sensitive areas less attractive to avian pests (crop management) and attracting pests away from sensitive areas (diversionary feeding).

In urban environments the two main bird management techniques are restricting access to food and bird-proofing of buildings to prevent access for loafing and nesting. Improvements in urban waste management would reduce the availability of waste and discarded food, whilst addressing deliberate provisioning may be achieved through education and/or enforcement.

Overall, there is a range of habitat manipulation measures. These vary in their applicability to different habitats, and in their implementation period and effectiveness. In some circumstances, measures such as regenerating or enhancing suitable nesting habitat, or refuge cover, or other preferred environmental features for prey species may take a period of time to achieve optimum effectiveness.

Shooting to scare

In respect to shooting, it is important to judge the effectiveness of pest control in terms of damage prevented and not the numbers of animals killed (Linz *et al*. 2015). For lethal techniques in general, an important but often over-looked aspect is the requirement to monitor changes in the extent of crop damage. A lethal control programme must have some defined measurable objective and the level that over abundant species must be reduced to (to get the desired response of the resource, e.g. reduced crop damage) must be known. If such information is not available there is a risk that lethal control focuses on killing individuals and not on the benefits or outcomes. Murton and Jones (1973) noted that a gunman roving around fields was the most effective way of keeping woodpigeons off the crops, although the least effective method of killing birds. Tracey (2012) concluded that, in vineyards and orchards, shooting as a method to scare birds from the crop, rather than to control populations, was effective in reducing damage.

Integrated management strategy

A recurring theme in the mitigation of the detrimental impacts of avian pests is the necessity for an integrated management strategy. When aiming to deter birds such an approach involves combining and interchanging a suite of different scaring techniques (including shooting to scare or kill) deployed unpredictably both spatially and temporally. Deterrence requires a proactive approach which involves monitoring the bids response to the current deterrent strategy and modifying the approach when appropriate.

In addition, habitat-based techniques should be utilised, where possible, such as diversionary (sacrificial) feeding areas and siting crops with respect to local topography (e.g. away from woods, close to human disturbance). Exclusion methods such as poly-tunnels (lambing) and netting (crops) should also be applied when appropriate. Although the adoption of an integrated strategy is accepted as best practice, the actual nature of any management programme (i.e. techniques, intensity, timing and duration) will need to be developed to address the site-specific features and context of individual sites.

Using an integrated management strategy on a landscape-scale, involving the cooperation and coordination of neighbouring farmers/landowners, has been effective in reducing crop damage and conflict between farmers and cranes (Austin & Sundar 2018; Nemtzov & Galili 2006).

The development of a cost-effective bird management plan requires assessments of the economic value of the resource. This value then serves as a baseline against which the financial value realised through a reduction in damage achieved by implementing management measures can be assessed.

Different types of economic analysis are available to assist in the formulation of pest management strategies (Tracey *et al*. 2007). Descriptive models help develop an understanding of economic relationships, e.g. marginal analysis which investigates the level of bird control or bird density that has the maximum economic benefit.

Descriptive models require accurate data on numerous factors, including the relationship between bird density and the level of damage imposed and the benefits of applying different levels of control. Much of this information is lacking in respect to pest birds and crop damage in general. In comparison, prescriptive models utilise value judgements and compare different management strategies using specific, subjective criteria.

Application of non-lethal management measures

This review has identified a number of non-lethal techniques that could be implemented as part of an overall integrated management strategy to mitigate the detrimental impacts of birds listed under General Licences GL34-36. The applications described in the preceding review are summarised against each licence and licensed sub-purpose (Table 1).

Table 1: Summary of non-lethal methods with potential to mitigate impacts of avian species listed under General Licences GL34-36

Purpose	Sub-purpose	Method	Technique	Main GL target species
Conservation	Wild birds	Exclusion; habitat manipulation; livestock practices	nest-cages; preserve and enhance suitable vegetation and environmental features for prey species; appropriate densities of livestock	corvids
	Fauna	n/a	n/a	n/a
	Flora	n/a	n/a	n/a
Public Health & Safety	Health - Spread of human disease	Habitat manipulation	restricting food availability in public places; bird-proofing of buildings	feral pigeons, Canada geese
	Safety - Slips, Trips & Falls	Habitat manipulation	restricting food availability in public places; bird-proofing of buildings	feral pigeons, Canada geese
	Safety - Nesting	Habitat manipulation	bird-proofing of buildings and structures	feral pigeons
	Safety - Other	Habitat manipulation	restricting food availability in public places; bird-proofing of buildings	feral pigeons, Canada geese
Serious Damage	Livestock - Spread of animal disease	Habitat manipulation	proofing of buildings; livestock food storage and delivery	all species
	Livestock - Predation/damage	Livestock practices	lambing indoors; shepherding	crow
	Foodstuffs for livestock	Habitat manipulation	proofing of buildings; livestock food storage and delivery	feral pigeon, woodpigeon, corvids

Purpose	Sub-purpose	Method	Technique	Main GL target species
Serious Damage	Crops	Deterrents, exclusion, habitat manipulation	audio-visual deterrents (reinforced), lasers, diversionary feeding, netting, covers, crop practices	woodpigeon, feral pigeons, rooks, parakeets, Canada geese, Egyptian geese
	Fruit	Deterrents, exclusion, habitat manipulation	audio-visual deterrents (reinforced), lasers, diversionary feeding, netting, covers, falconry	woodpigeon, feral pigeons, parakeets
	Growing timber	n/a	n/a	n/a
	Inland waters	Exclusion	barriers across sensitive areas	n/a

General references

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Appendix 1: Search terms

Laser

Web of Science

1. Laser + bird + deterrent* OR repell* OR scare* OR dispers*

Google scholar

1. bird repellent laser
2. pest bird laser
3. bird deterrent laser

Drone (UAV)

Web of science:

1. drone or UAV; bird; repel* OR deterr* OR scare OR pest OR harrass*

Google scholar:

2. bird repellent drone
3. bird repellent UAV
4. pest bird UAV
5. bird, UAV, repel* OR deterr* OR scare OR pest OR harrass*
6. bird UAV repel* OR deterr*
7. bird drone repel* OR deterr*

General

Google scholar:

1. biological control birds
2. diversionary feeding birds
3. exclusion birds
4. deterrent birds
5. non-lethal birds

Appendix 2: Tables

Table A1. Bird deterrent documents reviewed in this report

Comments in the 'EFFECTIVE?' column are a subjective decision based on the information available in the document.

√ = STUDIES SELECTED FOR FURTHER EVALUATION

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
1. Ahmed S, Khan H, Javed M, Rehman K (2012). Management of maize and sunflower against the depredations of rose-ringed parakeet (*Psittacula krameri*) using mechanical repellents in an agro-ecosystem. Int. J. Agric. & Biol. 14: 286-290.	Auditory, Visual, Pyrotechnics	Reflecting ribbons, multi-mirror reflectors, distress sound players, exploders (acetylene and gas), bird scaring models	Pakistan	Maize and sunflower fields	Ring-ringed parakeet	Yes (ribbons)	
2. Akram N, Khan HA, Muhammad MJ (2013). Inhibiting the House (*Corvus splendens*) damage on maize growth stages with reflecting ribbons in a farmland. Journal of Animal and Plant Sciences 23(1): 182-189.	Visual	Reflecting ribbons	Pakistan	Maize fields	Indian house crow	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
3. Ampatzidis Y, Ward J, Samara O (2015). Autonomous system for pest bird control in specialty crops using unmanned aerial vehicles. ASABE Annual International Meeting.	Visual	Autonomous UAV-based bird control system (UAV bears visual, audio and chemical deterrence)	USA	Field	Various	Prototy pe system	
4. APHA (2018). Brassicas, leafy salads, oilseed rape and legumes: Developing and evaluating management strategies to mitigate woodpigeon *Columba palumbus* damage to crops. APHA report to AHDB (Project FV426A).	Visual	Hand-held lasers	GB	Field	Woodpigeon	No	
	Visual	Hand-held lasers	GB	Roost	Woodpigeon	Partial	✓
	Visual	Automated laser	GB	Field	Woodpigeon	Yes	✓
	Visual	UAV (drone)	GB	Field	Woodpigeon	No	
	Visual and Auditory	Life-like mannequins, rope-bangers, gas cannons – reinforced with live shooting	GB	Field	Woodpigeon	Yes	✓
5. Austin J, Sundar K (2018). Methods to Reduce Conflicts between Cranes and Farmers. Chapter 6 In: Austin J, Morrison K & Harris J (Eds) (2018) Cranes and Agriculture: a Global Guide for Sharing the Landscape. International Crane Foundation.	Integrated management	Visual and auditory scarers (inc lasers), crop regimes, seed treatment, diversionary feeding, exclusion, habitat restoration, compensation	Global	Field	Crane spp.	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
6. Avery M, Keacher KL, Tillman EA (2008). Nicarbazin bait reduces reproduction by pigeons (*Columba livia*). Wildlife Research 35: 80-85.	Chemical	Reproductive inhibitor: Nicarbazin	USA	Aviary	Feral pigeon	Yes	✓
7. Avery ML, Yoder CA, Tilman EA (2008). Diazacon inhibits reproduction in invasive monk parakeet population. Journal Wildlife Management. Journal of Wildlife Management 72(6): 1449-1452.	Chemical	Reproductive inhibitor: Diazacon	USA	Field	Monk parakeet	Yes	✓
8. Baxter A (2007) Laser dispersal of gulls from reservoirs near airports 2007 Bird Strike Committee USA/Canada, 9th Annual Meeting, Kingston, Ontario. https://digitalcommons.unl.edu/birdstrike2007/2	Visual	Laser mounted on tripod	UK	Larger reservoir	Gull spp. (black-headed gull, common gull, lesser black-backed gull, herring gull, and great black-backed gull)	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
9. Baxter AB, Allan JR (2007). Use of lethal control to reduce habituation to blank rounds by scavenging birds. Journal Wildlife Management 72(7): 1653-1657	Auditory reinforced with live ammunition	Starter pistol firing blank and live rounds	GB	Landfill	Gull spp. Corvid spp.	Yes (gull spp.) No (corvid spp.)	✓
10. Beranger J (2007). Protecting heritage turkeys from predators. https://www.livestockconservancy.org/images/uploads/docs/ALBCturkey-8.pdf	Habitat manipulation	Natural and artificial cover	USA	Enclosures	Raptor spp.	Yes	
11. Bhusal S, Khanal K, Karkee, M, Steensma KMM, Taylor ME (2018). Unmanned aerial systems (UAS) for mitigating bird damage in wine grapes in: Proceedings of the 14th International Conference on Precision Agriculture. Monticello, IL: International Society of Precision Agriculture.	Visual	UAV (drone)	USA	Vineyard	not specified	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
12. Blackwell BF, Bernhardt GE (2004). Efficacy of aircraft landing lights in stimulating avoidance behaviour in birds. Journal of Wildlife Management 68: 725–732.	Visual	Pulsing aircraft landing lights	USA	Fenced holding area	Canada goose, brown-headed cowbird, European starling, herring gull, mourning dove	No	✓
13. Blackwell BF, Bernhardt GE, Cepek JD, Dolbeer RA (2002). Lasers as non-lethal avian repellents: potential applications in the airport environment. USDA National Wildlife Research Center – Staff Publications. Paper 147.	Visual - review	Lasers	USA	Cage, Field	Various	Partial	
14. Boothby C, Redfern C, Schroeder J (2019). An evaluation of canes as a management technique to reduce predation by gulls of ground-nesting seabirds. Ibis 161(2): 453-458.	Habitat Modification	Bamboo canes	UK	Field - Arctic tern colony	Gull spp. (herring gull, lesser black-backed gull, great black-backed gull)	Partial	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
15. Brown R (2017) Laser Scarecrows: Gimmick or Solution? *University of Rhode Island Vegetable Production Research Reports.* Paper 25.	Visual	Rotating laser on scarecrow	USA	Field - sweet corn	European starling, red-winged blackbird	Yes	✓
16. Buckley P, McCarthy G (1994) Insects, vegetation, and the control of laughing gulls (*Larus atricilla*) at Kennedy International Airport, New York city.	Habitat modification	Long grass	USA	Airport	Laughing gull	Yes	✓
17. Carter NB (Undated) *The use of border collies in avian and wildlife control programs*	Visual	Border collies	USA Israel	Field		Yes	
18. Cassidy FL (2015) The Potential of Lasers as Deterrents to Protect Birds in the Alberta Oil Sands and Other Areas of Human-Bird Conflict. Chapter 2: Response of water-associated birds to lasers varies among seasons, times of day, laser colours and ambient light.	Visual	Handheld laser	Canada	Water bodies	Waterbirds (over 20 species, including Canada goose)	Varied	✓
19. Castelli PM., Sleggs SE (2000) Efficacy of border collies to control nuisance Canada geese. Wildlife Society Bulletin 28(2): 385-392	Visual	Border collies	USA	Field	Canada goose	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
20. Cook A, Rushton S, Allan J, Baxter A (2008). An evaluation of techniques to control problem bird species on landfill sites. Environmental Management 41: 834-843.	Visual and Auditory	Bird-scaring kites, Pyrotechnics, Distress calls, Static distress calls, Wailers, Falcons, Hawks, Blank ammunition, Blank and lethal ammunition	GB	Landfill	Gull spp.	Varied	✓
21. Delwiche MJ, Houk AP, Gorenzel WP, Salmon TP (2005). Electronic broadcast call unit for bird control in orchards. Applied Engineering in Agriculture 21(4): 721-727.	Auditory	Distress calls	USA	Almond orchards	American crow	Yes	
22. Delwiche MJ, Houk A, Gorenzel WP, Salmon TP (2007). Control of Crows in Almonds by Broadcast Distress Calls Transactions of the ASABE. 50(2): 675-682	Auditory	Broadcast Distress Calls	USA	Field	American crow	Yes	✓
23. Dobeic M, Pintarič S, Vlahović K, Dovč A (2011). Feral pigeon (*Columba livia*) population management in Ljubljana. Veterinarski Arhiv 81 (2): 285-29	Contraceptive, Auditory, Egg collection	Progesterone, Ultrasound, Egg collection	Slovenia	Urban	Feral pigeon	Varied	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
24. Egan CC (2018). Evaluating the potential utility of drones to deter birds from areas of human-wildlife conflict. Chapter 3: evaluating the utility of drones to deter pest blackbirds from sunflower fields. Master's Thesis, North Dakota State University. https://library.ndsu.edu/ir/handle/10365/29171	Visual	Drones (3: predator model of aerial raptor, fixed wing, and multirotor)	USA	Fields (sunflower)	Red-winged blackbird	Partial	✓
25. Erickson WA, Marsh RE, Salmon TP (1992). High frequency sound devices lack efficacy in repelling birds. *Proceedings 15th Vertebrate Pest Conference*, pp. 103-104. University of California, Davis.	Review - ultrasonic	Ultrasonic	USA	Field	Various	No	
26. Erwin KL (1999). *Border collie effectiveness as a method of wildlife control*. Report prepared for Lee County Port Authority, Florida.	Visual	Border collies	USA	Field	Various	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
27. Esther A, Tilcher R, Jacob J (2012). Assessing the effects of three potential chemical repellents to prevent bird damage to corn seeds and seedlings. Pest management Science Volume 69, Issue 3 Special Issue: 8th European Vertebrate Pest Management Conference March 2013 pp: 425-430	Chemical: Seed treatment	Chemical: Anthraquinone Pulegone, Methyl anthranilate	Germany	Aviary, Field	Woodpigeon	No	✓
28. Foss C, Roning D, Merker D (2017). Intense short-wavelength light triggers avoidance response by Red-tailed Hawks: A new tool for raptor diversion? The Condor 119(3): 431-438.	Visual	Pulsing, bright, monochromatic LEDs	USA	Open field	Red-tailed hawk	Yes	✓
29. Fukuda Y, Frampton CM, Hickling GJ (2008). Evaluation of two visual bird scarers, the Peaceful Pyramid and an eye-spot balloon, in two vineyards. New Zealand Journal of Zoology 35: 217-224.	Visual	Peaceful pyramid, Eyespot balloon	New Zealand	Vineyard	European starling	No	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
30. Gagliardo A, Pollonara E, Vanni L, Giunchi D (2020). An experimental study on the effectiveness of a gel repellent on feral pigeons. European Journal of Wildlife Research 66(2) 10.1007/s10344-020-1365-4	Tactile	Bird Free gel repellent	Italy	Night and day roosts on buildings	Feral pigeon	Yes	✓
31. Giunchi D, Baldaccini NE, Sbragia G, Soldatini C (2007). On the use of pharmacological sterilisation to control feral pigeon populations. Wildlife Research 34(4): 306-318	Chemical	Reproductive inhibitor: Nicarbazin	Italy	Aviary	Feral pigeon	Partial	✓
32. Glahn JF, Ellis G, Fioranelli P, Dorr BS (2001) Evaluation of moderate and low-powered lasers for dispersing double-crested cormorants from their night roosts. Proceedings 9th Wildlife Damage Management Conference. Pennsylvania State University, University Park, PA.	Visual	Lasers	USA	Large pen, Field	Double-crested cormorant	No (captive) Yes (wild)	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
33. Gorenzel WP, Blackwell BF, Simmons GD, Salmon TP, Dolbeer RA (2002). Evaluation of lasers to disperse American crows, Corvus brachyrhynchos, form urban night roosts. USDA National Wildlife Research Centre – Staff Publications. Paper 446.	Visual	Lasers	USA	Urban roosts	American crow	No	✓
34. Gorenzel WP, Salmon T P, Imai R (2010) Response of Water Birds to Hazing with a Red Laser. Proceedings of the Vertebrate Pest Conference, 24(24). https://escholarship.org/uc/item/33z6p0fm	Visual	Red laser	USA	USA	25 species (including Canada goose)	Varied	✓
35. Haag-Wackernagel D, Geigenfeind (2008). Protecting buildings against feral pigeons. European Journal of Wildlife Research October 2008, Vol. 54, Issue 4, pp: 715–721	Habitat Manipulation	Habitat Manipulation	Switzerland	Pigeon loft	Feral pigeon	Yes	✓
36. Harris RE, Davis RA (1998) *Evaluation of the efficacy of products and techniques for airport bird control*. LGL report TA2193 to Aerodrome Safety Branch, Transport Canada	Review – devices for airport control	Various	Canada	Field	Various	Varied	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
37. Harris. E., Crom, E., Labuschagne, J, Wilson, A (2016). Visual deterrents and physical barriers as non-lethal pigeon control on University of South Africa's Muckleneuk campus. *SpringerPlus* 5, 1884. https://doi.org/10.1186/s40064-016-3559-5	Visual and Exclusion	Eagle Eyes, fire (flash) flags, bird spikes	South Africa	University campus	Feral pigeon	Yes (spikes)	
38. Holevinski, RA, Curtis PD, Malecki, RA (2007). Hazing of Canada geese is unlikely to reduce nuisance population in urban and suburban communities. Human-Wildlife Interactions 97. https://digitalcommons.unl.edu/hwi/97	Visual	Border collies, lasers, pyrotechnics, remote-controlled boats, strobe lights, kayaks, goose distress calls, combinations of some of these	USA	Urban, Suburban area	Canada goose	Yes (border collies)	✓
39. Honda T (2012). Line colour affects the collision risk and deterrence of crows. Journal of Ethology 30(1): 11-40.	Exclusion	Steel wires vs matt black wires	Japan	Field	Carrion crow, Jungle crow	Yes	✓
40. Isaksson D, Wallander J, Larsson M (2007). Managing predation on ground-nesting birds: the effectiveness of nest exclosures. Biological Conservation 136: 136-142.	Exclusion	Nest cages	Sweden	Field	Hooded crow, gull spp., mammals	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
41. Itoh N, Nakajima C, Takeuchi T, Shirai M, Ohta F, Kanno J (2018). Inspection of the effect of the crow deterrent system using camera system for long-term monitoring of bird flight trajectories at photovoltaic power plant. Ifac Papersonline 51(28): 339-343.	Auditory	Emits soundwaves with a timer	Japan	Power plant	Crow spp.	No	
42. Jacquin L, Cazelles B, Prevot-Julliard A-C, Leboucher G, Gasparini J (2010). Reproduction management affects breeding ecology and reproduction costs in feral urban Pigeons (*Columba livia*). Canadian Journal of Zoology, Vol. 88, No. 8, pp. 781-787, ISSN 0008-4301	Mechanical: Egg removal	Reproduction management	France	Pigeon houses	Feral Pigeon	Yes, but not feasible for wild pops.	✓
43. Jenni-Eiermann S, Heynen D, Schaub M (2014). Effect of an ultrasonic device on the behaviour and the stress hormone corticosterone in feral pigeons. Journal of Pest Science 87(2): 315-322.	Auditory	Ultrasound deterrent system	Switzerland	dovecote and in captivity	Feral pigeon	No	✓
44. Koyuncu T, Lule F (2009). Design, manufacture and test of a solar-powered audible bird scarer. International Journal of Biological, Veterinary, Agricultural and Food Engineering 3(6): 48-50.	Auditory	Solar powered audible bird scarer	Turkey	Field	Carrion crow	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
45. Kroos SM, Tylianakis JM, Nelson X (2012). Effects of Introducing Threatened Falcons into Vineyards on Abundance of Passeriformes and Bird Damage to Grapes. Conservation Biology 26(1): 142-149.	Visual	Falcons	New Zealand	Field - vineyards	European blackbird, song thrush, European starling, silvereye	Yes	✓
46. Kubasiewicz L, Bunnefeld N, Tulloch A, Quine C, Park K (2015). Diversionary feeding: an effective management strategy for conservation conflict? Biodiversity Conservation 25:1-22	Review – diversionary feeding	Diversionary feeding	Global	Field	Hen harrier, Eurasian kestrel, waterfowl spp.	Varied	
47. Laidlaw RA, Gill JA, Smart J (2015). Reducing the impacts of predation on breeding waders using landscape-scale habitat management. Defra Research Report on Project LM0301.	Habitat	Small mammal availability, field wetness & presence of tall vegetation in field verges	UK	Field	Lapwing, Redshank	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
48. Lambert M, Massei G, Dendy J, Cowan D (2017). Towards practical application of emerging fertility control technologies for management of rose-ringed parakeets. In 9th International conference on urban pests, Birmingham, UK, 9-12 July 2017 (pp. 179-187). International Conference on Urban Pests (ICUP).	Fertility Control	Species-specific bait feeder	UK	Aviary/ Field	Ring-necked parakeet	No	
49. Lecker CA, Parsons MH, Lecker DR, Sarno R, Parsons FE (2015). The temporal multimodal influence of optical and auditory cues on the repellent behaviour of ring-billed gulls (*Larus delawarensis*). Wildlife Research 42(3): 232-240.	Visual, Auditory	Conspecific distress calls, green or red lasers	USA	Field	Ring-billed gull	Varied	✓
50. Mahjoub G, Hinders M, Swaddle J (2015). Using a "Sonic Net" to Deter Pest Bird Species: Excluding European Starlings from Food Sources by Disrupting Their Acoustic Communication. Wildlife Society Bulletin 39(2):326–333; 2015; DOI: 10.1002/wsb.529	Auditory	Sonic net	USA	Aviary	European Starling	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
51. Manzoor S, Khan HA, Muhammad JM (2013). Inhibiting damage of watermelon (*Citrulus lanatus*) against some bird pests in an orchard of Faisal bad, Pakistan. Journal of Animal and Plant Sciences 23(2): 464-468.	Auditory	Distress calls	Pakistan	Urban field - watermelons	Common myna, Indian house crow, house sparrow	Yes	✓
52. Matsyura AV (2018a). Efficiency of bird laser repellents (the case of Rooks and Pigeons) (only abstract in English). Ukranian Journal of Ecology 8(2): 320-321.	Visual	Laser	Russia	Feeding and roost sites	Rook, feral pigeon	Yes	
53. Matsyura AV (2018b). Hawk kite as potential bird scare device (the case of pigeons and grain processing factory). Ukrainian Journal of Ecology 8(2): 334-336.	Visual	Hawk kite	Russia	Grain-processing factory	Feral pigeon	No	
54. Matsyura AV, Shapetko EV (2018). Effectiveness of sonic repellents against the Rooks in Kulunda Steppe (Altai Krai, Russia). Ukrainian Journal of Ecology 8(2): 313-314.	Auditory	Species-specific alarm calls with domestic relevance	Russia	Field	Rook	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
55. McIvor GE, Rowe C, Healy SD (2012). "Deterring Hooded Crows from Re-Nesting on Power Poles." Wildlife Society Bulletin 36(4): 729-734.	Visual	Fireflies (brightly coloured plastic discs that spin in wind)	UK	Power poles	Hooded crow	No	✓
56. Nemtzov SC, Galili E 2006. A new wrinkle on an old method: successful use of scarecrows as a non-lethal method to prevent bird damage to field crops in Israel. *In*: Timm, RM *et al.* (Ed.). *Proceedings of the 22nd vertebrate pest conference* pp. 222-224. Univ. of Calif., Davis.	Visual	Scarecrows, Humans with pyrotechnics	Israel	Field	Eurasian crane	Yes	✓
57. Nilsson L 2017 Factors affecting field use of large grazing birds: a review. Introductory Research Essay, Swedish University of Agricultural Sciences. Uppsala., Sweden.	Review -	Scaring plus diversionary feeding – 'push and pull' strategy	Northern hemisphere	Field	Crane spp., swan spp., goose spp.	n/a	
58. Paranjape AA, Chung S, Kim K, Shim DH (2018). Robotic Herding of a Flock of Birds Using an Unmanned Aerial Vehicle, in *IEEE Transactions on Robotics*, vol. 34, no. 4, pp. 901-915, Aug. 2018.	Visual and Auditory	UAV (drone) - quadrotor	South Korea	Campus	Egret sp. (species not specified) and loon sp. (species not specified)	Yes	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
59. Parrott D, Watola G (2008). Deterring mute swans from fields of oilseed rape using suspended high visibility tape. Crop Protection 27: 632-637.	Visual, Physical barrier	High visibility tape	UK	Field	Mute swan	Yes	✓
60. Peisley R, Saunders M, Luck G (2017). Providing perches for predatory and aggressive birds appears to reduce the negative impact of frugivorous birds in vineyards. *Wildlife Research 44*(4): 334-342	Habitat Modification	Perches for predatory birds	Australia	Vineyard	Frugivorous bird spp.	Yes	✓
61. Pennell C, Rolston P (2013). Avanex TM Unique Endophyte Technology – Bird deterrent endophytic grass for amenity turf and airports. Proceedings of the 22nd International Grassland Congress 453-455.	Chemical – conditioned taste aversion	Endophyte inoculated grasses	New Zealand	Field	Finch spp., gull spp., Canada goose	Yes	
62. Peterson S, Colwell MA (2014). Experimental Evidence That Scare Tactics and Effigies Reduce Corvid Occurrence Northwestern Naturalist 95(2): 103-112	Visual and Auditory	Effigies coupled with Distress calls and Human mock shooters	USA	Field (beach)	Raven, American crow	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
63. Rana RS, Narang ML, Patyal SK (2005). Depredatory birds and their ecofriendly management in apple orchards of Himachal Pradesh, India. Pp. 449-453. Proceedings VII on TZFTS.	Visual and Auditory	Bird scaring ribbons, Distress calls	India	Orchard	Corvid spp., Parakeet spp., Bulbul spp., Barbet spp.	Yes	not known
64. Rhoades CA, Allen P J, King DT (2019). Using Unmanned Aerial Vehicles for Bird Harassment on Fish Ponds. Proceedings of the Wildlife Damage Management Conference 18: 13-23	Visual	Drone	USA	Fish farms	Piscivorous birds (species not specified)	No	✓
65. Ronconi R, Cassady C (2006). Efficacy of a radar activated on-demand system for deterring waterfowl from oil sands tailing ponds. J. Appl. Ecol. 43: 111-119.	Auditory	Radar- activated cannon, Peregrine call	Canada	oil sands tailings ponds	Duck spp., wader spp., goose spp., swan spp., gull spp., tern spp., other	No	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
66. Schlichting PE, Holland AE, Beasley JC, Bryan AL, Kennamer RA, DeVault TL, Blackwell BF, Rhodes Jnr OE (2017). Efficacy of an Acoustic Hailing Device as an Avian Dispersal Tool. Wildlife Society Bulletin 41(3): 453-460.	Auditory	acoustic hailing device (sound output with narrow beam width and high volume)	USA	Nature park	New World vulture spp., gull spp., red-winged blackbird, diving duck spp., American coot	Effective (vulture spp, gull spp.)	✓
67. Seamans TW, Hicks CR, Preusser KJ (2007). Dead bird effigies: a nightmare for gulls. pp 1-10. Bird Strike Committee Proceedings. 2007 Bird Strike Committee USA/Canada 9th Annual Meeting, Kingston, Ontario.	Visual	Dead bird effigies	USA	Landfill, nesting colony, containment disposal facility	Ring-billed gull, herring gull	Varied	✓
68. Seamans TW, Barras SC, Bernhardt GE (2007). Evaluation of two perch deterrents for starlings, blackbirds and pigeons. International Journal of Pest Management, Vol. 53, No. 1, pp. 45–51, ISSN 0967-0874	Habitat Manipulation	Perch deterrents	USA	Aviary	Brown-headed cowbird, European starling, Red-winged blackbird	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
69. Senar J., Montalvo T, Pascual J, Peracho V (2016) Reducing the availability of food to control feral pigeons: changes in population size and composition. Pest Management Science/ Volume 73(2): 313-317.	Manipulation of food availability	Reducing the food provided by humans, and public education	Spain	Field (urban)	Feral pigeon	Yes	✓
70. Sherman DE, Barras AE (2004). Efficacy of a laser device for hazing Canada geese from urban areas of northeast Ohio. Ohio Journal of Science 103: 38–42.	Visual	Hand-held laser	USA	Urban areas	Canada goose	Partial	✓
71. Shivik JA (2004). Non-lethal alternatives for predation management. Sheep & Goat Research Journal 19: 64-71.	Various	Livestock practices, visual/acoustic scarers, repellents, fertility control	USA	Field – livestock areas	Not specified	Varied	
72. *Shivik JA (2006). Tools for the edge: what's new for conserving carnivores. Bioscience 56(3): 253-259.*	Various	Electronic guard, fertility guard, fladry, guard dog, hazing, translocation, training collar, radio or movement activated guard	USA	Field – livestock areas	Raptor spp.	Varied	

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
73. Smart J, Amar A (2018). Diversionary feeding as a means of reducing raptor predation at seabird colonies. Journal for Nature Conservation 2018 https://doi.org/10.1016/j.jnc.2018.09.003	Habitat Manipulation	Diversionary feeding	UK	Field	Eurasian kestrel	Yes	✓
74. Smith R, Pullin A, Stewart G, Sutherland W (2010). Is nest predator exclusion an effective strategy for enhancing bird populations. Biological Conservation 144: 1-10	Review – nest predator exclusion	Nest-cages, exclusion fences	Global	Field	Wader spp., tern spp., petrel spp., passerine spp.	Yes	
75. Soldatini C, Albores-Barajas YV, Torricelli P, Mainardi D (2008). Testing the efficacy of deterring systems in two gull species. Applied Animal Behaviour Science 110 (3-4): 330-340.	Visual, Auditory	Aviotek Bird Guard System OR humans with pyrotechnics and noisemakers OR a falconer with two falcons used alternatively	Italy	Refuse dump	Yellow-legged gull, black-headed gull	Partial	✓
76. Steensma K, Lindell C, Leigh D, Burrows C, Wieferich S, Zwamborn E (2016). Bird Damage to Fruit Crops: A Comparison of Several Deterrent Techniques. Proc 27th Vertebr. Pest Conf. Univ of Calif., Davis 2016: 196-203	Visual	Hawk-kites, inflatable tube-men, falconry	USA	Field - fruit	Various	Yes (falconry)	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
77. Stevens G, Rogue J, Weber R, Clark L (2000). Evaluation of a radar-activated, demand-performance bird hazing system. USDA National Wildlife Research Center – Staff Publications. 835. https://digitalcommons.unl.edu/icwdm_usdanwrc/835	Auditory, Chemical (bird tear gas), Pyrotechnics	Radar activated integrated hazing system	USA	Pond	Waterfowl spp.	Yes	✓
78. Stock B, Haag-Wackernagel D (2014). Effectiveness of Gel Repellents on Feral Pigeons. Animal 4(1): 1-15.	Tactile, Visual	Gel repellents	Switzerland	Pigeon loft	Feral pigeon	Yes	✓
79. Swaddle J, Moseley D, Hinders M, Smith E (2016). A sonic net excludes birds from an airfield: implications for reducing bird strike and crop losses. Ecol. Appl. 26(2): 339-45.	Auditory	Sonic net (spatially controlled noise that overlaps with frequency of bird vocalizations)	USA	Airfield	not specified	Yes	✓
80. Tracey J (2012). Ecology Impacts and Management of Pest Birds. PhD, University of York	Visual, Auditory, Netting (and lethal)	Gas guns, electronic devices and visual deterrents (shooting)	Australia	Orchards & Vineyards (101 over 7 years)	European starling, European blackbird, silvereye, house sparrow	Varied – netting best	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
81. Vaudry AL (1979) *Bird control for agricultural lands in British Columbia*. Publications – British Columbia Ministry of Agriculture 78-21. 19pp	Review – visual, Auditory, Exclusion	Various	British Columbia	Various	Various	Varied	
82. Vercauteren KC, Seward N, Hirchert D, Jones M, Beckerman SF (2005). Dogs for reducing wildlife damage to organic crops: A case study. Wildlife Damage Management Conferences – Proceedings. 130. https://digitalcommons.unl.edu/icwdm_wdmconfproc/130	Visual	Dogs & invisible fence; electric polytape	USA	Field	Deer	Yes - dogs	✓
83. Wang Z, Griffin AS, Lucas A, Wong KC (2019). Psychological warfare in vineyard: Using drones and bird psychology to control bird damage to wine grapes. Crop Protection DOI: 10.1016/j.cropro.2019.02.025	Visual and Auditory	Drone with distress call and crow taxidermy (drone was hexacopter multirotor)	Australia	Vineyard	Australian raven, European starling, Sulphur-crested cockatoo, Silvereye	Yes	✓

Reference	Category of deterrent	Device	Country	Site	Species	Effective	Replicated/ Controlled
84. Werner SJ, Clark L (2006). Effectiveness of a Motion-Activated Laser Hazing System for Repelling Captive Canada Geese. USDA National Wildlife Research Center - Staff Publications. Paper 126.	Visual	Motion-activated laser	USA	Wildlife research centre	Canada Goose	Yes	✓
85. Whisson D, Takekawa J (2000). Testing the effectiveness of an aquatic hazing device on waterbirds in the San Francisco Bay Estuary of California. Waterbirds: The International Journal of Waterbird Biology 23: 56-63	Auditory	Breco Bird Scarer (played various high intensity sounds at random)	USA	Open water	Greater scaup, lesser scaup, surf scoter, other waterbird spp.	No	✓
86. Yoshida H, Saeki M, Momose H (2019). Effective line installation technique for preventing crow intrusion into orchards. Applied Entomology and Zoology 54: 399-408.	Exclusion	Line – transparent and coloured	Japan	Aviary and field	Large-billed crow, carrion crow	Yes	✓

Table A2. 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.

Table A3. Selected studies investigating AUDITORY techniques.

Effectiveness score: 2 = very effective (>50% reduction in damage or number of birds), 1 = partially effective (up to 50% reduction), 0 = ineffective (no significant reduction).

Reference	Techniques evaluated	Conclusion	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
1. APHA (2018)	Gas cannons, rope-bangers and life-like mannequins reinforced with live shooting	Effective	2	2	2	2	There was a mean decrease of -30% to -38% in damage compared to an increase of +27% to +43% on control fields. Also, at harvest, the head size of mature plants was greater; and a higher percentage of plants was cut on first pass.	2
2. Baxter & Allan (2007)	Starter pistol firing blank and live rounds	Effective for gulls	2	2	1	0	The addition of lethal control had a substantial effect on gull numbers visiting the site. Although overall numbers did not decline due to culling, fewer gulls visited or remained near the site as the trial progressed (98% decline in gull numbers by the final week of the trial). Numbers of corvids visiting also initially declined but quickly resumed pre-trial numbers.	2
3. Cook *et al* (2008)	Distress calls	Partial	2	2	1	1	Effective initially (~45% reduction in gull numbers the day after control) but result is based on one trial only birds became habituated.	1
	Static distress calls	Partial	2	2	0	1	Effective initially (~40% reduction in gull numbers the day after control) but birds quickly became habituated and result is based on one trial only.	1
	Blank ammunition	Partial	2	2	1	1	Most effective at dispersing herring gulls (~40% reduction in numbers the following day) than lesser black-backed and black-headed gulls, which required addition of some lethal control. Effectiveness increased over the study period.	1

Reference	Techniques evaluated	Conclusion	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
	Blank and lethal ammunition	Partial	2	2	2	1	More effective at dispersing lesser black-backed and black-headed gulls (~40% reduction the following day) than herring gulls (~20% reduction), but effectiveness increased over the study period.	1
	Pyrotechnics	Partial	2	2	0	1	Effective initially (~100% reduction in numbers of lesser black-backed and black-headed gulls, ~50% reduction in herring gulls) but birds quickly became habituated and result is based on one trial only.	1
	Wailers	Partial	2	2	0	1	Partially effective initially for lesser black-backed and black-headed gulls (~10% and 30% reduction, respectively) but ineffective for herring gulls. Birds quickly became habituated and result is based on one trial only.	1
4. Delwiche *et al* (2007)	Species-specific distress calls	Effective	1	2	2	1	Significant effect when areas were pooled, and time separated from treatment. Savings were estimated to be $12 and $25 per ha in the two regions that had significant damage.	2
5. Jenni-Eiermann *et al* (2014)	Ultrasound deterrent system	Not effective	1	2	2	2	No effect on pigeons likely because they cannot hear ultrasound waves	0
6. Lecker (2015)	Species-specific distress calls	Effective	0	2	2	0	mean: 85% gulls take flight	2
	Green laser	Partial	0	2	2	0	mean: 50% (green laser) gulls take flight	1
	Red laser	Partial	0	2	2	0	mean: 5% gulls take flight	1

Reference	Techniques evaluated	Conclusion	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
	Species-specific distress calls and green or red lasers	Effective	0	2	2	0	mean: 80% (green + distress) and 80% (red + distress) gulls take flight	2
7. Mahjoub *et al* (2015)	Sonic net	Partial	1	2	1	1	Treatment reduced starling presence at treated food patch by 46% in captive birds	1
8. Manzoor *et al* (2013)	Distress call	Effective	1	2	1	0	At watermelon seedling stage, the damage was 1.192±0.023 in control period, whilst in treatment period remained 0.200±0.014; at foliage, flowering and mature stages, damage remained as low as 0.130±0.007, 0.155±0.010, and 0.138±0.020	2
9. Ronconi, & Cassady (2006)	Radar-activated cannon	Partial	1	2	0	1	Produced reactions in 12 of 30 activations	1
	Radar -activated peregrine call	Not effective	1	2	0	1	Not effective, maybe because peregrines do not call when hunting	0
10. Schlichting *et al* (2017	Acoustic hailing device	Partial	2	2	0	0	Was effective at dispersing some species (vultures, gulls) but not others (songbirds, ducks, coots).	1
11. Soldatini *et al* (2008)	Aviotek Bird Guard System	Not effective	1	2	2	1	Only effective for short period	0
	Humans with pyrotechnics and noisemakers	Partial	1	2	2	1	Best of three methods, but only effective for a short period	1
	Falcons	Not effective	1	2	2	1	Only effective for short period	0

Reference	Techniques evaluated	Conclusion	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
12. Stevens *et al* (2000)	Radar-activated hazing system	Effective	1	1	1	1	Waterfowl were 12.5 times less likely to fly over the hazed ponds relative to a non-hazed control pond. Of the waterfowl that did fly over both ponds, the likelihood of landing on the hazed pond was 4.2 times less relative to the control.	2
13. Swaddle *et al* (2016)	Sonic net (spatially controlled noise that overlaps with frequency of bird vocalizations)	Effective	1	2	2	2	Effective at excluding birds from airfield. Reduced presence of birds by 82% with no apparent habituation during 4-week trial.	2
14. Whisson & Takekawa (2000)	Breco Bird Scarer (played various high intensity sounds at random)	Not effective	1	2	2	1	Not effective, maybe because birds habituated to loud noise in San Francisco	0

Table A4. Selected studies investigating VISUAL techniques.

Effectiveness score: 2 = very effective (>50% reduction in damage or number of birds), 1 = partially effective (up to 50% reduction), 0 = ineffective (no significant reduction).

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
1. APHA (2018)	Automated laser	Effective.	2	2	2	2	Crop damage increased on both fields but was markedly lower on the laser-treated field (+9%) than on the control field (+89%). Switching of the laser between fields reversed these trends – crop damage decreased markedly on the now protected Field 2 (previously control) (-74%) and increased on the now unprotected Field 1 (previously laser-treated) (+33%)	2
2. Baxter (2007)	Tripod-mounted laser	Effective	2	1	2	1	Routine sweeps of the site (large waterbody) every 30 minutes throughout the night cleared all gulls. (if sweeps less frequent then gulls were still present in the morning)	2
3. Bhusal *et al* (2018)	UAV	Partial	0	1	1	0	Nearly 50% reduction in bird count when drones flown, but bird species not recorded, also drones flown for 5 hours at a time (not realistic)	1
4. Blackwell & Bernhardt (2004)	Pulsing aircraft landing lights	Not effective	1	2	2	1	Tested on: Canada geese, brown-headed cowbirds, European starlings, herring gulls, mourning doves. Only cowbirds showed response and response was not consistent	0
5. Brown (2017)	Rotating laser on scarecrow	Partial	1	2	2	2	Laser scarecrows are effective at preventing starlings and blackbirds from feeding in sweet corn fields. The maximum bird damage reported by growers in a protected field was 5% compared to 40% to 100% in unprotected fields.	1
6. Cassidy (2015)	Hand-held laser	Partial	1	2	2	1	Green lasers more effective than violet lasers. Responsiveness decreased with ambient light levels. Birds were more likely to respond in spring relative to autumn, and more likely to respond in morning relative to evening.	1

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
7. Cook *et al*. (2008)	Hawks	Partial	2	2	2	1	Reduced numbers of herring and lesser black-backed gulls by ~20% in first 24 hours but had no effect on black-headed gulls. Improved in effectiveness over the study period but there was a large amount of variation in their effectiveness. Had a lethal component.	1
	Falcons	Effective	2	2	2	1	Reduced gull numbers by ~50% in the first 24 hours. Improved in effectiveness over the study period. Had a lethal component.	2
	Helium-filled kites	Partial	2	2	2	1	Not significantly effective on any of the 3 occasions on which they were deployed (~30% reduction in all three gull species in first 24 hours but birds quickly became habituated).	1
	Pyrotechnics	Partial	2	2	0	1	Effective initially only and result is based on one trial only	1
8. Egan (2018)	UAV	Partial	0	2	1	2	Free ranging blackbird flocks, initiated flight response when every drone approached, though larger flocks and bigger fields make flocks less likely to abandon field	1
9. Foss *et al* (2017)	Pulsing, bright, monochromatic LEDs	Partial	0	2	1	0	Red-tailed hawks were more than 5 times more likely to abort approaches when high-brightness LEDs were in place then when they were not. There are potential applications to airfields and conservation purposes. However, the experiment was only run for a week and habituation was not accounted for.	1
10. Fukuda *et al* (2008)	Peaceful Pyramid®	Not effective	1	2	2	0	Treatment (pyramid or balloon) plots and control plots in each of two vineyards. Vineyard 1: total grape volume removed by birds – balloon 75%; pyramid 84%; control 82%. Vineyard 2: grapes (%) removed (i) <15m from device – balloon ~30%; pyramid ~45%; control 78%; (ii) 20-40m from device – no measurable effect cf control.	0
	Eye-spot balloon	Not effective	1	2	2	0		0

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
11. Gorenzel, *et al* (2010)	Red laser	Partial	1	2	1	1	Effectiveness varied across species. Pelicans, cormorants, herons, diving ducks and geese reacted immediately and most dependably to the laser. Grebes, gulls, shorebirds, dabbling ducks and coots did not react or only rarely reacted.	1
12. Gorenzel, *et al* (2002)	Lasers	Not effective	1	2	2	1	Not effective in an urban environment. Crows gave a startle response to the lasers by immediately flying from the roost but returning after a short period. They did not vocalise which would be a response to a perceived threat.	0
13. Holevinski *et al* (2007)	Border collies	Partial	1	2	2	2	>90% of geese removed in 94% of 113 events, but geese did not move far enough away to be dispersed from urban or suburban areas	1
	Lasers	Not effective	1	2	2	2	>90% of geese removed in 64% of 134 events, but geese did not move far enough away to be dispersed from urban or suburban areas	0
	Pyrotechnics	Not effective	1	2	2	2	>90% of geese removed in <20% of 27 events, but geese did not move far enough away to be dispersed from urban or suburban areas	0
	Remote-controlled boats	Not effective	1	2	2	2	Not effective (details not reported)	0
	Strobe lights	Not effective	1	2	2	2	Not effective (details not reported)	0
	Kayaks	Not effective	1	2	2	2	Not effective (details not reported)	0
	Goose distress call	Not effective	1	2	2	2	Not effective (details not reported)	0
	Border collies + remote-controlled boats	Partial	1	2	2	2	>90% of geese removed in 97% of 37 events, but geese did not move far enough away to be dispersed from urban or suburban areas	1
	Laser + pyrotechnics	Not effective	1	2	2	2	>90% of geese removed in 64% of 54 events, but geese did not move far enough away to be dispersed from urban or suburban areas	0

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
14. Kroos *et al* (2012)	Falcons	Effective	1	2	2	1	The introduction of falcons to vineyards was associated with a significant decrease in the abundance of introduced passerines and with a 95% reduction in the number of grapes removed relative to vineyards without falcons. Falcon presence was not associated with a change in the number of Silvereyes, but there was a 55% reduction in the number of grapes pecked in vineyards with falcons. The presence of a falcon could potentially result in savings of US$234/ha for the Sauvignon Blanc variety of grapes and $326/ha for Pinot Noir variety of grapes.	2
15. Lecker (2015)	Species-specific distress calls	Effective	0	2	2	0	Mean: 85% gulls take flight	2
	Green laser	Partial	0	2	2	0	Mean: 50% (green laser) gulls take flight	1
	Red laser	Partial	0	2	2	0	Mean: 5% (red laser) gulls take flight	1
	Conspecific distress calls and green or red lasers	Effective	0	2	2	0	Mean: 80% (green + distress) and 80% (red + distress) gulls take flight	2
16. McIvor *et al* (2012)	Fireflies (brightly coloured plastic discs that spin in wind)	Not effective	2	2	2	1	No evidence fitting fireflies to power-poles was effect at deterring crows from re-building their nests there	0
17. Nemtzov & Galili (2006)	Scarecrows, humans with pyrotechnics	Effective	1	2	2	2	The entire crane-agriculture management program was cost-effective for the farmers, since losses due to crane damage were reduced to almost nothing.	2
18. Parrott & Watola (2008)	Hi-visibility tape	Effective	2	2	2	2	On 12 fields of OSR, usage by mute swans was reduced by a median of 97% during a treatment period (hi-visibility tape suspended in herringbone pattern across the field) compared to a pre-treatment period.	2

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
19. Peterson & Colwell (2014)	Corvid effigies reinforced with 'death scene' and distress calls	Effective	1	2	1	0	Relative differences between treatment and control plots indicated that effigies reduced corvid abundance by 27 to 70% and corvid incidence 55 to 100%.	2
20. Rhoades *et al* (2019)	UAV	Partial	0	2	1	1	UAVs no better than human disturbance, but both reduced bird numbers by 50% in one trial.	1
21. Sherman, & Barras (2004)	Hand-held laser	Partial	1	2	2	2	Mean number of geese decreased from 92 to 14 at night over 5 days of treatment, but no change in numbers during day time. No difference in number of geese two weeks before harassment and post harassment.	1
22. Seemans *et al* (2007)	Dead bird effigies	Partial	1	2	1	0	Landfill – distance to effigies and/or numbers of gulls and habituation varied dependent on distance of effigies to active face; least response to effigies on active face. Containment disposal facility – habituation after two months. Nesting colonies – no effect.	1
23. Steensma *et al* (2016)	Falconry	Effective	1	2	1	0	Percent crop losses per day of blueberries per day significantly lower in blocks with falconry (0.20±0.04) compared to non-falconry (0.42±0.07).	2
	Hawk-kites	Not effective	1	2	1	0	No difference in amount of fruit damage between 'no-movement' and 'movement' kites. Control block had higher damage but still low compared to regional averages.	0
	Tube-men	Not effective	1	2	0	0	Of three fields, no consistent effect of tube-men.	0
24. Vercauteren *et al* (2005)	Dogs	Effective	1	0	1	1	Estimated annual losses at farm before introduction of dogs was $3,177 (1997) and $4,391 (1999); after dogs introduced (2001 and 2002) there was no damage.	2

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
	Electric poly-tape fence	Not effective	1	2	1	1	Estimated annual losses at farm before introduction of electric poly-tape barrier was $3,177 (1997) and $4,391 (1999); after tape deployed damage was $3,797 (2001) and $638 (2002).	0
25. Wang *et al* (2019)	UAV (hexacopter multirotor) with distress call and crow taxidermy	Partial	0	2	0	2	UAV can deter large birds (ravens and cockatoos) in a 50m radius for an extended period and deter small birds like silvereye for brief periods.	1
26. Werner & Clark (2006)	Motion-activated laser	Effective	1	2	2	1	The system reduced occupancy of treated area by 83%. Geese did not habituate when they were exposed over 20 consecutive nights, but effect disappeared 3 days after lasers were extinguished. (experiments done on wild-caught geese held in captivity)	2

Table A5. Selected studies investigating CHEMICAL techniques.

Effectiveness score: 2 = very effective (>50% reduction in damage or number of birds), 1 = partially effective (up to 50% reduction), 0 = ineffective (no significant reduction).

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
1. Avery *et al* (2008)	Fertility control	Effective	0	1	1	0	Only 9 of 22 eggs hatched, a 59% reduction from pre-treatment when each of the 11 test pairs produced 2 nestlings.	2
2. Avery *et al* 2008	Fertility control	Effective	0	1	2	0	Nest productivity (nestlings plus eggs with embryos) averaged 1.31 (SE ¼ 0.45, n ¼ 100 nests) at 6 treated sites compared to 4.15 (SE ¼ 0.68, n ¼ 50 nests) at 4 untreated sites, a 68.4% reduction.	2
3. Dobeic *et al* (2011)	Fertility control	Partial	1	0	1	2	The size of the feral pigeon population in Ljubljana decreased on average by as much as 49.1% in the six-year period, but since pigeons were migrating in search of food it was difficult to achieve reliable results from hormone maize feeding without treatment of pigeons at more locations throughout the entire city area. Also, the permanent use of the hormone can be detrimental to the environment due to general health protection, wild animals and possible environmental residue.	1
4. Esther *et al* (2012)	Seed treatment anthraquinone, pulegone and methyl anthranilate	Not effective	1	2	1	1	In aviaries, untreated seeds were clearly preferred over treated seeds by pigeons. There was no repellent effect if seedlings were offered to the pigeons in aviaries. Pheasants damaged >50% of the plants in the field irreversibly, irrespective of the seed treatment.	0

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
5. Giunchi *et al* (2007)	Fertility control	Partial	1	1	1	0	Results showed only a partial inhibition of reproduction of pigeons fed~38–82 mg nicarbazin day−1 (kg bodyweight)−1 (500 and 800 ppm in feed): 13% to -48% reduction in hatchability, which, according to the simulations would produce only a fleeting reduction of their abundance in the field	1

Table A6. Selected studies investigating EXCLUSION techniques.

Effectiveness score: 2 = very effective (>50% reduction in damage or number of birds), 1 = partially effective (up to 50% reduction), 0 = ineffective (no significant reduction).

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
1. Isaksson *et al* (2007)	Nest-cages	Partial	1	2	2	0	190 lapwing nests in 2002 and 2004, and 68 redshank nests in 2002. Of these, 37 lapwing nests and 34 redshank nests were protected by exclosures. Protected nests had significantly higher daily survival rate than unprotected nests in both lapwing (0.989 versus 0.966; $p < 0.0001$, $Z = 4.1$, $n = 190$ nests) and redshank (0.997 versus 0.964; $p < 0.001$, $Z = 3.67$, $n = 66$ nests). Taking into account incubation time, nest abandonment, hatchability and partial clutch loss, protected nests hatched more young than unprotected controls.	1
2. Honda (2012)	Lines	Effective	1	2	2	0	Collisions in metallic wire subplots and in matte black wire subplots occurred in 2 of 78 and 13 of 73 approaches, respectively. The crows that collided with wirelines were not injured and immediately flew away. Collision risk was higher in matte black wire subplots (Fisher's exact test $p = 0.002$).	2
3. Tracey J (2012)	Netting, scaring, (gas guns, electronic devices and visual deterrents), shooting	Netting most effective	1	2	2	2	Bird damage was significantly lower on netting (10.7+ 2.8%) and shooting (20.5+ 3.8%) sites than nil treatments (33.2+ 5.6%); and netting was more effective than shooting. The mean cost of netting and shooting treatments was $1,903+327/ha/site and $538+199/ha/site respectively. There were no significant differences between net types (permanent, drape over, extruded) and the number of birds shot had no effect on bird damage. Lower damage was reported on sites with gas guns compared to those with electronic devices and visual deterrents (Wald statistic: $F(1,74)=7.158$, $P=0.028$)	2

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
4. Vercauteren *et al* (2005)	Dogs	Effective	1	0	1	1	Estimated annual losses at farm before introduction of dogs was $3,177 (1997) and $4,391 (1999); after dogs introduced (2001 and 2002) there was no damage.	2
	Electric poly-tape fence	Not effective	1	2	1	1	Estimated annual losses at farm before introduction of electric poly-tape barrier was $3,177 (1997) and $4,391 (1999); after tape deployed damage was $3,797 (2001) and $638 (2002).	0
5. Yoshida *et al* (2019)	Transparent nylon lines	Effective	1	2	2	0	24-week experimental period alternating 3-week periods with and without nylon lines. Total crow intrusions with lines = 9; without lines = 2234.	2

Table A7. Selected studies investigating HABITAT MANIPULATION techniques.

Effectiveness score: 2 = very effective (>50% reduction in damage or number of birds), 1 = partially effective (up to 50% reduction), 0 = ineffective (no significant reduction).

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
1. Boothby *et al* (2019)	Bamboo canes at tern colonies	Partial	2	2	2	1	Canes reduced predation attempts (-45%), but did not reduce probability of success of predation events that did take place	1
2. Buckley & McCarthy (1994)	Keeping grass long (airport)	Partial	0	2	2	1	Controlling standing water, keeping grass long, and managing beetle populations in airports is the recommended strategy	1
3. Gagliardo *et al* (2020)	Bird Free gel repellent	Effective	1	2	1	1	Completely dissuaded pigeons from night roost, significantly reduced at day roost, and nest sites	2
4. Haag-Wackernagel & Geigenfeind (2008)	Habitat manipulation	Effective	1	2	2	0	Pigeon deterrent dimensions of openings can be achieved with a width of ≤4 cm, a height of ≤5 cm, and a square restriction of ≤6×6 cm. A 4- cm-wide ledge prevented pigeons from perching. Rough surface of sandstone needs a steeper inclination (45°) than slippery tinplate (20°) to prevent pigeons from perching.	2
5. Laidlaw *et al* (2015)	Small mammal availability, field wetness & presence of tall vegetation in field verges	Partial	2	2	2	0	Landscape management approaches that reduce predation pressure on reserve populations are also likely to benefit wider countryside populations - field wetness and presence of tall vegetation in field verges; the latter support small mammal populations (the primary prey of most nest and chick predators).	1
6. Peisley *et al* (2017)	Predator perches	Effective	0	2	2	1	Grapevines around perch sites suffered >50% less grape damage	2

Reference	Techniques evaluated	Conclusions	Context	Treat.	Expt. design	Cost-benefit	Results	Effectiveness
7. Seamans, *et al* (2007)	Anti-perching devices	Effective	1	2	2	0	Anti-perching wire and BirdBloxTM were effective perching deterrents when tested in an aviary setting. In aviary tests, BirdbloxTM was effective at keeping five species of common pest birds from perching on a desired perch.	2
8. Senar *et al* (2016)	Reduction of food availability	Partial	0	2	2	0	Pigeon abundance reduced 40% between Feb. and June and did not increase until following Jan. Effect was not apparent in control areas. Culling used to adapt pigeon population size to the reduced food supply initiated by the public restriction of feeding.	1
9. Smart & Amar (2018)	Diversionary feeding	Effective	2	2	1	0	Predation rates on tern chicks were 47% lower and productivity doubled in years when kestrels fed (216 chicks) compared to years when not fed (103 chicks).	2
10. Stock & Haag-Wackernagel (2014)	Repellent gels	Effective	1	2	1	0	*Contact gel*: (i) mean approaches to shelf per day – pre-treat = 23.3, Treat 1 (1-7 days) = 3.6, Treat 2 (8-26 days) = 0.75. (ii) mean time per landing on shelf (sec) - pre-treat = 170, Treat 1 (1-7 days) = 46, Treat 2 (8-26 days) = 56.*Optical gel*: mean landings on shelf per day – pre-treat = 18.6, Treat 1 (1-3 days) = 1.53, Treat 2 (4-25 days) = 1.01.	2