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RESEARCH

An Evaluation of Techniques to Control Problem Bird Species on Landfill Sites

Aonghais Cook · Steven Rushton · John Allan · Andrew Baxter

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Abstract Birds feeding on landfill sites cause problems in terms of nuisance to neighbors, flight safety, a threat to public health, and affecting the day to day site operation. A number of control measures exist to deter problem species; however, research into their effectiveness across sites and for multiple species has been limited. We use a modeling approach in order to assess the effectiveness of nine techniques — pyrotechnics, hand-held distress calls, static distress calls, blank ammunition, a combination of blank and lethal use of ammunition, the use of falcons, the use of hawks, wailers and helium-filled bird-scaring kites — at deterring three commonly recorded species — the Black-headed Gull (*Larus ridibundus*), the Herring Gull (*Larus argentatus*) and the Lesser Black-backed Gull (*Larus fuscus*) — from six landfill sites across the United Kingdom. The use of distress calls, falconry, and combinations of lethal and nonlethal use of ammunition were the most effective techniques for initially deterring birds from these sites. However, when habituation is considered, there is a clear difference between techniques such as falconry, which have a lethal aspect and may act to reinforce the deterrence, and the use of techniques such as distress calls, which do not. However there are problems related to legislation and public perception when lethal techniques are used.

A. Cook (✉) · S. Rushton
Institute for Research into Environmental Sustainability, Newcastle University, Newcastle Upon Tyne NE4 5AB, United Kingdom
e-mail: Aonghais.Cook@newcastle.ac.uk

J. Allan · A. Baxter
Bird Management Unit, Central Science Laboratory, Sand Hutton, York YO41 1LZ, United Kingdom

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Introduction

Landfill sites often host feeding assemblages consisting of a large number of birds of a relatively small range of species, notably gulls. These feeding assemblages pose a number of problems, both economically and to public health, within a landscape context.

Gulls pose a risk to aircraft (Blokpoel 1976; Burger 2001; Baxter 2003) and can interfere with the daily operation of landfill sites. In addition they have been found to carry a range of pathogens, harmful to both humans and livestock, such as *Salmonella* (Monaghan and others 1985; Ferns and Mudge 2000; Palmgren and others 2006), *Campylobacter* (Broman and others 2002), the avian flu virus H5N1 (Ellis and others 2004), *Esherichia coli* 0157 (Wallace and others 1997), and the infectious bursal disease virus (Hollmen and others 2000). Given the large number of birds gathering at these sites and their subsequent dispersal throughout the landscape, the potential for large scale transmission of disease is great.

The annual cost of bird control at a site in the United Kingdom can range between US $65–120 000, depending on the scale and methods used (Allan 2002). Given the expense and the potential problems associated with the presence of gulls on landfill sites, it is important to investigate the effectiveness and limitations associated with a range of different control techniques. These techniques can be split into two groups, those that involve large-scale population reduction, removing the problem permanently, and those that merely aim to deter birds.

A number of large-scale culls of gulls have been attempted (i.e., Bosch and others 2000; Guillemette and Brousseau 2001; Finney and others 2003). However, attempts at controlling populations at a large scale have often failed due to the immigration of individuals from neighboring populations and the need to apply the methods consistently across the whole population and dispersal of individuals within the landscape (Bosch and others 2000). Such large scale population control is also often controversial and may encounter legal obstacles, e.g., bird protection legislation.

While many studies have looked at the impacts of lethal control at a population level, few have looked at the impacts on bird abundance at individual sites. John F Kennedy Airport in New York, United States, initiated a program of shooting gulls flying over its runways in 1991 (Dolbeer and others 1993). This was highly successful in reducing the number of bird strikes with aircraft. However, there has been some debate as to whether the mechanism for this reduction is the deterrent effect of the shooting or an overall reduction in population size (Brown and others 2001).

Other tactics have also been used to deter birds from problem areas. Some of these, such as the use of birds of prey (summarized by Ericson and others 1990) have a limited lethal aspect, but have proven to be highly effective at keeping problem species away from areas such as airports (i.e., Blokpoel 1977). However, there are a number of limitations on their usage, such as cost and the prevailing climatic conditions. A number of nonlethal control techniques have also been developed. These include distress calls (i.e., Delwiche and others 2005), lasers (Gorenzel and others 2002), pyrotechnics (Olijynk and Brown 1999), fogging (Vogt 1997) and mylar flags (Belant and Ickes 1997). All studies found that while these techniques could be effective in dispersing flocks of birds causing a problem, they were subject to varying degrees of habituation, where birds become accustomed to, and subsequently ignore, the intervention (Bomford and O'Brien 1990; Andelt and Hopper 1996; Olijynk and Brown 1999).

In order to compare the efficacy of a range of control methods, it is important to examine their effectiveness at a range of sites. While studies investigating the effectiveness of these control methods have been compared (Gilsdorf and others 2002), no single study had examined the application of multiple techniques to multiple sites. Using a combined field observational and modeling approach, this study examines the responses of three species — the Herring Gull (*Larus argentatus*), the Lesser Black-backed Gull (*Larus fuscus*), and the Black-headed gull (*Larus ridibundus*) — to a variety of control methods at six landfill sites in the United Kingdom.

Methods

Count data from the six United Kingdom landfill sites shown in Fig. 1 were collected between 1999 and 2001. Regular supplies of domestic waste were deposited at each site (at least 250,000 tons per annum). The sites were characterized by being on the edge of towns and surrounded by large areas of farm and grass land.

During the study period, the numbers of Herring, Lesser Black-backed, and Black-headed Gulls feeding or loafing on the sites were recorded at hourly intervals on twice weekly, randomly selected sampling days either between dawn and midday or midday and dusk for a minimum of six hours on each occasion. Nine different control techniques, which are either routinely used on landfill sites or marketed for use on them, were instigated at these sites during the study period. However, these techniques were not applied equally across all sites and months (Tables 1 and 2) and this unbalanced design has implications for the analysis.

Each trial consisted of a pre-trial monitoring period of up to four weeks, followed by the implementation of a control technique independently for a period of up to 12 weeks, or until the birds failed to respond to the deterrence. This was confirmed by a morning or afternoon of consistent nil response by the target birds to the control measure.

Trials were conducted as follows: Where bird-scaring kites were used, three were deployed over the site for the study period. Pyrotechnics and distress calls were deployed "on demand" when birds were seen attempting to land.

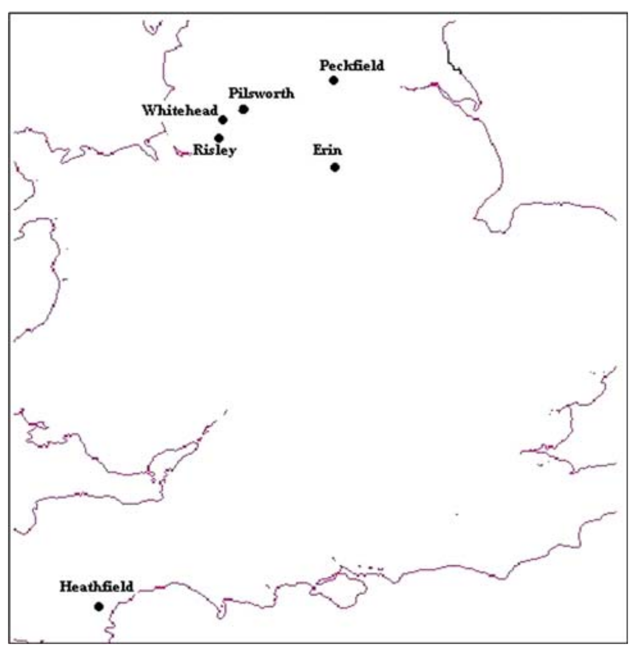

Fig. 1 Locations of landfill sites used in study

Table 1 The distribution of trials throughout the study period by site and control technique

	Hawks	Falcons	Distress calls	Helium-filled kites	Blank ammunition	Pyrotechnics	Wailers	Static distress	Blank and lethal ammunition	Total trials at site
Peckfield	2	3	2	1	1					9
Pilsworth	1	2	2	1			1		1	6
Heathfield	1	1	1	1		1			1	6
Whitehead	2	2	2		1					7
Erin	1	1	1		1			1		5
Risley		1	1		1					3
Number of trials for each technique	7	10	9	3	4	1	1	1	2	36

Table 2 Distribution of trials in each month and year, where trials of the same technique ran concurrently, number of trials indicated in parentheses

Method	January	February	March	April	May	June	July	August	September	October	November	December
Hawks		2000			1999			2000		2000	1999	1999, 2000
Falcons	2000, 2001	2001	2000	2000		1999, 2000			1999(2), 2000			
Distress calls	2000, 2001	2000				1999, 2000		1999	2000(2)		1999	
Bird scaring kites				1999			1999					1999
Blank ammunition			2000(2)				2000(2)					
Pyrotechnics					2000							
Wailers								2000				
Static distress calls											2000	
Blank and lethal ammunition	2001	2001										

However, due to economic considerations, the use of pyrotechnics was limited to a maximum of once every 15 minutes. The distress calls of Black-headed Gulls and Herring Gulls were used depending on which species constituted the majority of the count. Where this was the Lesser Black-backed Gull, Herring Gull distress calls were used.

In trials of falcons, hawks, and the lethal use of ammunition, gulls were targeted under Schedule 2 of the 1981 UK Wildlife and Countryside Act (as amended). Specific licenses were held under section 16 of the Act (WLF100085) for targeting Black-headed gulls. All hawks and falcons used in these studies were registered with the UK Department for Environment, Food and Rural Affairs under license 14008. Any carcasses were removed from the site. Up to three hawks or falcons were used at each site, although they were always flown independently. Their deployment was predominantly limited by weather, with hawks not flown in winds >33 km/h and falcons not flown in winds >46 km/h. Neither was flown during rain or fog.

The resulting data were used to construct a series of linear mixed-effects models for each trial period using the nlme extension in R (Ihake and Gentleman 1996). This method has the advantage of making a parsimonious model allowing cross-species comparisons, while also allowing the analysis of unbalanced data. By treating variables, such as species, as random effects, fewer degrees of freedom are used as the individual intercepts and coefficients for each species are treated as deviations from the mean population (Pinheiro and Bates 2000).

In order to normalize the count data it was log transformed and assessed using a quantile-quantile plot. Species, the presence of control, time of day, and day number were included in the full model as fixed effects. In addition, interactions between control and time, species, and day number were considered. Time was sine- and cosine-transformed in order to take account of the daily variation in behavior displayed by the study species. Control, species, and day number were also included in the full model as random effects. An AR(1) correlation structure, where adjacent observations have a higher correlation than nonadjacent observations, was included in the model to account for temporal autocorrelation. The models were constructed by dropping each factor sequentially and comparing the resulting model to the full model using a likelihood ratio test. When the two models differed significantly, the one with the lowest Aikaike Information Criterion (AIC) was chosen (Burnham and Anderson 1998). When comparing models in which the fixed effects differed, maximum likelihood (ML) was used, as comparing models in which the fixed effects vary using restricted maximum likelihood (REML) produces results which are not interpretable (Pinheiro and Bates 2000). For all other models REML was used.

The final most parsimonious models were assessed for temporal autocorrelation, and checked, using quantile-quantile plots and plots of fitted against observed values, to ensure assumptions of normality were met. The parameters were then used to calculate the initial effectiveness of each control method, as well as the rate at which the study species habituated to each technique. The initial effectiveness of each technique was taken as being the percentage drop in the number of birds present at 1200 hours, on the day before and the day after control commenced. The degree of habituation to each technique was taken as the gradient of the slope of the fitted values between the commencement of the control and the end of the study period. The effects of month and trial number on both the initial effectiveness and degree of habituation were then investigated for each species using a linear regression. Month was sine- and cosine-transformed in order to allow for seasonal variation in the behavior of the study species. The effects of site were investigated using analysis of variance. All analyses were conducted in R (R Development Core Team 2005).

Results

The number of gulls present on the landfill sites peaked around midday; the mean and maximum numbers of each species present at this time with no control present are shown in Table 3. The length of the trials varied from 18 days for the helium-filled kites at Heathfield to 128 days for falcons at Whitehead (Table 4). In trials of control with a lethal aspect, 322 gulls were shot, 31 were taken by falcons, and 12 were caught by hawks. In addition, 315 corvids were shot, 106 corvids and other birds were taken by falcons, and 57 corvids and other birds were taken by hawks. There was a great deal of variation in the initial change in gull numbers at the start of control; however this did not differ significantly between sites (Fig. 2, $p > 0.05$) and most of the variation is likely to be due to differences between techniques and the effects of the covariates.

The most parsimonious models considered day nested within species as random effects. All models met assumptions of normality and showed little or no evidence of temporal autocorrelation. The most parsimonious models are presented here (Table 4). In all but 6 trials, the application of control had a significant effect on the number of birds present. Hand held distress calls, blank ammunition, and falcons all failed to have an effect on one of the occasions on which they were deployed; however, helium-filled bird-scaring kites failed to have a significant effect on any of the 3 occasions on which they were deployed (Table 4).

The patterns of bird abundance during the trial periods could generally be fit into one of three categories. The first of these is illustrated by the use of falcons at Pilsworth Landfill Site (Fig. 3a and b). Here, while the number of gulls on the site was declining initially, the introduction of falcons on day 28 caused a greater decline. The number of birds recorded at the site then continued to drop for the duration of the trial. The use of helium-filled bird-scaring kites at Heathfield landfill site illustrates a second category (Fig. 4a and b). Here, numbers remain relatively constant, both before control was introduced and while it was applied. In cases like this, control had little or no impact on the number of birds recorded, and the majority of variation observed in bird numbers resulted from diurnal patterns (Table 4). In the final category, the number of birds observed dropped following the commencement of control measures, as seen when pyrotechnics were deployed at

Table 3 Mean and maximum numbers of each gull species observed at study sites at 12 noon

	Herring gull		Black headed gull		Lesser black-backed gull	
	Mean	Maximum	Mean	Maximum	Mean	Maximum
Peckfield	17.09 (+/−3.48)	490	165.22 (+/−21.95)	2450	26.40 (+/−4.05)	583
Pilsworth	53.88 (+/−11.81)	1900	69.40 (+/−12.33)	1150	196.53 (+/−26.27)	3154
Whitehead	80.75 (+/−17.04)	1425	119.18 (+/−16.90)	1310	64.45 (+/−10.56)	1395
Heathfield	2074.67 (+/−159.21)	7450	456.23 (+/−63.92)	3250	3.13 (+/−0.47)	32
Erin	50.89 (+/−13.96)	1238	151.63 (+/−35.72)	3700	94.39 (+/−16.31)	1302
Risley	39.76 (+/−14.99)	2050	49.63 (+/−11.84)	1360	24.17 (+/−5.46)	542

For mean values, Standard Errors shown in parentheses

Table 4 The parameters for the most parsimonious models of each trial

Control	Site	Trial length (days)	Intercept	Sin (2*pi*time/2400)	Cos (2*pi*time/2400)	Control	Day	Species	Sin (2*pi*time/2400) control	Cos (2*pi*time/2400) control	Control day	Control species	D^2 Deviance explained)
Blank ammunition	Erin	44	1.27	−0.26[a]	−0.58	−0.66							0.75
Blank ammunition	Peckfield	81	−2.14	−0.19[a]	−2.02	−0.25[a]		1.30[a]					0.52
Blank ammunition	Risley	63	−1.22[a]	−0.96	−3.63	3.53	0.04[a]		−0.25[a]	1.28	−0.06[a]		0.63
Blank ammunition	Whitehead	104	−0.06[a]	−0.22[a]	−3.16[a]	1.4		0.70[a]	−0.20[a]	1.34		0.58	0.42
Blank and lethal ammunition	Pilsworth	20	−2.54[a]	−0.90[a]	−9.36	2.92	−0.07		0.08[a]	4.1			0.83
Blank and lethal ammunition	Pilsworth	59	−11.28	−3.3	−13.42	8.12	0.48[a]		1.01[a]	5..39	−0.41		0.61
Distress calls	Erin	75	−0.86[a]	0.64[a]	−8.3	2.14	−0.04		−0.2	4.01			0.49
Distress calls	Heathfield	103	9.2	−0.72	−1.8	−4.13	−0.01[a]	−2.70[a]			0.02	0.61	0.69
Distress calls	Peckfield	63	0.79[a]	−0.26[a]	−2.55	−0.45[a]							0.55
Distress calls	Peckfield	71	0.73	−0.24[a]	−0.6	−0.51							0.34
Distress calls	Pilsworth	122	7..50	−1.94	1.93	−6.68	−0.04[a]	0.51[a]	1.03	−3.03	9.4		0.71
Distress calls	Pilsworth	27	−1.82[a]	1.96[a]	−7.23	0.93			−1.75	2.20[a]			0.76
Distress calls	Risley	86	9.45	−1.93	0.15[a]	−8.23	−0.11		0.78	−0.50[a]	0.12		0.65
Distress calls	Whitehead	113	1.17[a]	−0.22[a]	−2.02	−1.16[a]	−0.04	1.72[a]	−0.45	0.8	0.03	−0.6	0.54
Distress calls	Whitehead	106	6.84	−2.1	−3.7	−3.3		−1.73[a]	0.72	1.85		1.03	0.77
Falcons	Erin	66	−0.95[a]	−1.32	−11.84	0.35[a]	−0.25		0.7	5.72	0.13		0.57
Falcons	Heathfield	107	2.88	−0.77	−2.13	−0.76	−0.01						0.58
Falcons	Peckfield	115	0.13[a]	−1.99	−3.02	−0.33[a]	−0.18	1.81[a]	1.05	1.16	0.09	−0.7	0.62
Falcons	Peckfield	95	−0.64[a]	−0.54	−1.84	0.81	−0.01[a]		0.27	0.63	−0.01		0.37
Falcons	Peckfield	42	2.39	−0.33[a]	−1.07	−0.40[a]	−0.07						0.47
Falcons	Pilsworth	109	6.15	−1.96	−1.72	−1.87	−0.01	−1.82[a]	0.72	0..53[a]		0.84	0.68
Falcons	Pilsworth	106	2.11	−1.43[a]	−4.44	−0.33[a]	−0.04		0.29[a]	2..54[a]	0.01		0.61
Falcons	Risley	112	0.22[a]	−2.01	−2.16	−0.56	0.02		0.73	0.73			0.54
Falcons	Whitehead	128	0.08[a]	−0.93	−5.15	0.70[a]	0.01		0.38	2.79	−0.01		0.5
Falcons	Whitehead	74	4.44	0.88	−5.08	−1.95	−0.14		−0.43[a]	2.3	0.06		0.67
Hawks	Erin	109	−1.74[a]	−0.03[a]	−3.8	2.31[a]	0.04				−0.04		0.94
Hawks	Heathfield	102	2.85[a]	−1.6	−4.28	−0.03	−0.51[a]		0.43[a]	1.18	0.01[a]		0.32
Hawks	Peckfield	63	0.49[a]	−0.22[a]	−1.61	−1.17		0..35[a]					0.51
Hawks	Peckfield	72	0.01[a]	0.02[a]	−2.57	−0.72							0.57
Hawks	Pilsworth	68	−0.32[a]	0.41[a]	−5.36	1.72	−0.03[a]		−0.27[a]	1..90			0.63
Hawks	Whitehead	75	5..99[a]	1.15	−2.61	−3.06	0.06	−1.09[a]				0.79	0.74
Hawks	Whitehead	81	0.81[a]	−1.84	1.01[a]	−0.72[a]	0.03		0.94	−2.29			0.4
Helium−filled kites	Heathfield	18	2.61[a]	0.85	−2.77	−0.62[a]	0.02[a]						0.84

Table 4 continued

Control	Site	Trial length (days)	Intercept	Sin (2*pi*time/2400)	Cos (2*pi*time/2400)	Control	Day	Species	Sin (2*pi* time/2400) control	Cos (2*pi* time/2400) control	Control day	Control species	D^2 Deviance explained)
Helium–filled kites	Peckfield	57	−1.88	−0.68	−2.33	−0.94[a]	1.64[a]						0.68
Helium-filled kites	Pilsworth	48	1.91[a]	−1.1	−2.01	−1.04[a]	0.03[a]						0.64
Pyrotechnics	Heathfield	78	9.54	−1.27	−2.32	−3.13	−0.04	−2.93	0.32	0.3	0.03	0.49	0.69
Static distress calls	Erin	97	−1.10[a]	0.984[a]	−5.58	1.64[a]	−0.02	0.74	−0.06[a]	2..96			0.53
Wailers	Pilsworth	25	−2.94[a]	−1.28	−3.95	3.76	0.11[a]	1.22[a]	−0.20[a]	1.63	−0.1	−0.69	0.66

[a] insignificant variable

Likelihood ratio tests, however, supported inclusion of variable in final model. Also reported are the values for D^2 and the length of study period

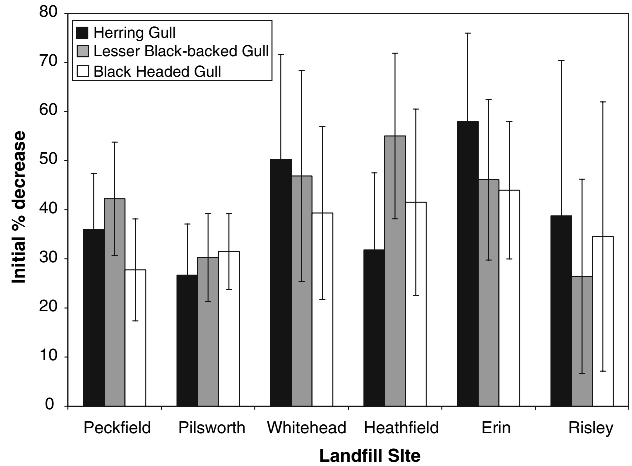

Fig. 2 Initial % decrease in bird numbers between 12 noon on the day before and after commencement of control at each landfill site (+/− Standard Error)

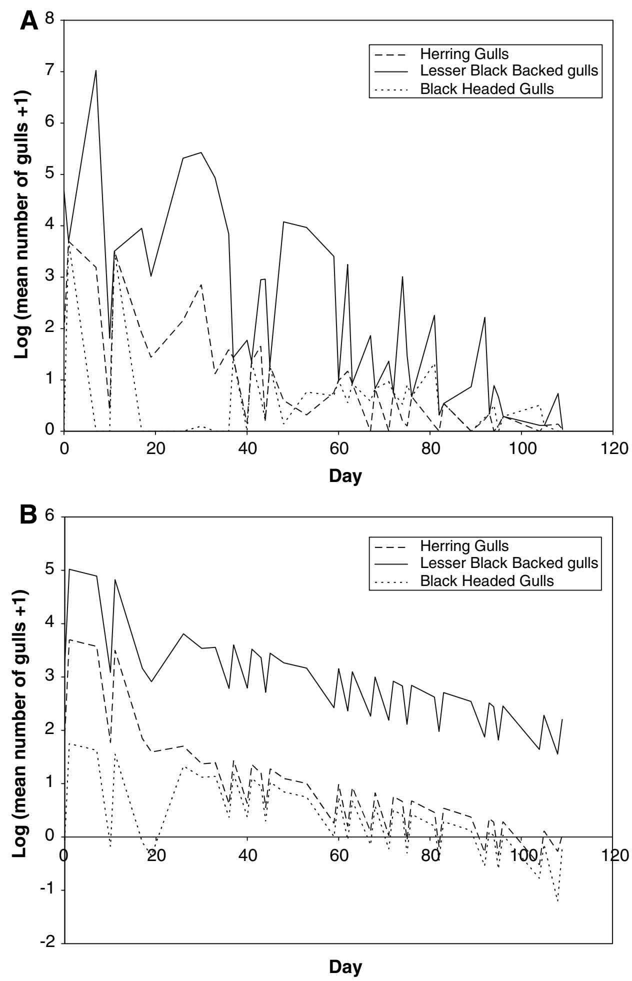

Fig. 3 The observed (**a**) and fitted (**b**) values for the trial of falcons at Pilsworth Landfill site starting in June 1999. Days 1–28, pre-control monitoring period, days 28 onwards control applied. $d^2 = 0.68$

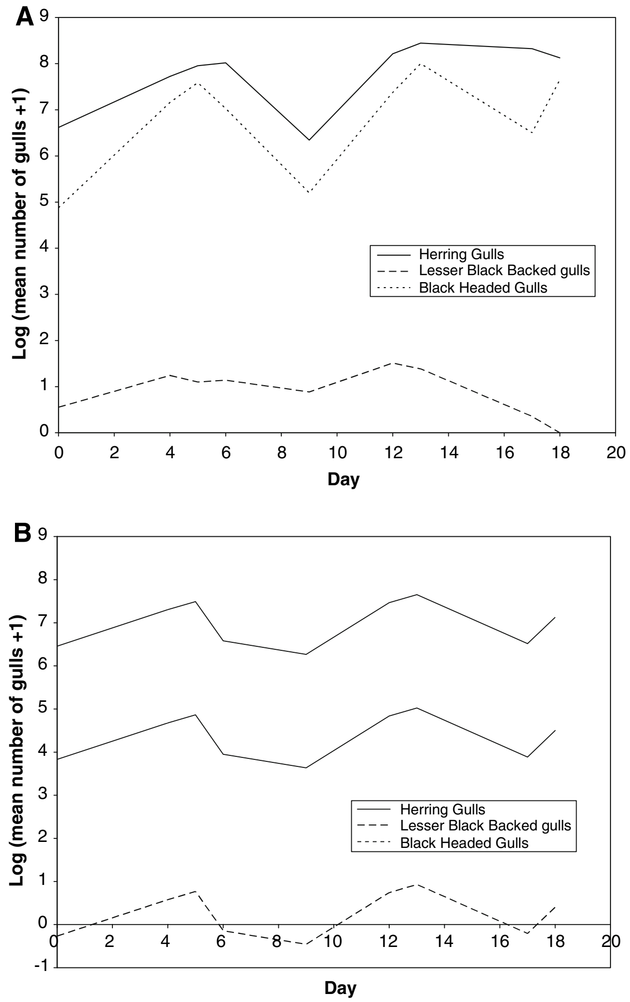

Fig. 4 The observed (**a**) and fitted (**b**) values for the trial of Helikites at Heathfield Landfill site starting in December 1999. Days 1–10, pre-control monitoring period, days 10 onwards control applied. $d^2 = 0.84$

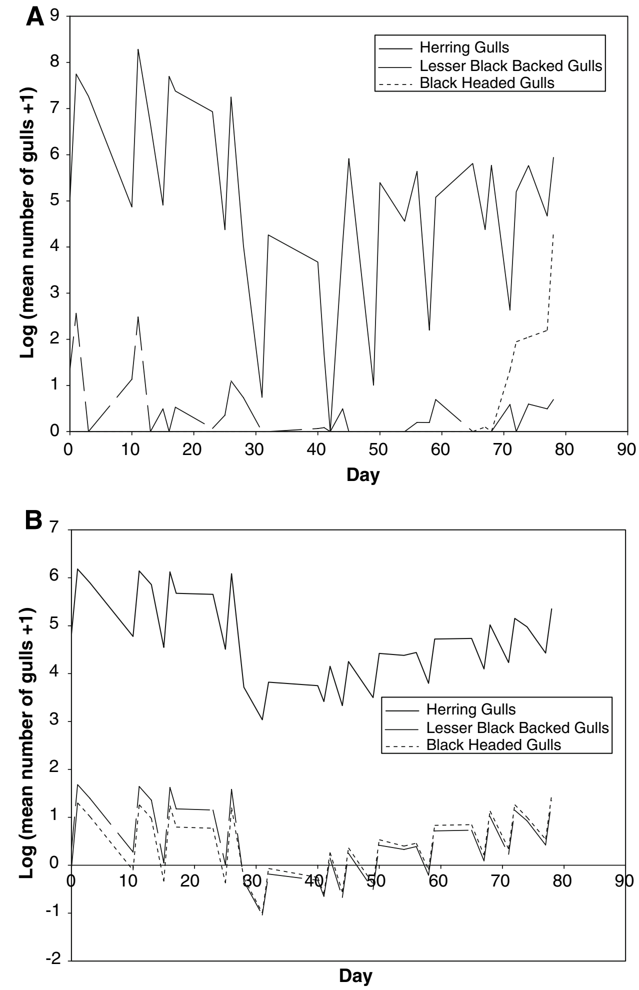

Fig. 5 The observed (**a**) and fitted (**b**) values for the trial of Pyrotechnics at Heathfield Landfill site starting in May 2000. Days 1–28, pre-control monitoring period, days 28 onwards control applied. $d^2 = 0.69$

Heathfield landfill site (Fig. 5a and b). The number of birds recorded, after control measures were introduced for the first time, then began to rise for the remainder of the trial.

The initial effectiveness (Fig. 6) and rate of habituation (Fig. 7) for each technique varied greatly, both within and between methods, and some of this variation will be explained by the model covariates. For all 3 species, distress calls and falcons produced large initial decreases. The use of static distress calls and pyrotechnics also produced large decreases among all three species. These results should be treated with caution as they are based on trials at a single location. Hawks, helium-filled bird-scaring kites, and wailers were the least effective of the control techniques included in the study. However, hawks showed a large amount of variation in their effectiveness and the results for wailers are based on a single trial. When ammunition was used, blanks were sufficient to disperse Herring Gulls; however, Lesser Black-backed and Black-headed Gulls required the reinforcement of some lethal control.

A significant interaction between control and species was recorded in 9 of the trials (Table 4). This indicates that there were inter-specific differences in the response of the birds to control. In the trials of blank ammunition and a trial of distress calls at Whitehead, falcons at Heathfield, and wailers at Pilsworth, these relationships were negative, indicating that Herring Gulls were most affected by the control. In a second trial of distress calls at Whitehead and one at Heathfield, the relationship was positive. This was also the case in trials of falcons at Pilsworth, hawks at Whitehead, and pyrotechnics at Heathfield, indicating that in these cases Black-headed Gulls were most affected by control.

The control techniques can be split into 2 groups with regards to the rate of habituation: those that increase in effectiveness over time, and those that decrease in effectiveness over time (Fig. 7). Falcons, hawks, ammunition,

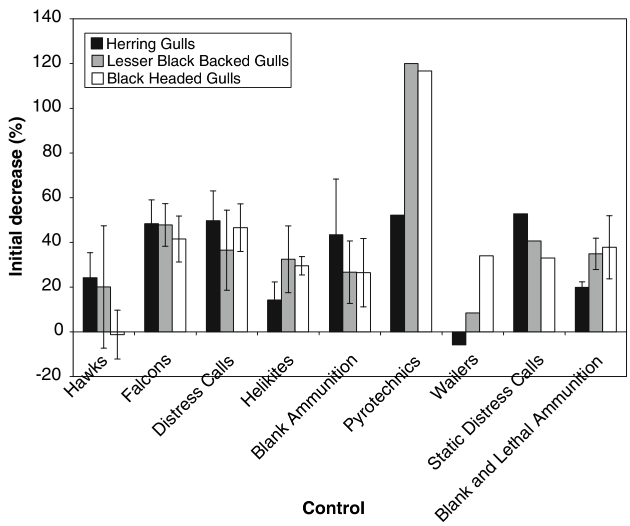

Fig. 6 The mean (%) decrease between 12 noon on the days before and after control commenced for each of the study species (+/− Standard Error) based on fitted values from models

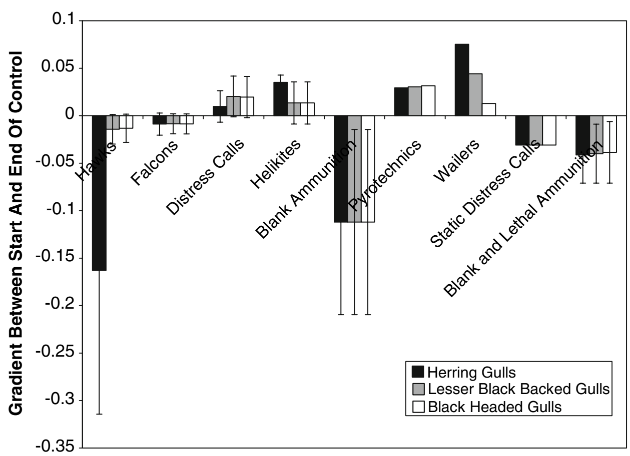

Fig. 7 The mean gradient between start and end of control for each technique and species (+/− Standard Error) based on fitted values from models

and static distress calls all showed negative gradients of bird abundance between the start and end of control, indicating that these methods improve in effectiveness over the study period. Again, however, it should be noted that these vary greatly, and that the static distress values are based on the results of a single trial. The remaining techniques all had a positive gradient between the start and end of control, indicating that they are becoming less effective over time.

Discussion

Of the techniques trialed on more than one occasion, hand held distress calls, the use of falcons, and both lethal and nonlethal use of ammunition had the greatest initial effect. Of these, the use of falcons, distress calls, and a combination of lethal and nonlethal use of ammunition were the most consistent and effective techniques. While distress calls were effective at dispersing all 3 species initially, birds became habituated to the technique. Lethal techniques, such as the use of falcons and ammunition, which reinforce visual and audio cues with the occasional death of individuals, have the opposite effect on habituation and more gulls were deterred as the trial progressed.

There was a difference between the response of the study species to hawks and to falcons. At first glance, this may seem surprising. However, falcons are more successful at capturing gulls than hawks (Baxter and Allan 2006). In addition, falcons tend to fly faster than hawks (Cramp and Simmons 1980) and the gulls may be able to outpace hawks, and therefore do not need to respond as quickly as they do to escape falcons. Two trials involving falcons, and one involving hawks, showed inter-specific differences in response to control, likely to result from differences in response to predators. Black-headed gulls showed lower initial decreases in response relative to those shown by both Herring and Lesser Black-backed Gulls. This may be a size related difference as response to predators is positively correlated with an individual's body mass (Fernandez-Juricic and others 2006), with smaller birds, such as the Black-headed Gull, being more agile, and thus able to escape predators more easily.

Distress calls have been widely used to control problem species (i.e., Andelt and Hopper 1996; Baxter 2000; Delwiche and others 2005). As a control, distress calls are often only of use for a limited period due to the effects of habituation. In addition, it is important to use the correct call. In this study distress calls were more effective at reducing the numbers of Black-headed Gulls and Herring Gulls than they were at reducing Lesser Black-backed Gulls. These differences may be due to the specific nature of distress calls (Boudreau 1968).

The use of pyrotechnics and static distress calls both had promising results for all three species. However, these are based on single trials, and, as such, further investigation is required before any firm conclusions can be drawn on their general effectiveness. Evidence from previous trials at roost sites provided mixed results (Gosler and others 1995; Olijnyk and Brown 1999). While pyrotechnics can be successful at dispersing gulls from roost sites in combination with distress calls (Gosler and others 1995), this relies on the presence of alternative roost sites nearby in order to be effective. When used in isolation over a period of years, pyrotechnics do not reduce the number of gulls at a roost, as a result of habituation (Olijnyk and Brown 1999). A number of studies have found that rotating the use and location of scaring devices, such as pyrotechnics, propane cannons, and distress calls, as well as limiting their use to critical times, reduces the rate of habituation (Littauer and others 1997; Reinhold and Sloan 1997; Stevens and others 2000; Ronconi and others 2004; Ronconi and St. Clair 2006).

Of the nonlethal techniques considered in this study, audible deterrents, such as distress calls, are more effective than purely visual methods, such as helium-filled bird-scaring kites. Other visual deterrents, such as mylar flags (Belant and Ickes 1997) and models of birds of prey (Conover 1979; Ronconi and St. Clair 2006), have also proved ineffective at deterring problem species. Even when combined with more effective techniques, purely visual stimuli have little impact on problem species (Ronconi and St. Clair 2006).

The number of organizations offering pest control, and in particular control of avian pests, has increased dramatically in recent years in the United Kingdom (BPCA 2006). However, as a result of the difficulties associated with conducting studies on large industrial sites, the focus has tended to be on a limited number of techniques on single sites and the results are often limited to the "grey" literature. In order to identify effective pest management techniques, it is important to collect data from multiple trials at multiple sites. This study illustrates the advantages of a modeling approach for dealing with the complex data that often arises from such a study.

When developing a control strategy, factors other than the effectiveness of any techniques need to be taken into consideration, such as public perception. Control of problem species has long been a contentious subject in ornithology (Grinnell 1932; McAtee 1933), and techniques with a lethal aspect are particularly controversial. Recently, however, there has been some acceptance by the public, of the need to control problem species and populations. This is especially true when there is a wider understanding of the nature of the problem (White and Whiting 2000; Barr and others 2002). There are also legal implications to consider. General licenses issued in the United Kingdom under the 1981 wildlife and countryside act do not permit the killing of the Black-headed Gull, one of the most commonly observed species on landfill sites and, as for this study, a special license must be obtained. In addition, there are limits imposed on the use of audible deterrents as a result of the 1990 environmental protection act, which has been used to prevent farmers from using such scarers (National Farmers Union 2005). As a result, the legality of any control measures must be taken into account when considering a management strategy on landfill sites.

Using a combination of the techniques that were found to be successful in this study will maximize the effectiveness of pest management schemes. We believe that it is important to both rotate the techniques used, and to use them in combination in order to minimize the effects of habituation. This study found that distress calls, falcons, and especially lethal and nonlethal use of ammunition were particularly effective at deterring problem species from landfill sites. However, distress calls were subject to habituation, suggesting that their usage should be limited and strictly on demand. They do, however, remain necessary as constraints imposed by public perception, legislation, and climatic conditions are likely to limit the use of more effective techniques, such as falconry, which involves the death of individual birds.

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References

Allan J (2002) The Costs Of Birdstrikes And Birdstrike Prevention. In: Clarke L (ed) Human Conflicts With Wildlife: Economic Considerations. US Department of Agriculture, Fort Collins, USA pp. 147–153

Andelt WF, Hopper. SN (1996) Effectiveness of alarm-distress calls for frightening herons from a fish-rearing facility. Progressive-Fish Culturist 58:258–262

Barr JF, Lurz PWW, Shirley MDF, Rushton SP (2002) Evaluation of Immunocontraception as a Publicly Acceptable Form of Vertebrate Pest Species Control: The Introduced Grey Squirrel in Britain as an Example. Environmental Management 30:342–351

Baxter A (2000) Use of distress calls to deter birds from landfill sites near airports. International bird strike committee. Amsterdam 17–21:402–408

Baxter A, St. James K, Thompson R, Laycock H (2003) Predicting the birdstrike hazard from gulls at landfill sites. International Bird Strike Committee. Warsaw 5–9

Baxter AT, Allan JR (2006) Use of Raptors to Reduce Scavenging Bird Numbers at Landfill sites. Wildlife Society Bulletin 34:1162–1168

Belant JL, Ickes SI (1997) Mylar Flags as Gull Deterrents. 13th Great Plains Wildlife Damage Control Workshop Proceedings. Lied Conference Centre, Nebraska City, Nebraska, April 16–19 1997. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Kansas pp 73–81

Blokpoel H (1976) Bird Hazards to Aircraft. Clarke, Irwin & Co. Ltd., Canada

Blokpoel H (1977) The use of falcons to disperse nuisance birds at Canadian airports: an update. Proc.World Conf. on Bird Hazards to Aircraft 3:179–187

Bomford O'Brien (1990) Sonic deterrents in animal damage control – a review of device tests and effectiveness. Wildlfie Society Bulletin 18:411–422

Bosch M, Oro D, Cantos FJ, Zabala M (2000) Short-term effects of culling on the ecology and population dynamics of the yellow-legged gull. Journal Of Applied Ecology 37:369–395

BPCA (British Pest Control Association) (2006) BPCA membership doubles over the last ten years. Professional Pest Controller 36:10–11

Brown KM, Erwin RM, Richmond ME, Buckley PA, Tancredi TJ, Avrin D (2001) Managing Birds and Controlling Aircraft in the

Kennedy Airport-Jamaica Bay Wildlife Refuge Complex: The Need for Hard Data and Soft Options. Environmental Management 28:207–224
Burger J (2001) Landfills, nocturnal foraging, and risk to aircraft. Journal of Toxicology and Environmental Health Part A.64: 273–290
Burnham KP, Anderson DR (2002) Model selection and Multi-model Inference A Practical Information-theoretic Approach. Springer-Verlag, New York
Cramp S, Simmons KEL (eds) (1980) The Birds of the Western Palearctic Volume II: Hawks to Bustards. Oxford University Press, Oxford, UK
Delwiche MJ, Houk AP, Gorenzel WP, Salmon TP (2005) Electronic broadcast call unit for bird control in orchards. Applied Engineering in Agriculture 21:721–727
Dolbeer RA, Belant JL, Sillings JL (1993) Shooting gulls reduces strikes with aircraft at John F. Kennedy International Airport. Wildlife Society Bulletin 21:442–450
Ellis TM, Bousfield RB, Bissett LA, Dyrting KC, Luk GSM, Tsim ST, Sturm-Ramirez K, Webster RG, Guan Y, Peiris JSM (2004) Investigation of outbreaks of highly pathogenic H5N1 avian influenza in waterfowl and wild birds in Hong Kong in late 2002. Avian Pathology 33:492–505
Erickson WA, Marsh RE, Salmon TP (1990) A review of falconry as a bird-hazing technique Proceedings of the Fourteenth Vertebrate Pest Conference 1990. University of Nebraska, Lincoln pp. 314–316
Fernández-Juricic E, Blumstein DT, Abrica G, Manriquez L, Bandy Adams L, Adams R, Daneshrad M, Rodriguez-Prieto I (2006) Relationships of anti-predator escape and post-escape responses with body mass and morphology: a comparative avian study. Evolutionary ecology research 8:731–752
Ferns PN, Mudge GP (2000) Abundance, diet and Salmonella contamination of gulls feeding at sewage outfalls. Water Research 34:2653–2660
Finney SK, Harris MP, Keller LF, Elston DA, Monaghan P, Wanless S (2003) Reducing the density of breeding gulls influences the pattern of recruitment of immature Atlantic puffins Fratercula arctica to a breeding colony. Journal of Applied Ecology 40:545–552
Gilsdorf JM, Hygnstrom SE, VerCauteren KC (2002) Use of frightening devices in wildlife damage management. Integrated Pest Management Reviews 7:29–45
Gorenzel WP, Blackwell BF, Simmons GD, Salmon TP, Dolbeer RA (2002) Evaluation of lasers to disperse American crows, Corvus brachyrynchos, from urban night roosts. International Journal Of Pest Management 48:327–331
Gosler AG, Kenward RE, Horton N (1995) The effect of gull roost deterrence on roost occupancy, daily gull movements and wintering wildfowl. Bird Study 42:144-157
Grinnell J (1932) Current discussion: The “control” of birds as causing popular disregard for the values of birdlife. Condor. 34:54–55
Guillemette M, Brousseau P (2001) Does culling predatory gulls enhance the productivity of breeding common terns? Journal Of Applied Ecology 38:1–8
Hollmen T, Franson JC, Docherty DE, Kilpi M, Hario M, Creekmore LH, Peterson MR (2000) Infectious bursal disease antibodies in Elder ducks and Herring Gulls. Condor 102:688–691
Ihake R, Gentleman R (1996) R: A language for data analysis and graphics. Journal Of Computational and Graphical Statistics 5:229–314
Littauer GA, Glahn JF, Reinhold DS, Brunson MW (1997) Control of Bird Predation at Aquaculture Facilities: Strategies and Cost Estimates. Southern Regional Aquaculture Centre Publication No. 402
McAtee WL (1933) The Meaning of bird control. The Wilson Bulletin 45:3–9
Monaghan P, Shedden CB, Ensor K, Fricker CR, Girdwood RWA (1985) Salmonella carriage by herring-gulls in the Clyde area of Scotland in relation to their feeding ecology. Journal Of Applied Ecology 22:669–680
National Farmers Union (2005) Code of Practice: Bird scarers. Available from http://www.malvern.whub.org.uk/home/mhc-env-birdscarers-cop.pdf (Accessed 01/06/2007)
Olijnyk CG, Brown KM (1999) Results of a seven year effort to reduce nesting by Herring and Great Black-backed Gulls. Waterbirds 22:285–289
Palmgren H, Aspan A, Broman T, Bengtsson K, Blomquist L, Bergstrom S, Sellin M, Wollin R, Olsen B (2006) Salmonella in Black-headed gulls (Larus ridibundus); prevalence, genotypes and influence on Salmonella epidemiology. Epidemiological Infection 134:635–644
Pinheiro JC, Bates DM (2000) Mixed-effects models in S and S-PLUS. First edition. Springer Verlag New York, LLC, New York, USA
R Development Core Team (2005) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria
Ronconi RA, St. Clair CC (2006) Efficacy of a radar-activated on-demand system for deterring waterfowl from oil sands tailings ponds. Journal of Applied Ecology. 43:111–119
Ronconi RA,St. Clair CC, O'Hara PD, Burger AE (2004) Waterbird deterrence at oil spills and other hazardous sites: potential applications of a radar activated on demand deterrence system. Marine Ornithology 32:25–33
Stevens GR, Rogue J, Weber R, Clark L (2000) Evaluation of a radar activated, demand-performance bird hazing system. International biodeterioration and biodegradation 45:129–137
Vogt PF (1997) Control of Nuisance Birds by Fogging with ReJeX-iT® TP-40. 13th Great Plains Wildlife Damage Control Workshop Proceedings. pp 63–67. Lied Conference Centre, Nebraska City, Nebraska, April 16–19 1997. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Kansas
Wallace JS, Cheasty T, Jones K (1997) Isolation of Vero cytotoxin-producing Escherichia coli O157 from wild birds. Journal Of Applied Microbiology 82:399–404
White PCL, Whiting SJ (2000) Public attitudes towards badger culling to control bovine tuberculosis in cattle. Veterinary Record 147:179–184