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# Experimentally Manipulating the Landscape of Fear to Manage Problem Geese.

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**Experimentally Manipulating the Landscape of Fear to Manage Problem Animals.**

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**ABSTRACT** Negative interactions between humans and wildlife are increasing, often leading to conflict between different stakeholders over appropriate management interventions; therefore effective and acceptable methods of pest and nuisance wildlife management are urgently sought. This study adopts a mechanistic approach, using knowledge of animal behavior, to develop and apply management tools aimed at solving important management issues. We experimentally tested whether introducing trained Harris's hawks *Parabuteo unicinctus* (through falconry) could be an effective management tool to reduce

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nuisance Egyptian geese *Alopochen aegyptiaca*. We hypothesised that falconry would result in elevated fear levels of geese, resulting in increased vigilance levels, reduced favorability of the site and locally reduced abundance. We conducted our study on three golf courses (one treatment and two controls) in the Western Cape, where they are considered a pest species. Our treatment involved flying the Harris's hawk directly at geese from golf carts. Vigilance levels and goose numbers were monitored before, during and after treatment. Goose vigilance levels at the treatment site increased by 76% and their numbers declined by 73% following falconry. No changes were observed at either control site. Although the hawks killed some geese, the decreases in abundance were almost three times greater than the numbers killed, indicating that indirect effects were considerably larger than the direct effect of mortality. During the treatment period vigilance levels were markedly higher in the presence of a golf cart, suggesting that geese learned to associate carts with the threat of predation. Post-treatment vigilance levels reduced significantly compared to levels detected during the treatment period and goose numbers on the experimental site increased rapidly, returning to pre-treatment levels within two months. Our results demonstrate the efficacy of falconry to reduce nuisance bird numbers and suggest there may be other applications where the deployment of trained predators can be used to mitigate negative human-wildlife interactions.

**KEYWORDS**: *Alopochen aegyptiaca*; Egyptian goose; Cape Town; falconry; landscape of fear; nuisance species; predator-prey dynamics; predation risk.

While global biodiversity continues to decline (Butchart et al. 2010), some species benefit from the continued anthropogenic induced changes to the environment to the extent their populations create management challenges (Fall and Jackson 1998, (Messmer 2009). European Starlings (*Sturnus vulgaris*) for example, can roost in large numbers in urban areas causing damage to buildings, whilst deer (*Cervus spp*), rabbits (*Oryctolagus spp*), rats (*Rattus spp*) and geese (*Branta spp*) can cause agricultural damage (Thearle 1968, Conover 2002, Leirs 2003, Hall and Gill 2005). Acceptable and effective, empirically based management solutions are urgently sought (Baruch-Mordo et al. 2011).

An array of lethal and non-lethal management techniques that vary in their efficacy have been employed to regulate problem animal populations, (Woodroffe et al. 2005). The use of lethal control is often controversial due to the public's negative perception of such measures (Conover and Chasko 1985, Loker et al. 1999, Ayers et al. 2010). Non-lethal control options such as the use of chemical repellents (Cummings et al. 1991), translocation (Massei et al. 2010), the establishment of alternative feeding areas or food sources (Redpath et al. 2001), providing economic compensation (MacLennan et al. 2009), exclusion of animals from designated areas (Graham and Ochieng 2008) and various methods of 'hazing', or persistent harassment (Conover and Chasko 1985, Castelli and Sleggs 2000), are often deemed more desirable (Coluccy et al. 2001, Shivik 2004). However, habituation to non-lethal methods has been cited as a major inadequacy, limiting their efficacy (Shivik 2004) which has resulted in an ongoing search for an effective and acceptable method for managing pest populations.

The fear of living with predators is known to have powerful effects on individuals and populations of prey species (Ripple and Beschta 2004, Laundre et al. 2010). When predators are present, prey become more vigilant and ultimately avoid areas of high predator density even at the cost of good foraging opportunities (Mao et al. 2005; Cresswell 2008; Sansom et al. 2009). By monitoring the amount of time nuisance animals spend being vigilant, we can, by proxy, determine whether the habitat is one that they perceive to be relatively safe. In situations where this is the case, the manipulation of fear has the potential to assist in the management of these problematic species.

Fear and predation risk can be increased by using falconry which is based on the idea that birds of prey can have lethal and non-lethal effects on prey population densities. Falconry has been applied to control pest birds, in residential and commercial settings (Erickson et al. 1990;), to reduce bird strikes by aircraft at airbases (McDonald 2001), to control gull populations at industrial sites (Blokpoel and Tessier 1987), to reduce corvid and gull numbers at landfill sites (Baxter and Allan 2006; Baxter and Robinson 2007), and to deter birds from crops (Daugovish and Yamomoto 1996). Despite these widespread applications, scientific evidence on the efficacy of falconry as an ecological tool is scarce. Two studies have been conducted at landfill sites in the UK, involving pseudo-experimental trials (Baxter and Allan 2006; Cook et al. 2008), and other studies have evaluated the efficacy of falconry to reduce nuisance bird populations on airfield sites (Chamorro and Clavero, 1994; Kitowski et al. 2010). These studies have suggested the success of falconry is largely site-specific, dependent on the type of raptor used, and is most effective when used in conjuction with other hazing techniques. While such pseudo-experimental studies are easier to implement, stronger inferences can be achieved through manipulative experiments with both spatial and temporal controls (Macnab 1983, Walters and Holling 1990; Johnson 2002; Reddiex and Forsyth 2006). Therefore, we aimed to experimentally test the efficacy of using trained birds of prey as agents of fear in an otherwise relatively safe habitat to reduce the local abundance of prey as a result of non-consumptive effects of predation.

In South Africa, populations of Egyptian geese (*Alopochen aegyptiaca)* (Linnaeus, 1766) have increased in recent decades (Mangnall and Crowe 2002), and are now regularly located in urban green spaces (e.g. golf courses in numbers exceeding hundreds of individuals

(Mackay et al. 2014). Large numbers of geese have created a significant problem for golf course managers, with concerns ranging from green and fairway damage, noise pollution, and harassment of native birdlife (Little and Sutton 2013).

We monitored goose vigilance levels and abundance at three golf courses before and after introducing falconry at one of these sites, while keeping the remaining two as controls. Also, we continued monitoring at the experimental site after the falconry had ceased. We hypothesised that exposing the geese to regular predator encounters at the treatment site would alter their perception of predation risk and their landscape of fear which would be reflected in a change in local habitat use, with geese moving away from the treatment site. We predicted an increase in their vigilance levels and a reduction in goose numbers at the treatment site relative to our control sites. Furthermore, because the raptors were flown from golf carts, we predicted that increase in vigilance levels at the experimental site would be more pronounced and sustained in the presence of golf carts than at the control sites.

## STUDY AREA

The study was conducted at three golf courses in the Western Cape, South Africa. Two golf courses, Steenberg (34°04'07" S, 18°25'36" E) and Westlake (34°08'0" S, 18°44'13" E), were control sites, where no falconry was conducted. The treatment site was conducted at Rondebosch Golf Club (33°57'25" S, 18°29'44" E). The two control sites were 3 km apart and were 15 km from the experimental site, all sites were located in suburban areas of Cape Town. Westlake and Steenberg golf courses were located close to the Zandvlei and Strandfontein wetlands, which were important areas of safety for roosting and moulting geese (Ndlovu et al. 2013). Rondebosch golf course is intersected by the Black River, and is close to three other golf coursesand the Raapenberg bird sanctuary, which all offer suitable habitat for Egyptian geese. On average the golf courses occupy 50–60 ha (Fox and Hockey 2007) and were used daily from sunrise until sunset throughout the year.

## METHODS

We recorded Egyptian goose vigilance behaviour once per week for 26 weeks at each golf course between mid-June 2014 and mid-January 2015, with an additional eight weeks of vigilance observations post-falconry at Rondebosch. The same methodology as used by Mackay et al. (2014) were followed and are detailed here. Vigilance filming was conducted on groups of geese of three or more birds. On most occasions, each filming day consisted of five filming bouts (watch-bouts), each of 15 minutes in duration. Watch-bouts were randomly spread throughout the afternoon, between 1200 and 1800, and with a similarly even spread for each golf course. We conducted 122 watch-bouts at Steenberg, 107 at Westlake, and 137 at Rondebosch. Different groups of geese were filmed for each of the five watch bouts to minimise pseudo-replication (Hurlbert 1984). Filming took place during the afternoons when the birds forage most actively (Halse 1985). Sleeping geese were not recorded. A Panasonic SDR-S50 video camera (Panasonic Corporation, Osaka, Japan) mounted on a 1.7-m tripod was used to record footage of the geese. The cameras and golf carts were positioned at least 10 m from the geese, so the observer did not influence vigilance behaviour (Mackay et al. 2014). For each watch-bout, the observer filmed the geese either on foot or from a golf cart. The filming was divided as evenly as possible between these two methods. The observer recorded the group size and the filming method for each watch-bout.

Vigilance behaviour was characterized as visual scanning performed by the geese, which increases the probability of detecting predators (Dimond and Lazarus 1974). Thus, a goose was deemed vigilant if its head was above the level of its back and non-vigilant when its head was below body level, which is a suitable assumption considering the foraging strategy of Egyptian geese (Barbosa 2002). Each watch-bout was paused at ten second intervals and the proportions of vigilant (heads up) geese and non-vigilant (heads down) geese within the frame were counted. For each watch-bout, we calculated the sum of the number of vigilant and non-vigilant geese recorded, which was used as the response variable in subsequent data analyses. Also, we recorded the number of geese in the group (which may differ from the numbers being filmed at any one time of the watch-bout). A group was defined as all birds within 30 m of one another. During the watch-bout, any observations occurring during a major disturbance to geese by golfers, a golf cart, lawn mowers or ground staff were excluded to ensure that the vigilance levels of the geese being observed reflected natural behaviour rather than vigilance initiated by human presence.

Absolute counts of Egyptian geese on each course were conducted twice per week for 29 weeks, between mid-June 2014 and mid-January 2015, and for an additional eight weeks at the experimental site following the cessation of falconry. Geese were counted from a golf cart along a pre-mapped route to avoid double counting. Counts were randomly spread throughout the morning, between 0600 and 1200, and the timing of counts was similar for each golf course. We conducted 54 counts at Steenberg, 56 at Westlake, and 60 at Rondebosch.

Additionally, at Rondebosch we carried out an additional 13 counts post-falconry. No additional counts were conducted at the two control sites because goose management activities changed at these sites after the treatment period and we could no-longer use these as viable control sites. Flightless goslings were not included in the final count data.

Falconry was conducted by independent registered falconers (Avian Pest Control (Pty) Ltd, trading as Raptor Force) with trained Harris's hawks (*Parabuteo unicinctus)* (Temminck 1824). Two different birds were used in the treatment. The falconer's objective was to harass the geese rather than to kill them.

Falconry was conducted for nine weeks, from 10 November 2014 until 10 January 2015. The first month involved a relatively persistent presence of the hawk at the course. Thus, falconry took place for a minimum of one hour a day, five days a week for the first week, reducing to one treatment day per week by weeks seven to nine (Fig. 1).The hawk was always flown from a golf cart. The handler and the hawk led in the front cart, whilst the data recorder followed in a second cart. The falconer approached the geese in the cart and released the hawk (an attack flight, referred to hereafter as a slip) onto the geese from varying distances so as to avoid potential habituation. Target areas within the golf course were chosen according to where geese had been seen during counts, and to ensure comprehensive coverage of the entire golf course throughout the study period.

All population counts and vigilance filming undertaken at the treatment site were undertaken at times when no falconry was taking place.

**Data analysis**

Statistical analyses were carried out using the statistical package R version 3.1.2 (R Development Core Team 2014). Means are presented with upper and lower 95% confidence limits.

In all analyses of vigilance levels, we used a generalised linear mixed-effects (GLMM) model using the lme4 package in R (Bates et al. 2014), fitted with a binomial error distribution. In all models, we controlled for the non-independence of records taken on the same day, by including the day on which filming took place at each site as a random effect. Our binomial response variable was the sum of the number of vigilant geese and the number of non-vigilant geese for each watch-bout. A previous analysis indicated an effect of group size on Egyptian goose vigilance levels (Mackay et al. 2014). Therefore, before examining for an effect of treatment on vigilance levels, we controlled for the initial group size during each watch-bout to test whether vigilance differed at each site before or during the treatment period. The model included the following fixed effect terms – site, treatment (two-level factor: pre-treatment and treatment) and the interaction between site and treatment.

Because hawks were flown at the geese from golf carts, we predicted that geese may associate the potential predation risk with the presence of a cart and become more vigilant around carts in general at the treatment site. Therefore we explored whether there were differences between vigilance levels filmed on foot, or from a cart, before and during the treatment period at the different sites. To do this we fitted a three-way interaction between site, treatment (before/during) and filming method (foot/cart). We additionally had information on the vigilance levels at the experimental site following the end of falconry. To explore how these levels changed, we used the model with data only from the treatment site and examined this using a three-level factor (pre-treatment, treatment and post-treatment) with the same binomial GLM.

Counts of Egyptian geese were analysed using a Generalised Linear Model (GLM), fitted with a Poisson error distribution. We tested for significant differences in the abundance of Egyptian geese between sites, and for an interaction between site and goose counts before and during the treatment period, our prediction was that if falconry was effective, reductions in goose numbers would be greater at the treatment site during the period when falconry was being implemented compared to the control sites. Therefore, the model included the following fixed effect terms: site, treatment (two-level factor: pre-treatment and treatment) and the interaction between site and treatment. Where a significant interaction was detected, we used a pairwise comparison to test between sites before and during the treatment period, using the LSmeans package (Lenth 2015). Additionally, we analysed goose abundance at the experimental site following the end of falconry. To explore how these levels changed we used the model with data only from the treatment site and examined this using three-level factor (pre-treatment, treatment and post-treatment) with the Poisson GLM.

## RESULTS

A Harris's Hawk was flown at geese 123 times at the treatment site. Goose fatalities (n=41) during this period averaged nine geese per week for the first three weeks, and two geese per week for the remaining seven weeks (Fig. 1).

After controlling for the influence of group size, there was a significant interaction between site and treatment ($\chi^2$ = 32.5, $df_{2,358}$, *P* = <0.01) on vigilance levels (Fig. 2). There was a significant increase in vigilance at the Rondebosch treatment site (Z = 5.6, *P* = <0.01), from 0.21 of the geese being vigilant pre-treatment (95% CL 0.178-0.244), to 0.37 (95% CL 0.324-0.416), equivalent to an approximate increase of 76%. Conversely, between this period there was a significant decrease (Z= -2.3, *P*= 0.02) in mean vigilance levels at the Steenberg control site from 0.20 (95% CL 0.170-0.230) to 0.14 (95% CL 0.116-0.180). No change in vigilance level was recorded at Westlake (Z= -0.5, *P*= 0.63) (before: 0.161 (95% CL 0.135-0.188; during: 0.150 (95% CL 0.120-0.188)). Examining vigilance levels at the treatment site across the three periods, we detected significant differences in vigilance levels between the pre-treatment, treatment and post-treatment period ($\chi^2$ = 19.9, $df_{2,181}$, *P* = <0.01).Vigilance levels post-treatment reduced to 0.26 (95% CL 0.21-0.32) (Fig. 2) which was significantly different from the vigilance levels during the treatment period (Z = -0.5, *P* = 0.01) and similar to the vigilance levels pre-treatment (Z = -2.6, *P* = 0.16).

Before falconry, goose numbers at the three sites showed similar fluctuation, with a generally increasing trend (Fig. 3). However, during this pre-treatment period, there were, on average, 50% fewer geese at the experimental site (Rondebosch: $\bar{x}$=100 (95% CL 97-103)) than at either of the control sites (Steenberg: $\bar{x}$ = 208 (95% CL 203-213) and Westlake: $\bar{x}$ = 211 (95% CL 207-216)). Following the introduction of falconry in November, the mean abundance of geese at the treatment site fell rapidly from 148 geese to only eight geese within two weeks, and remained below 30 geese with a mean of 27 individuals for the duration of the treatment period (Fig. 3).

We detected a significant interaction between sites during the pre-treatment and treatment periods ($\chi^2$ = 808, $df_{2,187}$, $P$ = <0.01) (Fig. 4). Mean numbers of geese increased significantly at the two control sites during the treatment period. At Steenberg geese increased from 208 individuals (95% CL 203-213) before treatment, to 297 individuals (95% CL 289- 304) during the treatment period (Z = 19.8, $P$ = <0.01), while at Westlake mean numbers increased from 211 (95% CL 207-216) to 280 (95% CL 272-288) (Z= 15.6, $P$= <0.01). Conversely, at the treatment site there was a significant decrease in mean goose numbers from 100 individuals (95% CL 97-103) pre-treatment to 27 individuals (95% CL 25-29) during treatment (Z = -19.9, $P$ = <0.01), representing a reduction in mean abundance of c. 73% (Fig. 3). After falconry ceased, the abundance of geese at the treatment site increased rapidly (Fig. 3). Examining the counts at the treatment site alone across all three treatment periods, we detected significant differences ($\chi^2$ = 1539, $df_{2,70}$, $P$ = <0.01). The mean abundance of 129 individuals (95% CL 123-135), post treatment was significantly greater than the mean during treatment (Z = - 32.7, $P$ = <0.01) and similar to the vigilance levels pre-treatment (Z = -2.6, $p$ = 0.16) (Fig. 4).

Following the introduction of falconry, vigilance levels at the experimental site were highest when filmed from a cart (+140%) compared to when filmed on foot (+25%), a relationship not detected at the control sites (Fig. 2 and Table 1). The three-way interaction between site, treatment period (pre-treatment/treatment) and filming method (on foot or by cart) was significant ($\chi^2$ = 504.3, $df_{2,353}$, $P$ = <0.01) (Fig. 2 and Table 1). In fact, at the treatment site pre-treatment vigilance was significantly lower when filmed from a cart (0.187 vigilance (95% CL 0.158-0.220)) than when filmed on foot (0.236 vigilance (95% CL 0.201-0.270)) (Z = -8.7, $P$ = <0.01). However, mean vigilance levels during treatment were significantly greater ($Z = 24$, $P = <0.01$) when filmed from a cart (0.452 vigilance (95% CL 0.403-0.50)) than when filmed on foot (0.285 vigilance (95% CL 0.245-0.270)). Post-treatment, vigilance levels filmed from a cart decreased by 41% to a mean of 0.265 (95% CL 0.211-0.327) and were significantly lower than the vigilance levels recorded from a cart during the treatment period ($Z= 4.2$, $P= <0.01$). However, vigilance levels in the presence of a cart were more than 40% higher than pre-treatment levels ($Z= -2.3$, $P= 0.02$). In contrast, vigilance levels at the treatment site filmed on foot during the post-treatment period (0.242 vigilance (95% CL 0.192-0.301)) were similar to those recorded before ($Z= -0.2$, $P=0.85$) and during treatment ($Z= 1.1$, $P= 0.27$).

## DISCUSSION

The use of trained birds of prey can significantly alter the perceived risk of predation among Egyptian geese as demonstrated by the significantly higher levels of vigilance recorded under treatment conditions than those during non-treatment conditions and at control sites. During falconry, vigilance levels at the treatment site increased by 76% and vigilance levels post treatment reverted to levels similar to those observed at the control sites during the pre-treatment period. However this did not happen immediately, indicating that some geese remained cautious for some time after the cessation of falconry. As far as we are aware, this is the first study to demonstrate changes in anti-predator behaviour in a target species as a result of falconry. Our results are consistent with modelled results (Bednekoff and Lima 1998) and empirical studies in avian species (Devereux et al. 2005) and mammals (Laundre et al. 2001; Li et al. 2009).

During the month before the falconry experiment, mean goose abundance at the treatment site was 148 individuals. The mean abundance of geese during the entire treatment period was 27 individuals (95% CL 25-29), representing an overall reduction of 73% when compared to the entire non-treatment period and 82% when compared to the mean goose abundance during the month preceding falconry. This decrease in goose abundance can largely be attributed to the non-lethal effects of predation pressure, the initial lethal impact representing just 14% of the initial reduction. Predator avoidance by habitat selection is widespread in the animal kingdom and has been demonstrated to occur in a variety of taxa (Ripple and Beschta 2004; Mao et al. 2005; Cresswell and Whitfield 2008). This experiment demonstrates that falconry is an effective application of this naturally occurring phenomenon, and can be used as a management tool to manipulate the risk of predation perceived by geese and other nuisance species to reduce their numbers. Earlier studies describe the success of falconry as site-specific and dependent upon the species of raptor used (Daugovish and

Yamomoto 1996; Baxter and Allan 2006; Kitowski et al. 2011), citing habituation as a major inadequacy (Cook et al. 2008; Soldatini et al. 2008). While fatalities in this study were higher than anticipated, they were reduced dramatically after the first two weeks of falconry to two individuals per week, which reinforces that no habituation to falconry occurred.

We predicted that the geese could learn to associate golf carts with the threat of predation since the hawks were always flown from the cart. While vigilance levels at the experimental site increased during falconry, there was a 140% increase in mean vigilance when the geese were filmed from the cart compared to an average increase in vigilance of just 25% when filmed on foot. Furthermore, there was still some recognition of a possible threat posed by the cart for some time after the cessation of the falconry. This was the reverse prior to treatment, where geese were more vigilant in the presence of an observer on foot than when in a cart. Our results demonstrate that geese became conditioned to fear golf carts as an indicator of increased predator risk.

Learning is widespread in the animal kingdom; many species alter their behaviour as a result of environmental information (Dukas 1998) and predator avoidance behaviour is known to improve with experience (Griffin 2004). Learning to respond to the cart as a potential threat is a form of associative learning traditionally referred to as classical conditioning, whereby a biologically insignificant event or object (the conditional stimulus), in this case the cart, is paired with a biologically significant event (Pavlov 1927), in this case an attack by a predator. Conditioned fear responses have been observed in a number of studies (Herzog and Hopf 1984; Chivers and Smith 1995; McLean et al. 1999). Golf carts are in constant use on a golf course, using them to release the hawk manipulated a previously neutral feature of this habitat, turning the carts into a new source of potential risk. The overall effect of falconry is enhanced, as geese become more vigilant in close proximity to a cart and are able to devote less time to foraging, thus further reducing the overall attractiveness of the habitat.

The results of this study, while they appear to be convincing are based on one treatment replicate. Stronger inferences can be made from experimental designs that consist of replicated treatment and control areas (Hurlbert 1984; Reddiex and Forsyth 2006; Prosser 2010). Due to the logistical problems of having more than one replicate treatment site for this study, the control site was instead replicated (Oksanen 2001). Additionally our results are backed up by changes in the levels of vigilance and strengthened by our post-treatment monitoring which showed that numbers and vigilance returned to pre-treatment levels following the end of falconry.

**MANAGEMENT IMPLICATIONS**

From a management perspective, it is important to note that falconry needs to be continuously applied to remain effective, evidenced by the post-treatment decrease in vigilance and increase in abundance (Figs 2 and 4). While an expensive option for wildlife managers the frequency of falconry visits can be reduced without compromising the efficacy of the technique as long as habituation is avoided. Previous studies reported the need to combine a number of methods of control to avoid habituation (Cook et al. 2008; Soldatini et al. 2008). Incorporating even a very low level of lethality can effectively instil enough of a consequence to ensure habituation is avoided (Baxter and Allan 2007). While we did not observe any habituation, we hypothesise that, while the non-lethal effect of falconry is demonstrably strong, its efficacy as a tool may indeed be reliant upon reinforcement, instilled by the few but regular instances of fatalities. Future studies would benefit from testing the efficacy of such tools under strictly non-lethal conditions.

Recent research has highlighted the importance of adopting a mechanistic approach, using knowledge of animal behaviour to develop tools to solve critical conservation and management problems (Blumstein and Berger-Tal 2015). In addition, it is vitally important when applying mechanistic knowledge to management problems, to evaluate the efficacy of management actions, with emphasis on experimental design (Walters and Holling 1990; Redpath 2013; Blumstein and Berger-Tal 2015). This study has demonstrated the merit of such an approach and our results indicate there may be other applications where the use of trained birds of prey can be used to mitigate negative human-wildlife interactions.

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*Associate Editor:*

**Figure captions:**

Figure. 1. Numbers of days per week that falconry was carried out (bars), the number of slips (attack flights) per week (—●—) and the number of Egypitian goose ***(Alopochen aegyptiaca)*** fatalities per week (- -▲- -). All falconry was carried out with a Harris's hawk ***(Parabuteo unicinctus)*** flown during the nine weeks between 10 November 2014 and 10 January 2015 at the Rondebosch Golf Club, Cape Town, South Africa.

Figure. 2. Mean proportion vigilance for Egyptian geese ***(Alopochen aegyptiaca)*** before and after the treatment at both control sites (dashed lines) and the treatment site (solid lines). Vigilance levels when filmed on foot (open circles) compared to when filmed from a cart (open triangles) are contrasted for each site. The means and their 95% confidence limits depicted are the results of a generalised linear model. The interaction between site, before/during treatment and by cart/on foot was significant ($p = <0.01$). The effect of group size and random variations between watch days were controlled for.

Figure. 3. Twice weekly averages of Egyptian geese counts ***(Alopochen aegyptiaca)*** ***(Alopochen aegyptiaca)*** at both control sites (dashed lines) and at the treatment site (solid line). Vertical dashed lines indicate the falconry treatment period between 10 November 2014 and 10 January 2015 which occurred at the experimental site (Rondebosch Golf Club).

Figure. 4. Mean abundance of Egyptian geese ***(Alopochen aegyptiaca)*** before and during the treatment period at both control sites (dashed lines) and at the treatment site (solid line) as well as post-treatment at the experimental site (Rondebosch Golf Club). The means and their 95% confidence limits depicted are the results of a general linear model. The interaction between site and treatment (before/after) was significant ($p = <0.01$).

Table 1. Mean vigilance of Egyptian geese (***Alopochen aegyptiaca)*** filmed on foot and from a golf cart at the three golf courses during the study period. Parameter estimates and significance values of pairwise contrasts are also presented. 'Before' refers to pre-treatment period and 'during' refers to the treatment period.

| | On Foot | | | | | |
|---|---|---|---|---|---|---|
| | before | | during | | before - during | |
| Site | Mean vig | 95%CI | Mean vig | 95%CI | Z ratio | *P* Value |
| Steenberg | 0.184 | 0.157-0.210 | 0.156 | 0.124-0.190 | -1.2 | 0.22 |
| Westlake | 0.155 | 0.130-0.180 | 0.161 | 0.123-0.200 | 0.2 | 0.8 |
| Rondebosch | 0.236 | 0.201-0.270 | 0.285 | 0.245-0.330 | 1.8 | 0.08 |
| | By Cart | | | | | |
| | before | | during | | before - during | |
| Site | Mean vig | 95%CI | Mean vig | 95%CI | Z ratio | *P* Value |
| Steenberg | 0.211 | 0.181-0.240 | 0.135 | 0.107-0.170 | -3.3 | <0.01 |
| Westlake | 0.168 | 0.141-0.200 | 0.142 | 0.111-0.180 | -1.1 | 0.27 |
| Rondebosch | 0.187 | 0.156-0.220 | 0.452 | 0.403-0.500 | 8.8 | <.01 |

**Summary of conclusions and management implications**

We demonstrate the efficacy of falconry to reduce nuisance bird numbers and highlight the benefits of adopting a mechanistic approach, using knowledge of animal behavior, to develop and apply management tools aimed at solving important management issues.

**Figure. 1**

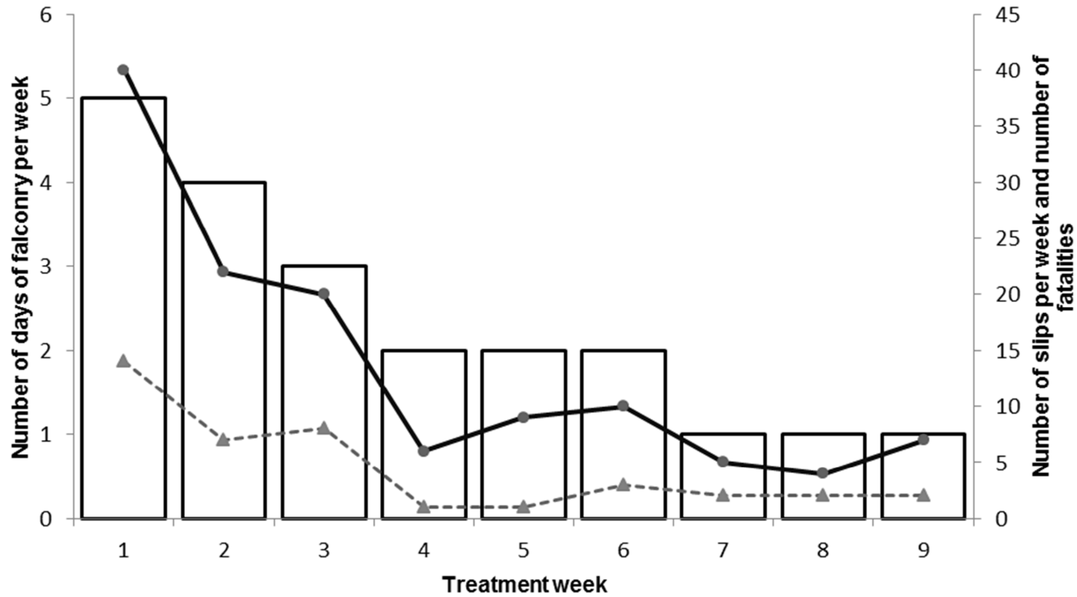

6
5
4
3
2
1
0
Number of days of falconry per week
45
40
35
30
25
20
15
10
5
0
Number of slips per week and number of fatalities
1
2
3
4
5
6
7
8
9
Treatment week

**Figure. 2**

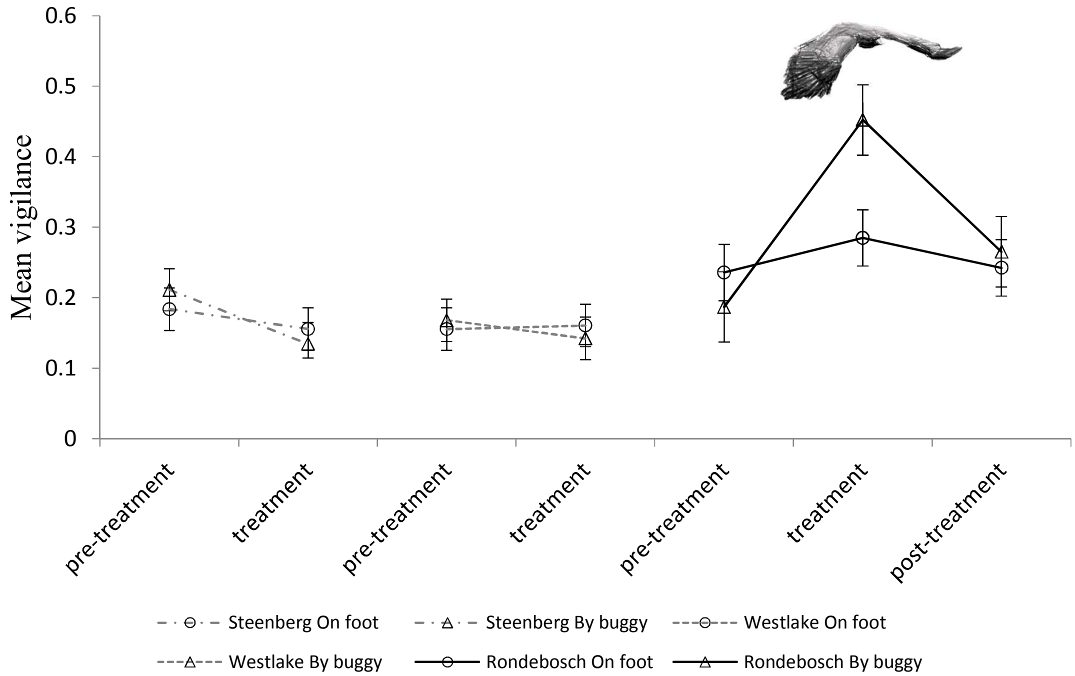

0.6
0.5
0.4
0.3
0.2
0.1
0
Mean vigilance
pre-treatment
treatment
pre-treatment
treatment
pre-treatment
treatment
post-treatment
Steenberg On foot
Steenberg By buggy
Westlake On foot
Westlake By buggy
Rondebosch On foot
Rondebosch By buggy

Figure. 3

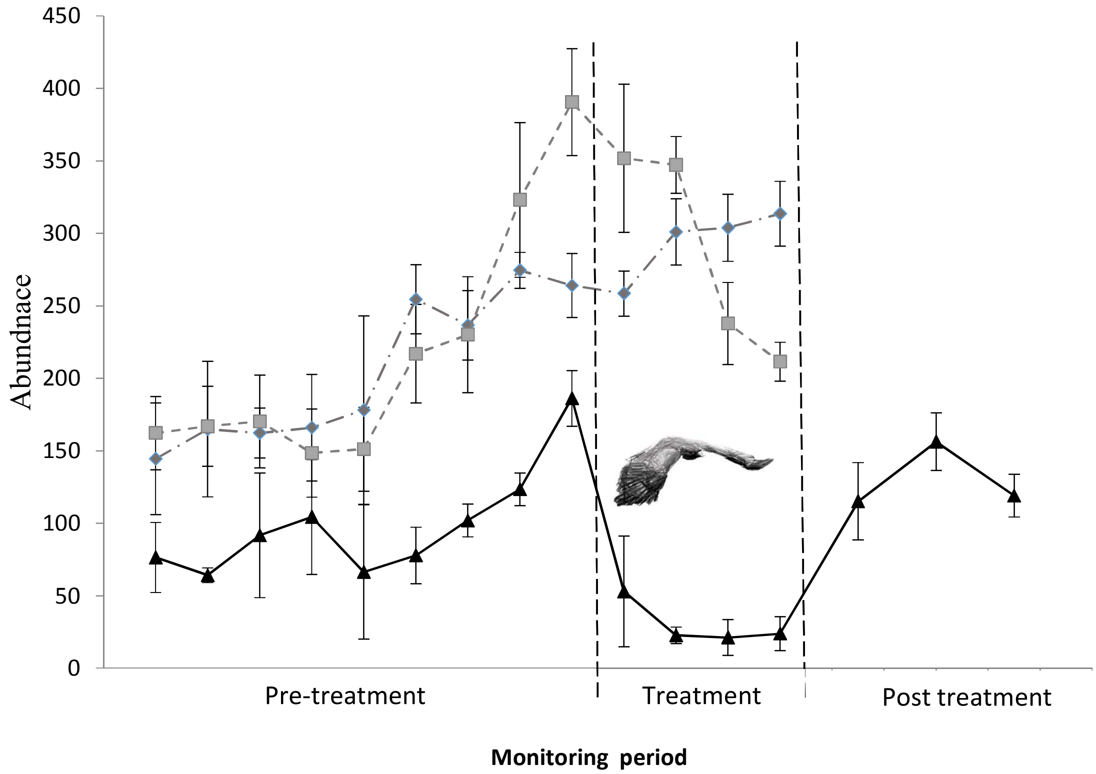
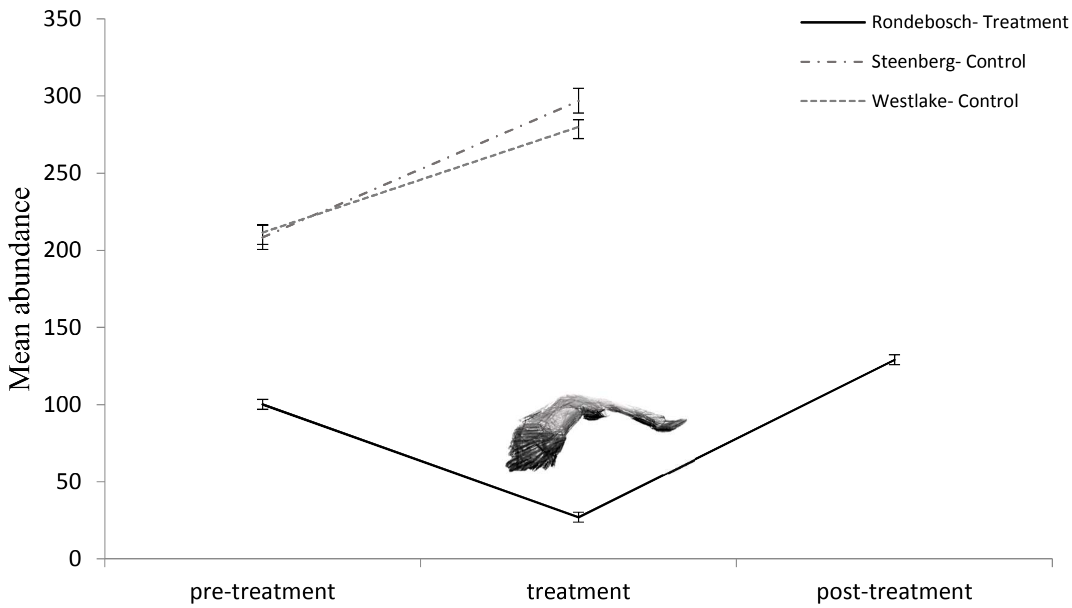

450
400
350
300
250
200
150
100
50
0
Abundnace
Pre-treatment
Treatment
Post treatment
Monitoring period

**Figure. 4**


350
300
250
200
150
100
50
0
Mean abundance
pre-treatment
treatment
post-treatment
Rondebosch- Treatment
Steenberg- Control
Westlake- Control