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# The effectiveness of regulatory signs in controlling human behaviour and Northern gannet (*Morus bassanus*) disturbance during breeding: an experimental test

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## ABSTRACT

Human disturbance to wildlife is on the rise and disturbance management is a key activity in conservation. Although disturbance can be controlled with relative ease in nature reserves that are properly resourced and managed by employed staff, most reserves do not fall into this category, and most wildlife exists outside managed reserves entirely. Thus, developing and demonstrating the effectiveness of simple, low-cost approaches to minimising disturbance is an important objective in conservation. In this study we examine the effectiveness of regulatory signs in controlling the behaviour and impacts of visitors on a colonial island-nesting bird, the Northern gannet (*Morus bassanus*), on an unmanaged island. First, we found that the percentage of successful nests declined with proximity to the disturbed edge of the colony, and was much higher in an undisturbed control area. Second, the number of birds displaced by visitors correlated negatively with the minimum visitor approach distance. Third, visitor proximity to the colony was dramatically reduced in the presence of a regulatory sign in comparison to periods without signs, which resulted in fewer birds being displaced from their nests. Photographers were the only visitor group who didn't always comply with the sign. Our results show that breeding success in a species often thought to be well adapted to human presence, suffers from tourist pressure, and that simple and informative regulatory signs can be a cost-effective way of reducing the disturbance caused by visitors at unmanaged wildlife sites.

## 1. Introduction

Disturbance can be defined as an event or continuous occurrence that promotes a physical or psychological change in an individual, thus affecting its ability to exploit its surroundings and carry out normal behaviours (Coetzee & Chown, 2015; Geffroy, Samia, Bessa, & Blumstein, 2015; Weston, Dodge, Bunce, Nimmo, & Miller, 2012). Disturbances to wildlife that lead to changes in state, can in turn reduce fitness of both parent and offspring (Carney & Sydeman, 1999; Coetzee & Chown, 2015; Gill, 2007; Palacios, D'Amico, & Bertellotti, 2018; Tarlow & Blumstein, 2007). Commonly these negative effects for young arise through a direct impact on parental investment, either by reducing offspring care and viability (Verhulst, Oosterbeek, & Ens, 2001), or because animals abandon the current breeding attempt entirely (Tremblay & Ellison, 1979). In some species, habituation can reduce the

impact of disturbance (Nisbet, 2000; Steidl & Anthony, 2000; Villanueva, Walker, & Bertellotti, 2014; Walker, Boersma, & Wingfield, 2006; Webb & Blumstein, 2005) but some species never habituate (Bleich, Bowyer, Pauli, Nicholson, & Anthes, 1994), or appear to habituate behaviourally but sustain long-term physiological impacts that are harder to measure (Cyr & Romero, 2009; Walker, Boersma, & Wingfield, 2005, 2006). Despite the wide range of potential negative effects that tourism-disturbance can have on wildlife, disturbance continues to be a major problem worldwide, especially outside nature reserves, and experimental evidence for the effectiveness of counter-disturbance measures is limited.

Management of tourist sites is often vital when controlling disturbance (Burger, 2003; Hill et al., 1997; Rodgers & Smith, 1997). Spatial and temporal closures, buffer zones, and physical barriers such as fences can work to change the animal's perception of a threat, and to stop

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visitors advancing too close (Batey, 2013; Ikuta & Blumstein, 2003; Knight & Gutzwiller, 1995), while warden systems can help enforce rules and regulations regarding appropriate behaviour and respectful distances (Burger, 2003). However, these measures are expensive and can take away from the visitor experience. On the other hand, passive education in the form of verbal interpretation or signage can be a cost-effective approach to changing visitor behaviour without greatly impacting the touristic value of the site (Marschall, Granquist, & Burns, 2017; Medeiros et al., 2007; Zeppel & Muloin, 2008). It has long been assumed that signs are an effective way of enhancing visitor experience and promoting sustainable interactions with wildlife (VanderWalde, 2007; Zeppel & Muloin, 2008). Ham and Krumpke (1996) outline methods of changing behaviours by changing beliefs about wildlife via interpretation. Few studies, however, have tested how effective signage is at modifying human behaviour and their subsequent effects on wildlife. Experimental signage has been shown to have some success in modifying visitor behaviour when put up near sensitive seal sites without wardens (Marschall et al., 2017), and wardening and signage used together resulted in Little Terns (*Sternula albifrons*) being 34 times more likely to nest successfully (Medeiros et al., 2007). Sign design is also important (Acevedo-Gutierrez, Acevedo, Belonovich, & Boren, 2011; Barton, Booth, Ward, Simmons, & Fairweather, 1998); for example Marschall et al. (2017) found that signs were most effective if rationale for their use was included, not just a simple instruction. Despite the widespread belief that signs are an integral part of disturbance management, few experimental studies are available that clearly demonstrate the effectiveness of their usage.

Birds are among the most threatened taxa in the world, and seabirds in particular are among the most at risk (European Commission (EC), 2016). Although the reasons for this are diverse, increasing tourism is likely to increase the pressure some species and populations are under (Hockin et al., 1992). Human disturbance has been shown to impact birds causing reduced immunity (Palacios et al., 2018), reduced feeding time (Lafferty, 2001), changed patterns of habitat use (Fernández-Juricic & Tellería, 2000; Jakubas & Manikowska-Ślepowańska, 2013), altered foraging sites (Finney, Pearce-Higgins, & Yalden, 2005), reduced incubation (Verhulst et al., 2001) and provisioning (Verhulst et al., 2001), increased nest failure (Bolduc & Guillemette, 2003) and predation (Frid & Dill, 2002; Tremblay & Ellison, 1979), and site abandonment (Webber, Heath, & Fischer, 2013). Ground-nesting birds are at particular risk when nesting in accessible locations (Andresen, 2015), and those that infrequently encounter terrestrial predators, such as seabirds, are also distinctly susceptible (Chardine & Mendenhall, 1998). After long-term disturbance, seabirds have shown increased heart rates consistent with an imminent fight or flight response (Holmes, Giese, & Kriwoken, 2005), high levels of stress-induced corticosterone (Ellenberg, Setiawan, Cree, Houston, & Seddon, 2007; Villanueva et al., 2014), reduced foraging (Velando & Munilla, 2011), nest failures (Anderson & Keith, 1980; Ellenberg et al., 2007), high nestling mortality rates (Watson, Bolton, & Monaghan, 2014; Wheeler, 2009), increased nestling predation (Piatt, Roberts, Lidster, Wells, & Hatch, 1990), abandonment of nests and skipping of a breeding year (Carney & Sydeman, 1999). Studies investigating the use of signs at seabird locations are limited to one (Medeiros et al., 2007), and none have tested experimentally whether their use can be of benefit at unmanaged sites in the absence of formal wardening.

The Northern gannet (*Morus bassanus*) is a long-lived seabird that nests colonially on cliffs in the North Atlantic. It lays one egg, while parents share incubation and brooding duties, alternating foraging trips to sea (Hamer et al., 2007; Lewis et al., 2004). Leaving the nest unattended carries a high risk of predation from gulls, temperature stress, or conspecific sabotage (Nelson, 1963). As a K-strategist, the gannet is thought to have a higher likelihood of nest abandonment in areas of high disturbance than other species (Stearns, 1992). Our study site, Great Saltee, is a privately-owned island that supports 4700 breeding pairs of Northern gannets (Newton, Lewis, & Trewby, 2015). It is the main one of

two islands that form the Saltee Islands Special Area of Conservation and Special Protection Area, under the EU Habitats Directive and Birds Directive respectively (European Commission (EC), 2016). Here the Northern gannet is listed as a species of special conservation interest, with an objective to maintain favourable conditions for their continued breeding success (National Parks and Wildlife Service (NPWS), 2011). Throughout the summer season, a ferry runs trips several times daily carrying tourists to the island, which can reach 100 visitors a day in peak times (personal communication with ferry owners). Not only is the island un-managed and un-wardened, visitors are provided with few guidelines regarding appropriate behaviour, and there are no restrictions as to where people can walk.

We examined the effectiveness of signage at deterring human disturbance at this colony of the Northern gannet (*M. bassanus*). Our aims were: 1) to quantify the effect of disturbance on breeding success on Great Saltee; 2) to quantify visitor disturbance on bird behaviour; 3) to experimentally test the effect of signage on visitor and 4) gannet behaviour. Specifically, we expected that disturbance would increase with increasing visitor numbers and increasing proximity to the colony, and that the addition of a sign would reduce close approaches and the numbers of birds that flew from the nest.

## 2. Methods

Data were collected during the breeding season on Great Saltee Island (Lat: 52.125/Long: -6.597222) from the start of May to the middle of July 2017. Landing on the island was permitted only between 11 a.m. and 4 p.m., and so observations at the gannet colony only took place between 12 and 3.30 p.m., allowing for travel/set up time. All of the experimental and most of the observational work was done on the “disturbed” plot of the main colony at the southernmost tip of the island (Fig. 1a), where gannets were known to be heavily disturbed because people could walk up to the birds unrestricted.

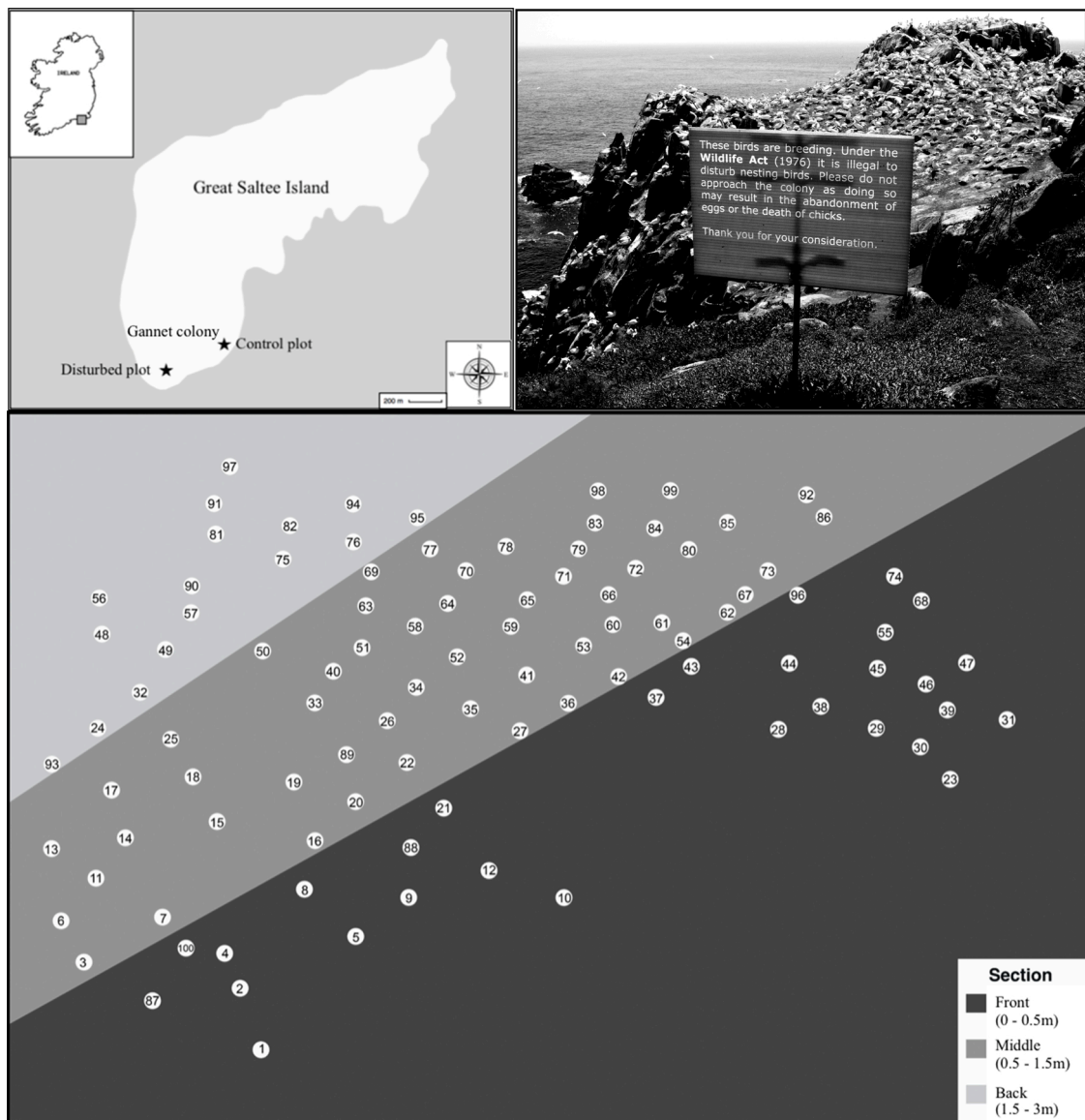
### 2.1. Breeding success

To quantify the level of failure that was likely caused by disturbance, we compared the breeding success of gannets at the “disturbed” part of the main colony to that observed at a control “undisturbed” plot (Fig. 1a), where human access was effectively impossible.

100 nesting gannet pairs were selected from plots within the disturbed and undisturbed areas, each of which was approximately 18 m<sup>2</sup> in area, collectively representing approximately 2.1 % of the island’s entire colony. Nesting pairs were identified if they were paired up and exhibiting pair bonding behaviour (Nelson, 1963), and were either in the process of nest building, or already sitting on a nest. Additionally, prospecting birds without a partner, or a nest, were also included under their own category when they were within the study areas. Nests were mapped, numbered, and monitored on 13 visits across the season. Using high definition photos and video it was possible to identify each nest individually according to location next to rocks and land features, and therefore to monitor progress throughout the season. The locations of prospectors were also mapped in this way.

Incubation start dates and hatching dates were recorded, as were egg and chick losses, determined primarily when eggs or chicks suddenly disappeared between visits. Zoom lenses enabled close observation of chicks including flight feather development, which enabled use of this characteristic as a definite marker of nesting success. Nests were recorded as successful if the chick was alive at the last visit in late July, by which time all chicks were either starting to lose their white downy feathers, or had started to grow black flight feathers. Although further mortality is likely to have occurred before birds fledged due to further disturbance, this does not affect the ability to draw conclusions about the main hypothesis.

At the disturbed plot, nests were further divided into sections (front, middle and back) (Fig. 1c). Front was open to approaches from visitors



**Fig. 1.** Clockwise from left: (a) Location map of Great Saltee island, showing locations of disturbed and undisturbed plots. (b) Slope down to the disturbed plot from the main approach path with sign in place. (c) Numbered gannet nests ( $N = 100$ ) in the disturbed plot. Strips represent sections (front, middle and back) with birds at the front being closest to visitors and most susceptible to disturbance. Visitors could enter from the slope or the platform and approach right up to nests on the periphery of the front section (in particular 1, 10, 23, 31 and 47).

who could walk directly up to the birds, and contained 29 % of the disturbed nests in a 0.5 m band. The middle section extended from 0.5 to 1.5 m and contained 56 % of the disturbed nests, but was not open to direct approaches. Meanwhile the back section extended from 1.5 to 3 m and contained the remaining 15 % of nests. These birds were the furthest away from human approach in the disturbed plot.

## 2.2. Visitor behaviour, disturbance and signage

Total visitor numbers and total disturbance events per day were recorded at the disturbed plot for the entire duration of the study. To examine the effect of visitors on bird behaviour, and of signage on both visitor and bird behaviour, detailed observations were collected by video during a total of  $50 \times 15$ -minute sample periods, across 13 research days, using a Nikon D3300 DSLR with a Nikon 70–200 mm f2.8 lens. The camera was located approximately 10 m uphill from the main colony, and there was no indication that birds were disturbed in any way by the observer's presence. The approach path from which all visitors

arrived was clearly visible from this location.

A sample period was defined as a fifteen minute observation period and was categorised into control samples (C;  $N = 13$ ), where no visitors were present; disturbance samples (D;  $N = 17$ ), where visitors were present and no sign was on display; and sign treatment samples (D<sub>s</sub>;  $N = 20$ ), where visitors were present and a regulatory sign was on display before the visitors started arriving (Fig. 1b). The order in which these samples was collected was randomised with respect to category. Control sample periods were recorded at random times after there had been no visitors in the vicinity for at least 15 min. For D and D<sub>s</sub>, video recording began when a visitor passed the observation station; any new visitors that arrived subsequently were treated as separate groups in the 15 min sample. Type of visitor, number of people in the group, and minimum approach distance to the colony were recorded, and approach distances were estimated in metres from landmarks identified earlier. Visitors were defined as 'photographers' if they were carrying cameras with large lenses and/or tripods, and intent on engaging in photography, 'tourists' if they had just point and shoot cameras or day rucksacks, and

weren't intent on getting pictures, and 'birdwatchers' if they were specifically using binoculars or telescopes to view the birds better, with no camera equipment.

During the sign treatment periods, the sign was placed on the edge of the approach path before the slope leading down to the gannetry. Previous research on sign content concluded that signs are most effective when an explanation is given alongside an instruction (Ballantyne & Hughes, 2006; Marion & Reid, 2007; Marschall et al., 2017; VanderWalde, 2007). Thus our sign stated "These birds are breeding. Under the Wildlife Act (1976) it is illegal to disturb nesting birds. Please do not approach the colony as doing so may result in the abandonment of eggs or the death of chicks. Thank you for your consideration" (Fig. 1b).

Back in the laboratory the following data were taken from the 15 min video samples: the number of birds moving off nests as an immediate reaction to the disturbance event (in D and D<sub>s</sub>); and the number of birds moving off their nests independently of any obvious disturbance event (D, D<sub>s</sub>, and C). The latter both served to record delayed responses to visitors still in the area throughout the 15 min period, but also provided a natural baseline of nest departures when no visitors were present (i.e. during C periods). Departures of a single parent when both parents were presented was not recorded as a disturbance event, since this was likely reflecting a natural change in nesting duties (Nelson, 1963). Similar data were recorded for non-breeding, prospecting birds.

### 2.3. Analysis

Pearson's chi-squared tests were used to examine whether the proportions of nests that i) hatched chicks, and ii) nested successfully, varied. First between the disturbed and undisturbed plots, and second, between sections within the disturbed plot. All other analyses on counts of birds and visitors were conducted using Generalised Linear Mixed Models with a Poisson error and Log link function, using SPSS Statistics 24. In all cases day was included as a random effect to account for repeated measures taken from the same day.

The numbers of prospectors disturbed during the 15-minute samples was modelled, first, against the number of visitor groups and the average visitor group size as explanatory variables for the disturbed and control samples in combination, and second, additionally against average (minimum) visitor group proximity for the disturbed plot alone (this last variable was inapplicable during the control sample periods). The same was done for the number of breeding birds disturbed, but in this case the pattern of errors suggested poor model fit, so Pearson's correlation was used to explore the associations further.

The effect of signage on the number of visitors recorded in each of four distance zones at the disturbed plot was examined using a GLMM with a Poisson error, a log link and with day as a random effect. The zones were selected by the natural distribution of distances which were clumped in the following: <1 m; between 1 and <2 m; between 2 and 5 m inclusive; and >5 m. Post hoc comparisons of disturbance and sign treatment samples were made using GLMMs restricting the dataset to each zone in turn.

Finally, the effect of signage on the numbers of prospectors disturbed was analysed by modelling the numbers disturbed per 15 min against treatment, which included disturbance samples and sign treatment samples; the samples from the undisturbed plot were also included to examine how well the sign treatment compared to areas free of all visitor disturbance. Post hoc comparisons between treatments were made by restricting the dataset to the relevant factor levels. The same analysis was repeated for breeding birds; in this case the error distribution suggested a weak model fit, so post hoc pair-wise comparisons between different treatment levels were conducted using a Kruskal Wallis H test.

## 3. Results

### 3.1. Breeding success

There was no difference in hatching success between the disturbed and the undisturbed plot, whereas within the disturbed plot, hatching success was lower in the front section (26 %) compared with the middle (48 %) and with the back (79 %) (Table 1a and b).

Overall nesting success by the end of the season was equally low in the front and middle sections (21% and 32 % respectively), and both were lower than at the back (60 %). Overall, using the standard measure for seabird nesting success (Mavor, Heubeck, Schmitt, & Parsons, 2006) the figures equated to an overall success rate of only 33 % in the disturbed group, compared with 52 % in the undisturbed plot (Table 1a).

### 3.2. Visitor behaviour and disturbance

The mean  $\pm$  SD total number of visitors to the colony per day (between the hours of 12 and 3.30 pm) was  $18.8 \pm 9.44$  (range 8–33, N = 10). 68.5 % were classified as photographers, 29.6 % were regular tourists, and the remaining 1.9 % were birdwatchers (N = 188 visitors). The mean  $\pm$  SD approach distance to the colony by photographers, tourists and birdwatchers respectively was  $2.55 \pm 2.1$  m,  $4.46 \pm 1.31$  m and  $8.00 \pm 0$  m. Thirty-one approaches to within a metre of the colony were recorded and all of these were photographers.

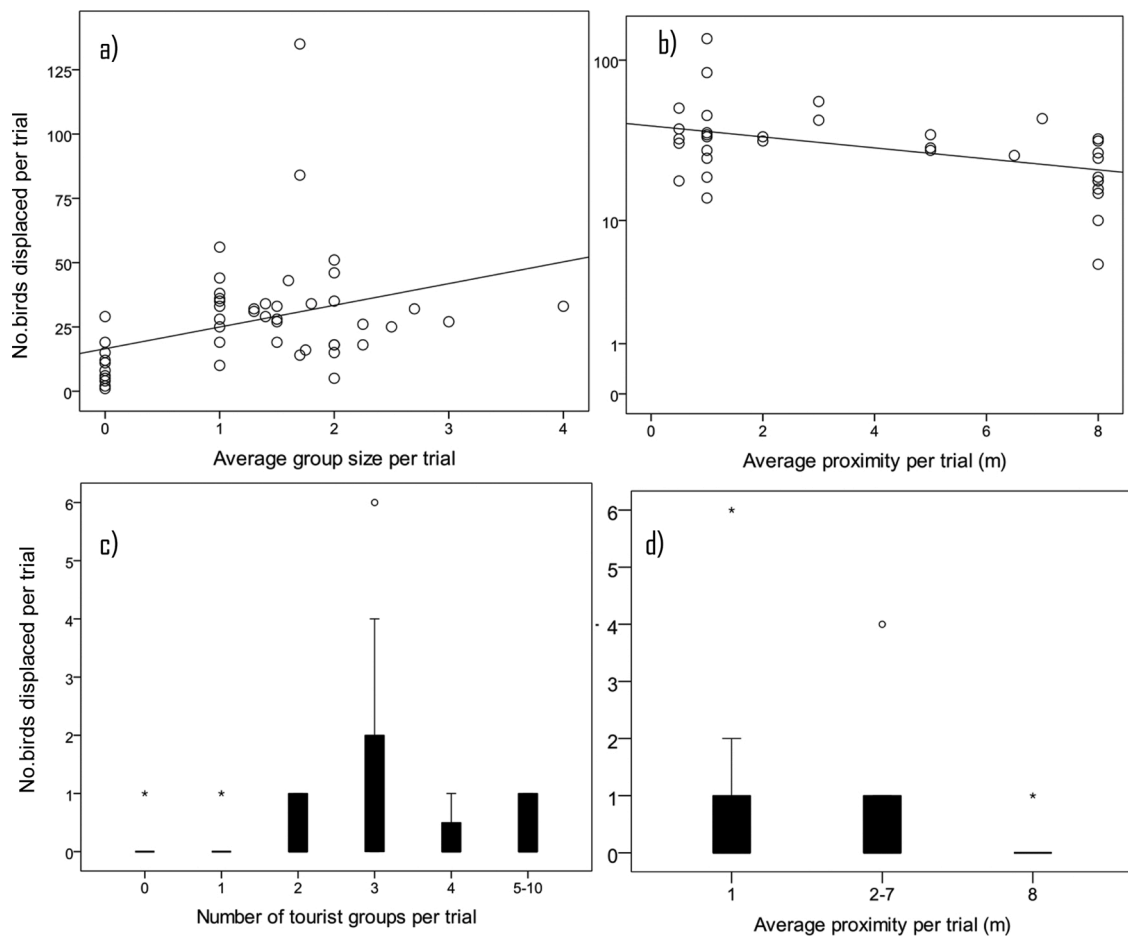
Across all treatments, the number of prospectors displaced per 15 min observation period increased with the average visitor group size ( $F_{[1,47]} = 28.9$ ,  $P < 0.001$ ;  $B \pm SE = 0.229 \pm 0.043$ ; Poisson GLMM; Fig. 2a) and the number of visitor groups ( $F_{[1,47]} = 34.03$ ,  $P < 0.001$ ;  $B \pm SE = 0.098 \pm 0.017$ . During disturbed samples alone, disturbance to prospectors increased with closer average proximity ( $F_{[1,33]} = 33.431$ ,  $P < 0.001$ ;  $B \pm SE = -0.105 \pm 0.018$ ; Fig. 2b), and with number of groups ( $F_{[1,33]} = 5.731$ ,  $P = 0.023$ ;  $B \pm SE = 0.049 \pm 0.021$ ), but was not influenced by average group size ( $F_{[1,33]} = 0.033$ ,  $P = 0.856$ ;  $B \pm SE = 0.011 \pm 0.061$ ).

The number of breeders displaced across all treatments also increased with the average group size but not the number of groups (Poisson model, log link:  $F_{[1,47]} = 4.154$ ,  $P = 0.047$ ;  $B \pm SE = 0.796 \pm 0.3905$ ;  $F_{[1,47]} = 1.272$ ,  $P = 0.126$ ;  $B \pm SE = 1.128 \pm 0.265$ ). However, examination of residual errors showed a poor fit so univariate non-parametric tests were also conducted, suggesting that in fact number of groups was having a marginal effect (Pearson's  $r = 0.316$ ,  $P = 0.025$ , N = 50; Fig. 2c), not average group size (Pearson's  $r = 0.095$ ,  $P = 0.514$ , N = 50). During disturbed samples alone, none of the variables predicted the number of breeders disturbed (see Table S1). Once again, the residual pattern was poor and subsequent non-parametric tests suggested

**Table 1**

$\chi^2$  tests of differences in hatching success and nesting success a) between the main disturbed and undisturbed plots, and b) between different sections of the disturbed plot. Hatching success refers to the numbers of nests that laid an egg that hatched successfully. Nesting success is whether at the end of the study period a live, grown chick remained in the nest, beginning to gain black flight feathers. % success is indicated for each plot (a), or for each section (b).

	Hatching success			Nesting success		
	$\chi^2$	p	%	$\chi^2$	p	%
a) Between plots						
Disturbed (N = 100) vs. Undisturbed (N = 100)	1.32	0.25	46, 55	7.38	0.007	33, 52
b) Within the disturbed plot						
Front (N = 29) vs. Back (N = 15)	9.66	0.002	26, 79	6.81	0.009	21, 60
Front (N = 29) vs. Middle (N = 56)	3.74	0.05	25, 48	1.24	0.27	21, 32
Middle (n = 56) vs. Back (N = 15)	4.16	0.04	48, 79	3.9	0.05	32, 60



**Fig. 2.** The relationship between the numbers of (a + b) prospecting, and (c + d) breeding gannets displaced with respect to average visitor group size or average visitor group proximity during sample periods. (a) and (c) are based on data from all three treatments (C, D, D<sub>s</sub>) and (b) and (d) are based on data from visitor treatments alone (D and D<sub>s</sub>).

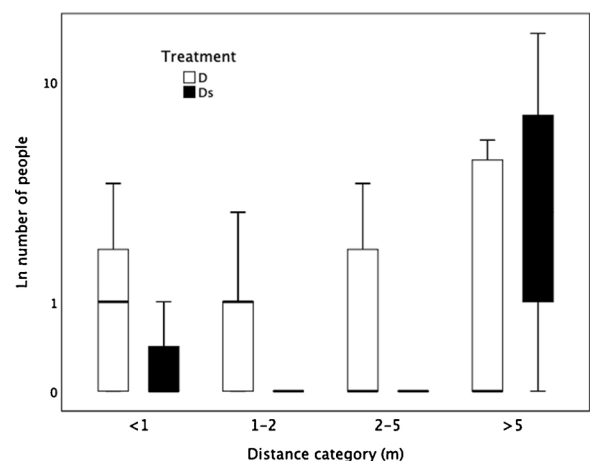
a tendency for the numbers displaced to increase with average group proximity (Pearson's  $r = -0.284$ ,  $P = 0.089$ ,  $N = 37$ ; Fig. 2d).

### 3.3. Signage and visitor behaviour

The number of visitors recorded in each of the four distance categories was influenced by the presence of signs (distance  $\times$  sign,  $F_{[3,140]} = 13.952$ ,  $P < 0.001$ ; Poisson GLMM; Fig. 3). Post hoc comparisons showed that the number of people recorded differed between sign treatment and disturbance periods within each of the bands (<1 m,  $F_{[1, 35]} = 5.616$ ,  $P < 0.023$ ,  $B \pm SE = 3.302 \pm 1.393$ ; 1–2 m,  $F_{[1, 35]} = 5.476$ ,  $P < 0.025$ ,  $B \pm SE = 2.079 \pm 0.889$ ; 2–5 m,  $F_{[1, 35]} = 3.966$ ,  $P < 0.054$ ,  $B \pm SE = 1.462 \pm 0.734$ ; >5 m,  $F_{[1, 35]} = 4.218$ ,  $P < 0.048$ ,  $B \pm SE = -0.592 \pm 0.288$ ; D<sub>s</sub> set to zero in all comparisons; Poisson GLMM, log-link function, day as random effect). Thus, the number of people recorded in the 3 nearest categories to the birds was lower in the sign treatment than in the disturbance treatment, while as expected the number of people recorded in the furthest distance category was higher in the sign treatment. Of the 11 visitors who ignored the sign and approached the colony to within a metre, all were photographers.

### 3.4. Signage and bird disturbance

The number of prospecting birds taking flight also varied with treatment ( $F_{[2, 47]} = 88.615$ ,  $P < 0.001$ ; sign,  $B \pm SE = 3.213 \pm 0.052$ ; control,  $B \pm SE = -0.901 \pm 0.108$ ; disturbance,  $B \pm SE = 0.500 \pm 0.085$ ; GLMM, Poisson error, log link, day as random effect; Fig. 4a). However, this was driven primarily by a difference between the control and the



**Fig. 3.** Boxplot showing the number of visitors approaching to within set distance categories from the edge of the disturbed gannet colony during the disturbance (D;  $N = 17$ ) and sign treatment (D<sub>s</sub>;  $N = 20$ ) sample periods, involving 87 and 106 visitors to the colony total respectively.

other two treatments; there was no difference between the sign and disturbance treatments ( $F_{[1, 35]} = 0.06$ ,  $P = 0.808$ ).

The number of breeding birds taking flight also varied with treatment ( $F_{[2, 47]} = 11.62$ ,  $P < 0.001$ ; sign,  $B \pm SE = -1.792 \pm 0.500$ ; control,  $B \pm SE = -0.572 \pm 1.119$ ; disturbance,  $B \pm SE = 2.338 \pm 0.560$ ;

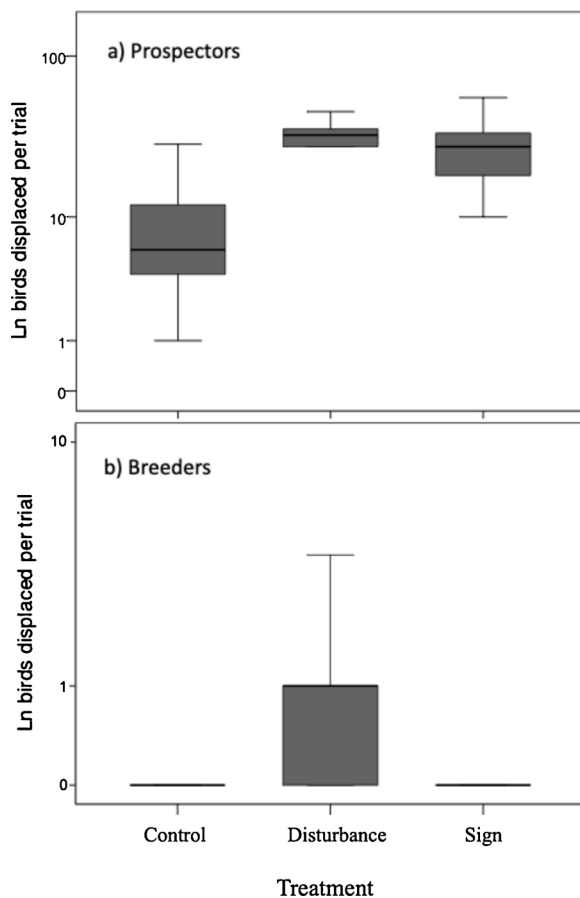


Fig. 4. Boxplots showing the number of a) prospecting and b) breeding gannets displaced from the disturbed plot during the following sample periods: no visitor controls (C), disturbance with no sign (D), and sign treatment (D<sub>s</sub>). Birds displaced per 15 min trial is on a Log<sub>10</sub> scale.

GLMM, Poisson error, log link, day as random effect), suggesting the number disturbed was substantially higher for the disturbance (D) treatment than for the other two treatments (Fig. 4b). The error distribution was poor but the preceding conclusions were confirmed by further non-parametric tests (D<sub>S</sub>-D,  $H = 12.045$ ,  $P = 0.002$ ; C-D,  $H = -14.154$ ,  $P < 0.001$ ; C-D<sub>S</sub>,  $H = -2.109$ ,  $P = 0.583$ ).

## 4. Discussion

### 4.1. Breeding success

Gannets on Great Saltee nesting in closer proximity to visitors were more likely to fail compared to those in more isolated locations. This was true when comparing the undisturbed plot and the disturbed plot, and when comparing failure rates within the disturbed plot, which were higher the closer they were to the disturbed edge. Younger birds often obtain less favourable nesting locations at the front or edges of colonies (Nelson, 1963), and these spots can have higher stress and lower reproductive success even when there is no tourist disturbance (Herring & Ackerman, 2011), and we cannot separate these effects from those due to disturbance alone. Nevertheless, although our main objective in this paper was not to experimentally test the effect of proximity to tourism on gannets generally, which would necessitate replication at the level of independent sites (realistically, islands), the observed difference at our colony was likely caused by disturbance for the following four reasons: i) nesting success was 0.33 in the disturbed group compared to 0.52 chicks fledged per occupied nest in the undisturbed group; ii) the effects of the signage on human behaviour and gannet disturbance were considerable;

iii) 10 separate incidents of egg predation from gulls caused directly by human behaviour at the front of the disturbed plot were observed on just one day during the season (J. Quinn, pers. comm.), but no such incidents were observed at the back of the colony or on the undisturbed plot, where human access was effectively impossible; and iv) the average success rate was lower than 0.7 reported for gannets in Britain and Ireland generally (1986–2006 JNCC) (Mavor et al., 2006). Although the gannet is often assumed to be a robust, approachable species (Samia, Nakagawa, Nomura, Rangel, & Blumstein, 2015) our results suggest this is not the case in the context of deleterious effects on parental care, and our data agrees with a number of other seabird species that have also shown that visitor or investigator disturbance impacts nesting success (Burger, 1981; Carney & Sydeman, 1999; Ellenberg, Mattern, Seddon, & Jorquera, 2006; Piatt et al., 1990; Robert & Ralph, 1975; Watson et al., 2014).

### 4.2. Disturbance and signage

Our study showed that number of visitors, group size and proximity of approach all influenced the level of disturbance to some extent in prospecting and breeding birds, all of which have previously been reported as important in one or more studies (Beale & Monaghan, 2004; Blumstein, Anthony, Harcourt, & Ross, 2003; Geist, Liao, Libby, & Blumstein, 2005; Glover, Westona, Maguire, Miller, & Christie, 2011; Holmes et al., 2005; Mallory, 2016; Steidl & Anthony, 2000; Weston et al., 2012). For breeding birds, and in agreement with existing literature (Burger & Gochfeld, 1993), proximity of approach was the most important factor in breeding bird displacements (Fig. 2). We also found that photographers approached the colony more closely than other tourists. Their effects may have been especially pronounced, given the considerable equipment they carry. Indeed another study has shown that the orientation of observers, and their apparent size as a result, can also affect levels of disturbance (Geist et al., 2005). Thus the precise nature of the disturbance was important, both in terms of the numbers and sizes of groups, and in terms of the kinds of tourists present.

Signage had a major impact on visitor behaviour. Fewer people approached the colony to within 1 m in the presence of the sign, and fewer proceeded to the other close distance categories too (Fig. 3). Overall 74 % of visitors then chose to remain a minimum of 5 m from the birds, and most of these at 8 m. Of the 11 visitors who ignored the sign and approached the colony to within a metre, all were photographers, who were also involved in 84 % of disturbance events. Since this group may also see themselves as birdwatchers and vice versa, this suggests that signage targeting anyone engaged in photography generally may be needed to impact their behaviour. In general however, our results support the findings of two other studies that signage can be a highly effective technique for ensuring compliant behaviour of visitors around wildlife (Marschall et al., 2017; Weston et al., 2012). These latter two studies were on shorebirds and seals respectively on coastal sites with high footfall, so the addition of our study on seabirds on an island site with low footfall broadens the generality of these findings collectively. Both these studies focused on visitor actions as a direct consequence of the management techniques, but not on how this then impacted the behaviour of the study species.

In addition to affecting visitor behaviour, our results showed that signage also had a major effect on the number of gannets disturbed. This was primarily true for breeding birds, while prospecting birds were disturbed by the presence of visitors even when the signs were there. This result is to be expected since prospectors are far more outwardly sensitive to disturbance (Nelson, 1963), and as they do not have nests they are less tied to a specific location, and are usually found on the margins of colonies. For breeders, sign treatment periods showed lower disturbance rates than disturbance periods with no sign, and actually had a similar bird displacement rate to control periods. This suggests that interpretation restricting visitors to 8 m proximity would minimise the numbers of birds flushed from nests, and would also have the

potential to reduce disturbance effects to that of an undisturbed area, effectively all but negating disturbance effects. Indeed even restricting viewers to 2 m away would significantly reduce the level of disturbance. This simple interpretation could prevent unnecessary egg loss and nestling mortality, which could in turn increase overall breeding success rates in the colony. Long-term interpretation is inexpensive, and in the absence of clearly marked paths on the island, would remove some of the ambiguity and serve as a better reference point on where to walk.

Signage has been shown to positively affect success in sea and shorebirds breeding on public beaches (Medeiros et al., 2007; Weston et al., 2012), although these studies were not conducted exclusively with interpretation, and instead considered a combination of signs, wardening and temporal closures. One significant aspect of the current study is that the signage worked at an unmanaged site and in the absence of any official wardening system. Although every attempt was made by the observer to remain inconspicuous (e.g. recording was done 10 m from the colony), we cannot be entirely sure visitors were unaware of the observer's objective, though we think this is unlikely because the observer was largely out of sight behind a rock and, if spotted, visitors should have had no reason to conclude the observer was anything other than a tourist. Thus, we suggest the sign would be effective in the absence of wardens.

This study also differs to others in that the site was offshore and visited expressly for the purposes of tourism, rather than being on a frequently used public beach, or overlapping with other activities. Signage has been shown to work on advising the public to stay back (Medeiros et al., 2007; Weston et al., 2012), but our results suggest it can also be effective when visitors have arrived solely for the purpose of viewing a large wildlife colony, and where diverting means they will not get such a close view. Arguably, visitors here are already interested in the wellbeing of the birds, so providing an informative message is very effective, and the precise wording of this explanation, or sign, is an important consideration (Marschall et al., 2017). We also suspect that the presence of multiple tourists at any one time may facilitate the effectiveness of the sign, with people more likely to behave as requested in front of others. Despite the effectiveness of the signs alone, the addition of a warden during the season, and/or information given on-board the boat prior to arrival (Zeppel & Muloin, 2008), may further increase the effectiveness of the sign, as multiple management options working in cooperation have proved to be very effective elsewhere (Batey, 2013).

## 5. Conclusion

With little information available on the long-term effects of disturbance on seabirds, and on *M. bassanus* in particular, as well as a scarcity of data on how signage can manage this disturbance, our research paves the way for more effective management techniques at unmanaged bird colonies. Our results demonstrate that a simple, well-designed sign can make a substantial difference to appropriate behaviour around breeding wildlife, and in turn on their impacts on the wildlife. One of the main problems in conflicts between wildlife and people is a lack of understanding and awareness (Grossberg, Treves, & Naughton-Treves, 2003; Taylor & Knight, 2003), so providing clear interpretation, either written or verbal, can go a long way to alleviating the problem (Ballantyne & Hughes, 2006; Marion & Reid, 2007; Marschall et al., 2017).

The data suggests that restricting visitors to 8 m proximity would minimise the numbers of birds flushed from nests and displaced amongst the colony, and that even restricting approaches to > 2 m could reduce effects. This simple guideline could easily be applied to large numbers of unmanaged wildlife sites at little cost. With rising visitor numbers across Great Saltee in particular (D. Bates, pers. comm.), and wildlife viewing sites in general (World Tourism Organization, 2018), coinciding with falling seabird numbers (JNCC, 2015), it is imperative we find ways to alleviate conflicts and mitigate damage.

By way of a postscript, a permanent sign was erected at the disturbed

colony in 2019 and appears to be working well, helped in 2020 by restricted access to the island due to Covid-19, when the breeding colony is more extensive than in normal years (M. Jessopp, pers. comm).

## Declaration of Competing Interest

The authors report no declarations of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.jnc.2020.125915>.

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