



Conflicts between touristic recreational activities and breeding shearwaters: short-term effect of artificial light and sound on chick weight

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Abstract

Human disturbances are increasingly becoming a conservation concern for many populations of colonial seabirds. Colonially reproducing species are particularly vulnerable to localised disturbances because detrimental elements can simultaneously affect the entire population. Studies of petrels and shearwaters have shown that light pollution, in particular, can be harmful for both fledglings and adults, but little is known of the way such anthropogenic elements affect the quality of parental care at the nest. Chick provisioning in petrels and shearwaters occurs exclusively at night and is also negatively correlated with the amount of moonlight. We tested the hypothesis that high-intensity light and sound disturbances will disrupt nest attendance and thus affect weight gain in chicks but that the magnitude of such effects would be modulated by moonlight conditions. We measured the effect of two outdoor disco events on overnight weight gain in 26 chicks of Scopoli's shearwaters (*Calonectris diomedea*) from a breeding colony on Linosa Island. The two disco events occurred under contrasting moonlight conditions (moonless vs moonlight). Chicks situated closer to the disturbance gained significantly less weight compared to conspecifics from nests further away but the effect was only evident on the moonless night. Our results suggest that light and sound disturbances can have a negative effect on parental care in *C. diomedea* but moonlight might moderate the bird's perception and thus the magnitude of the disturbance. However, while occasional disturbances may impact short-term weight gain in *C. diomedea* chicks, such effects are not perceivable at fledging when measured as differences in the weight or the date at which they left the nest.

Keywords Artificial light disturbance · Sound disturbance · Conservation on islands · Moonlight · Scopoli's shearwater (*Calonectris diomedea*)

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Introduction

Human activities have been singled out as major conservation concerns for seabird species (Croxall et al. 2012). Many seabird species reproduce in mass colonies, a life-history characteristic that is particularly vulnerable to localised disturbances because detrimental elements can simultaneously affect the entire population. For example, petrel and shearwater colonies are vulnerable to artificial light, which can disrupt orientation, increase exposure to predators and lead to an overall higher mortality rate for fledglings (Telfer et al. 1987; Le Corre et al. 2002; Rodríguez and Rodríguez 2009) and adults (Montevecchi 2006). However, little is known of the way in which light pollution impacts shearwater's breeding behaviour, chick provisioning and the quality of parental care at the nest as a whole. Importantly, weight gain by chicks is

directly determined by parental nest attendance and is thus a reliable measure of the quality of parental care (Hamer and Hill 1993), but disturbance factors such as human presence may determine an increase of chick heart rate, due by stress, and thus the energy expenditure, as was found for adult birds (Weimerskirch et al. 2002).

During the chick rearing phase, adult shearwater attendance at the colony occurs at night and is negatively correlated with the levels of moonlight (Rubolini et al. 2015). The correlation of nest attendance behaviour with moonlight levels has likely evolved to minimise the predation risk from diurnal predators such as gulls (Mougeot and Bretagnolle 2000). If the influence of moonlight on parental nest attendance (Bourgeois et al. 2008, Riou et al. 2011) reflects a causative relationship to some extent, artificial lights could disrupt or intensify the causal link and thus affect parental care behaviour in a way that may impact fledging success and fitness.

In the Mediterranean, many islands that serve as breeding sites for shearwaters are also popular tourist destinations and the peak of tourism season (July and August) frequently coincides or overlaps with the period of hatching and chick rearing in the breeding colonies. It is therefore important to understand how the contact with human populations affects the breeding colonies and which disturbances are having a significant impact on the breeding success of the birds. While the possible effects of artificial lights have received some attention (e.g. Rodríguez et al. 2016), effects of sound disturbances that may be disruptive to the bird's breeding have so far not been investigated. High levels of artificial sounds, for example, might potentially interfere with vocal communication between individuals, which is important for mate recognition in breeding shearwater pairs (Bretagnolle 1996, Curé et al. 2016). Furthermore, sound pollution may compound the effects of light disturbances and magnify the impact on chick-provisioning behaviour by the parents.

Here, we test the hypothesis that breeding pairs of shearwaters avoid attending their chick when exposed to high levels of artificial light and sound disturbances. We investigated how the touristic recreational activity (outdoor disco), under different moonlight conditions, affect the parental care at the nest by measuring the (short-term) effect on chick weight gain and the (long-term) effect on fledging success.

Material and methods

Scopoli's shearwaters (*Calonectris diomedea*) are pelagic seabirds that breed in colonies on remote and often barren offshore islands (Warham 1990). Females lay single-egg clutches in end of May and parental care is shared between the monogamous pair (Warham 1990). Incubation time of *C. diomedea* lasts approximately 50 days and parents engage in chick provisioning throughout summer, from the second half of July

until fledglings leave the nests in mid to late October (Müller et al. 2015).

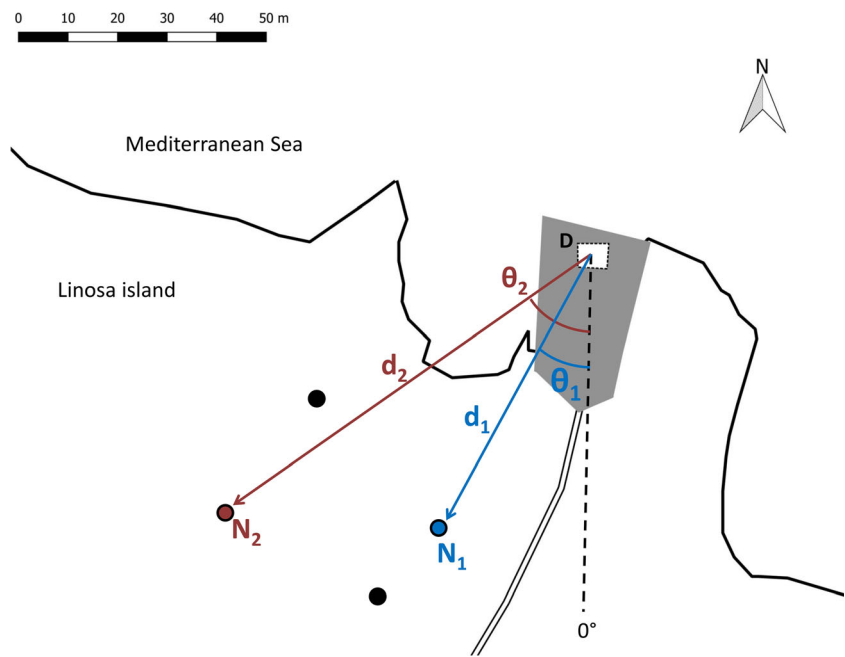
The study reported here was conducted on Linosa (35° 52' N, 12° 52' E), a small Mediterranean island in the Sicily Channel that hosts approximately 10,000 breeding pairs and represents the largest colony of Scopoli's shearwaters in Italy (Massa and Lo Valvo 1986). Nesting on Linosa Island occurs in natural cavities and caves formed in volcanic rock. The shearwater colony on Linosa is situated on the opposite side of the human settlement and is thus largely free from light pollution throughout the year. Our study took advantage of two large outdoor disco events that took place adjacent to the shearwaters colony during the 2004 breeding season (2nd and 9th August). On both occasions, the events began soon after sunset (20:30) and continued throughout the night until 05:30, approximately half an hour before dawn. Two 700 W speakers producing up to 100 dB of sound and six sodium 100 W Lamps producing more than 70,000 lm were oriented towards the colony and operated throughout both events (Fig. 1). We did not measure sound and light intensity for each nest to avoid any additional disturbance to birds. The intensity of light and sound disturbance to nests decreased gradually across the colony and thus affected nests differently according to their position and distance from the source.

The first event (EVENT1) took place under near-moonless conditions: the moon rose at 12:09 and set at 23:37 (first quarter moon phase and 47% of moon surface illuminated), while the moon was visible throughout the entire night during the second event (EVENT2), rising at 18:45 and setting at 04:45 (93% of moon surface illuminated).

We weighed chicks before (19:30) and after (06:30) each monitoring night to the nearest 5 g using a 1000-g capacity spring balance and calculated the net change in body weight (ΔW) for each chick. Hatching date was recorded by visual monitoring of nests and used as a measure of chick age (± 2 days).

We monitored a total of 52 nests, 26 nests were randomly chosen from nests that were situated within approximately 320 m of the disturbance source (between 48.13 and 309.9 m) and 26 nests with similar aged chicks were selected randomly from part of the colony that was 400–600 m away from the disturbance and thus not affected by the light and sound disturbance during the two events. Chicks from the nests that were closer to the noise disturbance were monitored on the nights with disturbance events and the 26 nests situated further from the disturbance (CONTROL) were monitored on different nights with no disturbances but with similar moonlight conditions as in the event nights: the night before the first event (CONTROL1: the moon rose at 10:12 and set at 22:01 with first quarter phase of moon 40% of moon surface illuminated) and the night after the second event (CONTROL2: the moon rose at 18:14 and set at 04:54 with full moon phase 100% of moon surface illuminated). Control chicks were used to test if moonlight condition affected the change in chick

Fig. 1 Map of the area nearby the disco, with examples of the measurements of distance (d) in meters and angle (θ) in degrees of two nests from the outdoor disco



weight, independently of the presence of the anthropogenic disturbances. We assumed that moonlight condition in a certain night was similar for all chicks because of the flat topography of the study site. The sky in all four nights was clear, with no cloud cover.

Data analysis

While ΔW data fulfilled homogeneity requirements (the Fligner-Killeen test of homogeneity of variances: $\chi^2 = 2.97$, $df = 3$, p value = 0.39), it did not meet the assumption of normality (the Shapiro-Wilk normality test: $W = 0.96$, p value = 0.002) and we therefore used the non-parametric Kruskal–Wallis test and the Dunn’s post-hoc test with *DescTools* R package (Signorell 2015) for multiple comparisons among the four nights.

We created a nest Position Index (PI) which assigns each nest with a value that reflects the level of exposure to the light and sound disturbance. The PI was calculated as a function of distance from the disturbance source and the angle of the nest’s offset from the central vector at which the disturbance was transmitted (Fig. 1). Higher PI values indicate a higher level of exposure to the light and sound disturbances. Values for both distance and angle for each nest were standardised around the overall mean for all 26 nests. We performed a principal component analysis (Venables and Ripley 2002) and obtained the PI, which explained 86.4% of the variance (standard deviation = 1.31), from the first principal component using the following formula:

$$PI_i = (-0.7071 \times d_i) + (-0.7071 \times \theta_i)$$

where d_i is the linear distance of the nest from the disturbance source (in meters) and θ_i is the angle of offset from the transmission vector (in degrees).

We ran a linear mixed-effects model to test for an effect of nest PI on chick ΔW using disturbance event night as a two-level factor variable (EVENT1, EVENT2) and nest ID as a random factor (R-package “nlme,” Pinheiro et al. 2014). Fledging dates and fledgling weights from CONTROL and EVENT nests were compared using a Wilcoxon test and a student t test respectively. All statistical analyses were performed with R 3.3.3 (R Core Team 2017).

Data availability The datasets were analysed during the current study available from the corresponding author on reasonable request.

Results

Shearwater chicks from both CONTROL and EVENT nests gained more weight on nights with less moonlight but there was no significant difference in ΔW between CONTROL and EVENT chicks following nights with similar moonlight conditions (Kruskal–Wallis rank sum test for ΔW by group: $X^2 = 19.34$, $df = 3$, $p < 0.001$; Dunn’s test, EVENT1 vs EVENT2: mean-rank-difference = 19.71, $p < 0.05$; Dunn’s test, CONTROL1 vs CONTROL2: mean-rank-difference = 24.13, p value < 0.01 ; Fig. 2).

Variation in spatial exposure to the anthropogenic disturbances (PI) had a significant effect on ΔW of chicks following EVENT1, under low moonlight conditions (Table 1;

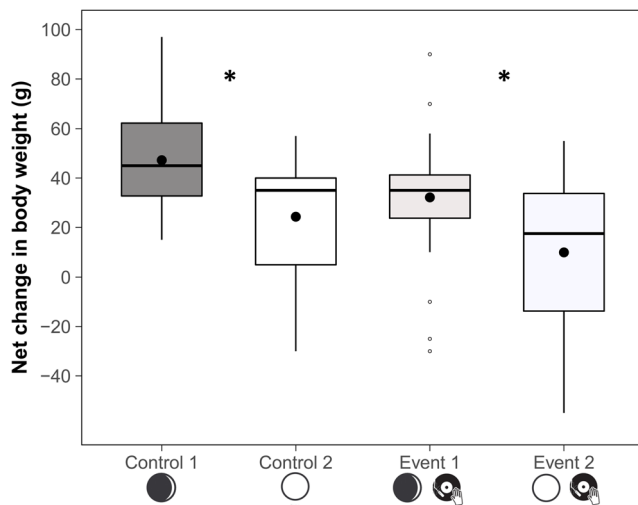


Fig. 2 Net change in body weight (ΔW) during disco events (EVENT1: with no moon, EVENT2: with full moon) and during control nights (CONTROL1: with no moon, CONTROL2: with full moon) represented in boxplots (black line as median, black dot as mean, box as interquartile range, whiskers as min-max values, open dots as outliers)

Fig. 3). The effect was not significant during EVENT2 when moonlight exposure was high (Table 1; Fig. 3). Chicks' ΔW tended to be higher after EVENT1 compared to EVENT2 in the low-exposure anthropogenic disturbance area (low PI), but they converged in the high-exposure anthropogenic disturbance area (high PI; Table 1, Fig. 3). All 52 chicks survived and fledged successfully. Mean fledging date was 17/10/2014 \pm 3 days (\pm SD), with a mean weight of 659.1 \pm 68.24 g (\pm SD). There was no significant difference in fledging dates (the Wilcoxon test rank sum test: $W = 357$, $p > 0.05$; Fig. 4 A) or fledging weight ($n = 26$, 676.3 \pm 73.78 g; t test: $t = 1.84$, $df = 48.07$, $p > 0.05$; Fig. 4 B) between CONTROL and EVENT chicks.

Discussion

Understanding how anthropogenic disturbances are affecting wildlife populations is increasing in urgency as human populations encroach further into natural habitats and human-

Table 1 Linear mixed-effects model with chick weight gain after disco events (ΔW) as dependent variable and chick ID as random factor. EVENT1: night with disco event and moonless. EVENT2: night with disco event and moonlight. PI (position index): position of each nest from the disco (see "Materials and methods" section). EVENT1 is taken as reference level factor

	Estimate	SE	t	p value
Intercept	38.24	5.85	6.54	< 0.001
Position Index (PI)	-14.19	3.49	-4.07	< 0.001
Event (EVENT2)	-25.68	8.27	-3.10	< 0.01
PI \times Event	8.83	4.93	1.79	0.086

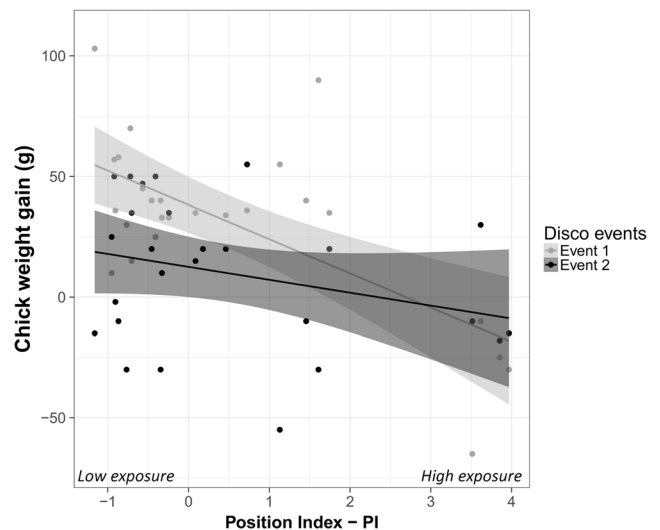


Fig. 3 Net change in body weight (ΔW) in relation to nest Position Index (PI) during disco events (EVENT1: with no moon, EVENT2: with full moon) represented in two regression lines (grey lines and dots: EVENT1, black lines and dots: EVENT2) with confidence intervals

wildlife encounters are becoming more common (Watson et al. 2014; Yorio et al. 2001). Seabird nesting colonies present a particular concern because reproduction in these species is restricted to few locations and colonies may not be able to relocate if conditions become untenable (Palczyński et al. 2015). We found that Scopoli's shearwater chicks gained less weight during nights with higher levels of moonlight regardless of the presence of light and sound disturbances (Fig. 2). The light and sound disturbances did, however, have a negative effect on chick weight gain on the highly exposed (PI value) nests but only when natural moonlight levels were absent (Fig. 3). Furthermore, the short-term effects of the disturbance on highly exposed nests did not persist and manifest as detrimental for fledging success, weight and fledging date (Fig. 4). Our results confirm previously reported patterns of moonlight effects on nest attendance (Rubolini et al. 2015) and further suggest that parental care at the nest may be impaired by light and sound disturbances when natural moonlight levels are absent and disturbance levels are high.

The fact that reduced provisioning during the night of the disturbance with low moonlight levels had no perceivable effect on the weight and age at fledging suggests that chicks have sufficient metabolic reserves to buffer against some stochastic fluctuations in feeding regimes. Procellariiformes chicks accumulate fat reserves to face irregular food provisioning (Ricklefs and Schew 1994) and the cost of reduced provisioning over a single night was clearly within the sustainable range that shearwater chicks can incur.

We found no difference in weight change between disturbance and control nights and similarly no effect of nest position and thus intensity of exposure (PI), when natural moonlight levels were high. Thus, high moonlight levels possess a dominant effect that drown out any effects from the disturbance.

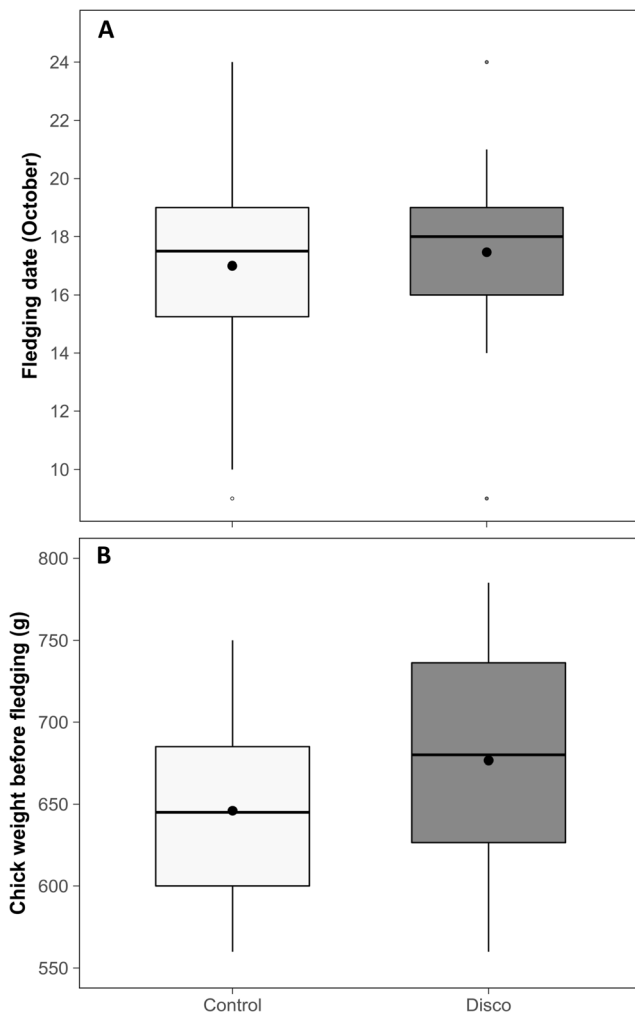


Fig. 4 Chick fledging date (a) and fledging weight (b) between chicks exposed to the disco events (Disco) and chicks placed far from the disco events (Control) represented in boxplots (black line as median, black dot as mean, box as interquartile range, whiskers as min-max values, open dots as outliers)

Furthermore, the absence of an effect of the disturbance on the moonlit night suggests that sound, in and of itself, may not represent a contributing factor to the impact on parental nest attendance. However, sound disturbance may have deleterious effects on bird behaviours that are not related or do not manifest as variation in parental provisioning. For example, sound disturbances may interfere with vocalisation between mates, which is an important aspect of communication in many seabird species (Storey 1984, Bretagnolle 1996, Curé et al. 2016). We could not directly identify the separate contribution of sound and light factors in the overall disturbance and thus suggest that more research is needed to address this question.

We cannot entirely exclude the possibility that physiological stress caused by the light and sound disturbances may have contributed to the differences in weight gain of chicks (e.g. through heart rate increase or food regurgitation) but the absence of such an effect on the moonlit night suggests that the

effect was predominantly due to a reduction in parental feeding. While it is possible that the disturbance affected the chicks directly and that such an effect was only evident when feeding was frequent, evidence from burrow-nesting seabirds suggests that human disturbance does not affect chick growth during the early stages of chick development (Albores-Barajas et al. 2009).

The weight gained (or lost) by a chick during a single night depends on nest attendance and provisioning by the parents (Hamer and Hill 1993). Consequently, the overnight change in chick weight may directly reflect the level of attendance by the parents. Reduction of colony attendance during nights with high levels of moonlight has been extensively recorded in petrels, where it was suggested to reflect a predator avoidance strategy (Mougeot and Bretagnolle 2000; Riou and Hamer 2008; Oro et al. 2005). Scopoli's shearwaters attend their nests exclusively at night and parents perform foraging trips that can last from one to several days (Cianchetti-Benedetti et al. 2017). Shearwater chicks may have evolved a capacity to cope with highly variable feeding regimes because they may, at any given night, receive food from one, both or neither of their parents.

Our study suggests that high levels of light and sound disturbances may be detrimental to shearwaters because of the disruption of parental nest attendance but that such effects should have little to no impact on fitness if such disturbances are sufficiently infrequent. However, it remains crucial to further our understanding of the impact, which touristic anthropogenic activities have on breeding birds, and to identify and effectively manage human activities in important breeding grounds such as Linosa Island, the biggest colony of Scopoli's shearwater in Europe.

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Authors' contributions MCB, PB and GD carried out the fieldwork; PB analysed the data; MCB, PB and BM drafted the manuscript; and GD designed and coordinated the study. All authors gave final approval for publication and approved the final version of the manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

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