Attraction of petrels to artificial lights in the Canary Islands: effects of the moon phase and age class
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The extent and intensity of artificial night lighting has increased with urban development worldwide. The resulting light pollution is responsible for mortality among many Procellariiformes species which show nocturnal activity on their breeding grounds. Here, we report light-induced mortality of Procellariiformes during a 9-year study (1998–2006) on Tenerife, the largest island of the Canary archipelago. A total of 9880 birds from nine species were found grounded, the majority being Cory’s Shearwaters Calonectris diomedea (93.4%). For this species the majority of grounded birds were fledglings (96.4%), which fall apparently while leaving their nesting colony for the first time; for the smaller species (storm-petrels) adult birds were more often grounded than fledglings. For almost all species, grounding showed a seasonal pattern linked with their breeding cycle. Certain phases of the moon influenced grounding of Cory’s Shearwater, with the extent of grounding being reduced during phases of full moon. The percentage of fledglings attracted to lights in relation to the fledglings produced annually varied between species and years (0–1.3% for the Madeiran Storm-petrel Oceanodroma castro; 41–71% for Cory’s Shearwater). Mean adult mortality rates also varied between species (from 0.4% for the European Storm-petrel Hydrobates pelagicus and the Cory’s Shearwater, to 2.3% for the Manx Shearwater Puffinus puffinus). Here we show that light-induced mortality rates are of concern, at least for petrels and small shearwaters. Thanks to efforts involving civil cooperation, 95% of grounded birds have been returned to the wild. To minimize the impact of artificial lights on petrels we recommend several conservation measures: continuing rescue campaigns, alteration of light signatures and reduction of light emissions during the fledging peaks. Furthermore, we recommend that a monitoring program for petrel populations be implemented, as well as further studies to assess the fate of released fledglings and continued research to address why petrels are attracted to lights.

Keywords: anthropogenic perturbation, Atlantic Ocean, light pollution, moonlight, seabirds.

Urban development has brought the need for artificial lighting of roadways, shopping centres, stadiums, homes and more. The use of artificial lights at night has many physiological, epidemiological and ecological consequences for wildlife (Verheijen 1985, Rich & Longcore 2006, Navara & Nelson 2007). For birds in the order Procellariiformes (hereafter referred to as ‘petrels’) that commonly attend breeding colonies at night, artificial lighting has been reported to cause behavioural anomalies and increased predation rates by gulls (Ruiz & Martí 2004, Oro et al. 2005). Moreover, artificial lights can attract and disorientate birds (Verheijen 1981, Longcore & Rich 2004), particularly fledglings. Fledglings are attracted by lights during their first flights to sea, either falling to the ground with fatal injuries, being killed by predators or dying from starvation (Imber 1975, Telfer et al. 1987, Le Corre et al. 2002). Inexperienced birds would be
attracted to artificial lights because of incorrect visual orientation, as visual cues for first-time navigation to the sea at night would depend on the extent of moon and star light (Telfer et al. 1987).

Alternatively, petrels may also tend to search for lights to improve their chances of getting a meal, because they feed mostly on bioluminescent squid (Imber 1975, Klomp & Furness 1992, Montevecchi 2006).

Many petrels have undergone substantial declines in recent times; more than 50% of the species are threatened, mostly due to the presence of introduced predators in their breeding grounds and the impact of commercial fisheries at sea (BirdLife International 2000). Although many of these endangered species breed on islands inhabited by people, very few studies have focused on the impacts of artificial lighting at night. In Hawaii, where this problem was identified very early on, lights have affected three species (Telfer et al. 1987). On Réunion Island, light-induced mortality is known to affect four species, two of them endemic and classified as Critically Endangered (Le Corre et al. 2003, Salamolard et al. 2007). In both archipelagos, conservation measures have been implemented to reduce the impact of artificial lights, and action plans have begun to be developed (Reed et al. 1985, Telfer et al. 1987, Ainley et al. 1997, Podolsky et al. 1998, Le Corre et al. 2002, Salamolard et al. 2007). Apart from these two locations, light-induced mortality has been reported on several other islands and for several additional species, some of them Critically Endangered, but a precise quantification estimate of mortality is lacking (Carlile et al. 2003, Baccetti et al. 2005, Raine et al. 2007, see also Le Corre et al. 2002 and references therein).

In the Canary Islands, attraction of petrels to artificial lights was first detected in 1990 with the regional government subsequently responding by carrying out awareness campaigns (Anonymous 1995). Nine petrel species have been recorded as grounded near urban lights and many thousands of birds have been released back into the wild (Anonymous 1992, 1993, 1995, Viceconsejería de Medio Ambiente 1995, Martín & Lorenzo 2001).

The aim of this paper is to report the temporal and spatial patterns of light-induced mortality and its potential impact on petrel populations on Tenerife Island. Based on our results and a review of relevant literature, recommendations and actions are proposed to reduce attraction of these seabirds to artificial lights.

**METHODS**

**Study area and species involved**

The Canary Islands are a volcanic archipelago located 100–450 km off the Atlantic coast of northwest Africa (27°37’–29°25’N and 13°20’–18°19’W). The group comprises seven major islands as well as some small islets and rocks. Tenerife is the largest island (2034 km² and up to 3718 m asl), and is situated in the central part of the archipelago (Fig. 1). Approximately 800 000 people live on Tenerife, the majority of whom are concentrated along the coast (Morales & Pérez 2000). Urbanization and infrastructure have increased considerably during the last 40 years, currently occupying 5.7% of the total area of the island.

Seven petrel species breed regularly in the Canary archipelago, six of them in Tenerife: Bulwer’s Petrel Bulweria bulwerii, Cory’s Shearwater Calonectris diomedea, Manx Shearwater Puffinus puffinus, Macaronesian Shearwater Puffinus baroli, Madeiran Storm-petrel Oceanodroma castro and European Storm-petrel Hydrobates pelagicus.
Other non-breeding petrel species are regularly sighted in Canary waters (Martín & Lorenzo 2001) and may be susceptible to attraction from artificial lights.

**Collection of the grounded birds and rescue campaigns**

Awareness campaigns carried out by Cabildo Insular de Tenerife have involved local news media, talks in primary schools and high schools, stickers, posters, and public release of rescued birds, among other actions. As part of the education initiative, people were asked to collect fallen birds and telephone the ‘Centro de Recuperación de Fauna Silvestre La Tahonilla’ (onwards CRFS-La Tahonilla), depending on the island government (Cabildo Insular de Tenerife). Birds were collected by staff of the CRFS-La Tahonilla, examined and identified. Birds were ringed (except Cory’s Shearwater fledglings) and released at the coast during daylight to avoid being attracted again by lights. Injured birds were either held for rehabilitation or euthanized. For each bird, date, location, age class, phase of the moon and date and location of release were registered. Age class (adults or fledglings) was determined using a combination of feather coloration and wear, biometrics, and the presence of down or an incubation patch. Analysis of the geographic distribution of the light-induced mortality was based on 31 municipalities of the island (Fig. 1). As a proxy for light pollution, we estimated the number of inhabitants and the urbanized area (ha) below 400 m of altitude of each municipality. The data analysed spanned the years 1998–2006.

**Effects of the phase of the moon**

The effect of the phase of the moon on the number of petrels was only assessed for Cory’s Shearwater due to the small numbers of birds found grounded for the remaining species. To determine the effect of the phase of the moon on numbers of fledglings grounded, we assigned a value (0–14), where 0 corresponded to new moon and 14 to full moon. We ran a Spearman rank correlation between this score and the number of fledglings during the period 1998–2006. In addition, the moon phase was estimated as a binary variable with periods of full moon (the exact day of full moon ± 2 days) and new moon plus intermediate phases (all other days). This permitted us to test for differences in the mean number of petrels collected between these periods using a Mann–Whitney U-test. To avoid background noise, we only used the period between 25 October and 25 November, when more than 95% of Cory’s Shearwater fledglings were grounded as a consequence of artificial lights.
Impact of light-induced mortality on the petrel population

Without the aid of rescue campaigns, most of the grounded petrels would either be killed by predators or die of starvation and injuries (Imber 1975, Telfer et al. 1987, Le Corre et al. 2002). Even if the birds are not injured, they are unable to take off as many species need a long runway to take off. Therefore, we assumed that all grounded birds would die in the absence of intervention.

Petrel populations often include a large proportion of ‘floaters’, immature birds and adult non-breeders (Warham 1990). The proportion of floaters with respect to the total population is not known in the Canary Islands. We estimate annual adult mortality as the number of adult birds grounded relative to the size of the population, assuming a rate of 37% for floaters (immature and non-breeder adults; Ristow 1998) and number of breeders given in Table 1. Furthermore, we estimate a minimum adult mortality rate based on the total number of breeders (Table 1). To estimate the impact of light-induced mortality at fledging we had to determine the total number of fledglings lost (FL) and the total number of fledglings produced annually by the population (FP). The proportion of fledglings lost (PL) is then

\[
PL(\%) = \frac{FL}{FP} \times 100
\]

The number of fledglings produced annually depends on the breeding success (BS, number of birds which successfully fledge out of the number of eggs laid per female), and on the number of breeding pairs (BP). Therefore if the number of fledglings produced each year is:

\[
FP = BS \times BP
\]

then

\[
PL(\%) = \frac{FL}{BS \times BP} \times 100
\]

The total annual number of fledglings attracted by lights (FL) is hard to estimate and depends on several factors, especially the efficiency of the awareness campaign conducted each year before the fledging season. For the purpose of our study we used estimates available in the literature, and we assumed BP was constant among years. BS has not been estimated for these species in the Canary Islands, therefore we used published information from other Macaronesian archipelagos whenever possible (Table 1). Despite all these sources of constraints, estimates give us a rough idea of the magnitude of the problem.

RESULTS

Species affected, age-related variation in fallout, and success of rescue campaigns

Over the 9 years of study, at least 9880 petrels from nine species (Table 2) were found grounded in urban areas of Tenerife. Cory’s Shearwater represented 93.4% of the birds recovered. In addition to the local breeding species, three non-breeding petrel species were also recovered: Great Shearwater Puffinus gravis, Leach’s Storm-petrel Oceanodroma leucorhoa and White-faced Storm-petrel Pelagodroma marina hypoleuca. The mean number of birds recovered annually was 1098 ± 212 (sd). Most grounded birds were fledglings (93.9%) which probably were leaving the nests for the first time.

### Table 2. Number of petrels found grounded on the island of Tenerife from January 1998 to December 2006.

<table>
<thead>
<tr>
<th>Species</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>Total</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulweria bulweri</td>
<td>38</td>
<td>41</td>
<td>51</td>
<td>34</td>
<td>39</td>
<td>34</td>
<td>42</td>
<td>31</td>
<td>30</td>
<td>340</td>
<td>3.4</td>
</tr>
<tr>
<td>Calonectris diomedea</td>
<td>886</td>
<td>873</td>
<td>890</td>
<td>869</td>
<td>1311</td>
<td>806</td>
<td>1252</td>
<td>1359</td>
<td>985</td>
<td>9231</td>
<td>93.4</td>
</tr>
<tr>
<td>Puffinus puffinus</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>23</td>
<td>0.2</td>
</tr>
<tr>
<td>Puffinus gravis</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0.0</td>
</tr>
<tr>
<td>Puffinus baroli</td>
<td>25</td>
<td>27</td>
<td>16</td>
<td>29</td>
<td>10</td>
<td>10</td>
<td>12</td>
<td>7</td>
<td>8</td>
<td>144</td>
<td>1.5</td>
</tr>
<tr>
<td>Oceanodroma castro</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>7</td>
<td>3</td>
<td>31</td>
<td>0.3</td>
</tr>
<tr>
<td>Oceanodroma leucorhoa</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>17</td>
<td>14</td>
<td>6</td>
<td>2</td>
<td>58</td>
<td>0.6</td>
</tr>
<tr>
<td>Pelagodroma marina</td>
<td>3</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>37</td>
<td>0.4</td>
</tr>
<tr>
<td>Hydrobates pelagicus</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>0.1</td>
</tr>
<tr>
<td>Total</td>
<td>960</td>
<td>962</td>
<td>973</td>
<td>954</td>
<td>1377</td>
<td>879</td>
<td>1328</td>
<td>1415</td>
<td>1035</td>
<td>9880</td>
<td></td>
</tr>
</tbody>
</table>

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time (Table 3). Fledglings of larger Procellariiformes (Bulwer’s Petrel and the shearwaters) were more heavily affected than those of the smaller species (storm-petrels). Fewer than 6% of the birds were found dead, or dying and were euthanized. Thus rescue campaigns released more than 94% of the grounded birds.

### Seasonal aspects and effects of the phase of the moon

Pooling all species together, light-induced mortality occurred in every month of the year (Fig. 2). The highest numbers were recorded in October and November (16.6% and 74.7%, respectively), coinciding with the first flights of Cory’s Shearwater fledglings. The majority of species exhibited a clear seasonal pattern, which was related to their breeding phenologies. For five of six breeding species in Tenerife the peak of light-induced mortality occurred during the period when fledglings undertook their first flights (Fig. 2).

A negative correlation was detected between the phase of the moon and the number of Cory’s Shearwater fledglings grounded through the period 25 October to 25 November of all studied years (Spearman rank correlation, \( r = -0.26, \ P < 0.001, \ n = 288 \)). Fewer Cory’s Shearwater fledglings were found daily during full moon than at any other stage of the lunar cycle. Statistically significant differences were reached for years in which a full moon did not coincide with the usual fledging peak (Table 4). A lower number of fledglings were found when the full moon coincided with the mean date of first flight, but no statistical significant correlation was detected (see Fig. 3).

### Geographic distribution of light-induced mortality

Geographically, the grounding of birds was more intensive in coastal cities and tourist resorts and the majority of rescues were carried out at an altitude of less than 400 m asl. Thus, more than 65% of birds were found in the municipalities of the southwest coast (Fig. 1). The distribution of the birds found was related to the extent of urban areas: statistical significance and positive correlations were detected between the number of inhabitants and urban areas below 400 m asl, and the number of birds grounded (log (x + 1) transformed data; Pearson correlation coefficient, \( r = 0.63, \ P < 0.001, \ n = 31 \) and \( r = 0.65, \ P < 0.001, \ n = 30 \); respectively).

### Estimation of the light-induced mortality at the population level

The percentage of fledglings affected by artificial lights varied highly between species and years, 95% confidence limits ranging between 0% and 60.5%. Approximately half of the Cory’s Shearwater fledglings are affected by ‘light dazzling’, followed in importance by Macaronesian Shearwater fledglings (33.9 ± 19.9%; Table 5). In general, annual adult mortality was low, ranging between 0% and 5% of the adult population. Adult Manx Shearwaters were the most affected species, whereas adult Cory’s Shearwaters and European Storm-petrels were least affected. The estimates of adult mortality for the two different scenarios, only assuming breeding individuals and assuming that 37% of the individuals are floaters, are presented in Table 6.

### DISCUSSION

Magnitude, seasonality and distribution of grounded birds

Nine petrel species were affected by light pollution in the study area. This represents the highest
Figure 2. Monthly distribution of the light-induced mortality of petrels in Tenerife Island during the period 1998–2006. Y-axis shows the number of birds grounded: dark bars represent adults and lined bars fledglings. Horizontal bars indicate phenologies of petrels in the Canary Islands (white: not present in the Canary Islands or present in very low numbers; black: colony attendance or at least present at sea in the proximity of the islands; grey: incubation; lines: chick rearing; after Martín & Lorenzo 2001). Phenologies of Puffinus puffinus, Puffinus baroli, Oceanodroma castro, Pelagodroma marina and Hydrobates pelagicus are not well known in the Canary Islands.
number of species affected by light pollution in any studied archipelago to date. The absolute number of grounded birds is lower than in the Hawaiian archipelago (Telfer et al. 1987, Podolsky et al. 1998), but higher than in Réunion or the Malta Islands (Le Corre et al. 2002, Raine et al. 2007). The numbers of grounded Cory’s Shearwaters in the Canary Islands are only comparable with the estimates for Newell’s Shearwater Puffinus auriculularis newelli on Kauai, Hawaii (Telfer et al. 1987, Podolsky et al. 1998).

Although the species involved are different, there are similarities between our results and those from other studies. Mortality shows a seasonal pattern that varies according to the breeding schedules of each species, and mainly coincides with the date when fledglings undertake their first flights to the sea (Telfer et al. 1987, Le Corre et al. 2002). Interspecific differences in the number of grounded birds appear to be correlated with a differential degree of attraction to lights for each species, even when differences in the population size of each species are taken into account. As in other studies, the smaller species were least affected (Telfer et al. 1987, Le Corre et al. 2002).

The geographical pattern of light-induced mortality could be a consequence of the presence of important colonies and mass tourism developments in the southwestern part of the island. Lights from towns that are not near the coast or those at higher altitudes (above c. 400 m asl) did not attract petrels. This might be related to the distance to the breeding colonies, as reported for Réunion Island, where 35% of grounded Barau’s Petrels Pterodroma baraui were found in a little town at 1500 m asl located just below an important breeding colony (Le Corre et al. 2002).

### The effect of the phase of the moon on grounding birds

The maximum number of grounded fledglings varies annually with the lunar phase, producing a bimodal distribution around the date of full moon, or shifting the peak of fledgling grounding. As a rule, during full moon (± 2 days) a lower number of grounded fledglings were recovered than at other phases of the moon. This could be a consequence of two non-mutually exclusive factors. On the one hand, full moon could inhibit the first flight of young shearwaters. Indeed, during full-moon nights, petrel activity at breeding colonies decreases (Imber 1975, Bretagnolle 1990), apparently as an anti-predator mechanism (Watanuki 1986, Mougeot & Bretagnolle 2000, Oro et al. 2005). On the other hand, fledglings might fall in lower numbers because a greater ambient light reduces attraction towards artificial lights (Reed et al. 1985, Montvecchi 2006). If the latter hypothesis were correct, we would expect the number of grounded fledglings to vary among years according to the period elapsed between full moon and the middle of the fledging peak. Lower weights and longer wings of grounded fledglings were documented on Réunion Island during the last part of the fledging period in years when a full

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### Table 4. Mean number (± sd) of birds found daily during the fledging peak of Cory’s Shearwater (25 October–25 November) in relation to the phase of the moon.

<table>
<thead>
<tr>
<th>Year</th>
<th>Full moon (n)</th>
<th>Intermediate moon phases (n)</th>
<th>Mann–Whitney U test (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± sd</td>
<td>Mean ± sd</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>12.8 ± 7.5 (5)</td>
<td>31.2 ± 28.7 (27)</td>
<td>54.0 (0.51)</td>
</tr>
<tr>
<td>1999</td>
<td>1.9 ± 2.6 (8)</td>
<td>38.0 ± 31.1 (24)</td>
<td>17.0 (&lt; 0.001)***</td>
</tr>
<tr>
<td>2000</td>
<td>19.8 ± 17.0 (5)</td>
<td>27.2 ± 29.8 (27)</td>
<td>66.0 (0.94)</td>
</tr>
<tr>
<td>2001</td>
<td>16.6 ± 5.1 (5)</td>
<td>27.8 ± 31.7 (27)</td>
<td>54.5 (0.50)</td>
</tr>
<tr>
<td>2002</td>
<td>5.0 ± 0.7 (5)</td>
<td>45.3 ± 40.9 (27)</td>
<td>27.0 (0.035)*</td>
</tr>
<tr>
<td>2003</td>
<td>22.0 ± 8.0 (5)</td>
<td>24.0 ± 23.9 (27)</td>
<td>58.0 (0.62)</td>
</tr>
<tr>
<td>2004</td>
<td>7.43 ± 7.9 (7)</td>
<td>46.0 ± 42.4 (25)</td>
<td>34.5 (0.016)*</td>
</tr>
<tr>
<td>2005</td>
<td>5.6 ± 5.6 (5)</td>
<td>47.2 ± 47.6 (27)</td>
<td>32.5 (0.069)</td>
</tr>
<tr>
<td>2006</td>
<td>36.0 ± 15.7 (5)</td>
<td>27.5 ± 18.7 (27)</td>
<td>52.0 (0.42)</td>
</tr>
<tr>
<td>Total</td>
<td>13.12 ± 13.11 (50)</td>
<td>34.78 ± 34.39 (238)</td>
<td>3932.0 (&lt; 0.001)***</td>
</tr>
</tbody>
</table>

The number of occurrences of full moon (the exact day of full moon ± 2 days) and intermediate moon phases (all other days) respectively in the period studied are indicated by (n).

* and *** significant at α = 0.05 and α = 0.001 levels respectively.
The full moon coincided with the peak of the fledging period. This pattern seems to support the first hypothesis (inhibition of first flight by the full moon, Le Corre et al. 2002). We did not find any evidence against this hypothesis in our study. Further studies to clarify these patterns are warranted.
Effects on population size

Estimates of the number of birds affected may be biased because of several sources of error. First, we assume that the number of breeding pairs did not change during the course of our study period. Secondly, the number of breeding pairs reported in the literature may not be reliable due to the secretive breeding behaviour of petrels (nocturnal activity, underground nests, communal burrows with only one entrance, etc.), and the rugged relief of Tenerife which makes it very difficult to provide an accurate estimate of population size (Gregory et al. 2004). Thirdly, the breeding success of petrels from Tenerife may be different from other populations studied and probably changes annually. Also, given that not all birds were banded, we could have recaptured some of them. However, recaptures of banded birds were negligible (n = 18 of > 10 000) on Kauai (Telfer et al. 1987). Although the number of grounded birds on Tenerife per year is striking, actual numbers impacted are certainly higher than the numbers reported here because it is assumed that not all grounded birds are recovered.

Despite these biases, the rough estimates reported in this paper provide valuable information relevant to the population dynamics of the studied species (Le Corre et al. 2002, Day et al. 2003). Petrel species are long-lived organisms (Warham 1990) and they are more vulnerable to changes in adult mortality rates than changes in fledgling mortality rates (Simons 1984, Jones 2002). Although adult mortality is very low, mortality rates reported on Tenerife could be high enough to have severe effects on the population dynamics of some species, especially for the rare or threatened ones.

Populations of the Macaronesian and Manx Shearwaters deserve particular attention given their rarity, their local threatened status and because Tenerife lies at the southern extremity of their breeding ranges. The Manx Shearwater appears to be more severely affected than the

Table 5. Numbers of fledglings grounded (minimum and maximum values per annum, and mean ± sd) and estimates of the numbers of fledglings affected by light pollution (95% confidence limits and mean ± sd) for each breeding species on Tenerife Island during the period 1998–2006.

<table>
<thead>
<tr>
<th>Species</th>
<th>Fledglings</th>
<th>Percentage of affected fledglings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Bulweria bulwerii</td>
<td>16</td>
<td>31</td>
</tr>
<tr>
<td>Calonectris diomedea</td>
<td>775</td>
<td>1327</td>
</tr>
<tr>
<td>Puffinus puffinus</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Puffinus baroli</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Oceanodroma castro</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hydrobates pelagicus</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6. Estimates (95% confidence intervals and mean ± sd) of the proportion of adults affected by dazzling from lights for each breeding species in Tenerife Island during the period 1998–2006, under two different scenarios.

<table>
<thead>
<tr>
<th>Species</th>
<th>Percentage of affected adults: only breeding individuals</th>
<th>Percentage of affected adults: breeding and floaters individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% CI</td>
<td>Mean ± sd</td>
</tr>
<tr>
<td>Bulweria bulwerii</td>
<td>(1.5, 2.4)</td>
<td>1.96 ± 0.7</td>
</tr>
<tr>
<td>Calonectris diomedea</td>
<td>(0.6, 0.8)</td>
<td>0.7 ± 0.1</td>
</tr>
<tr>
<td>Puffinus puffinus</td>
<td>(2.8, 4.5)</td>
<td>3.6 ± 1.3</td>
</tr>
<tr>
<td>Puffinus baroli</td>
<td>(0.6, 1.6)</td>
<td>1.1 ± 0.7</td>
</tr>
<tr>
<td>Oceanodroma castro</td>
<td>(0.9, 1.9)</td>
<td>1.4 ± 0.8</td>
</tr>
<tr>
<td>Hydrobates pelagicus</td>
<td>(0.3, 1.0)</td>
<td>0.7 ± 0.6</td>
</tr>
</tbody>
</table>

In the first scenario, we only considered breeders. In the second one, we considered 37% of adult population to be composed of floaters (immatures and non-breeding adults, Ristow 1998).
Macaronesian Shearwater. We think it could be due to their different breeding habitats, the former being an inland breeder, where it may be more vulnerable to light pollution (Rodríguez et al. 2008). The Macaronesian Shearwater breeds primarily in coastal cliffs and, like the Wedge-tailed Shearwater Puffinus pacificus at Réunion Island, fledglings do not cross over the illuminated urban areas to reach the sea, thus decreasing the risk of light attraction (Le Corre et al. 2002). In addition, our data suggest that the number of Macaronesian Shearwater breeding pairs is probably slightly higher than that stated in the literature (Lorenzo 2007), although this number has probably decreased during the study period if we take into account a decline in the number of rescued birds by CRFS-La Tahonilla.

Assessment of rescue and awareness campaigns
Thanks to rescue campaigns, 94.7% of grounded birds were released during the study period 1998–2006. These campaigns have been carried out over 16 years (Anonymous 1995), and assuming an average of 1098 downed petrels per year, this means that over 16,000 birds have been released.

However, the fate of released fledglings remains unclear. Fledglings of Cory’s Shearwater have been observed to be unable to fly at sea due to the lack of waterproofing of their feathers (A. Rodríguez and B. Rodríguez pers. obs.). It is also possible that grounded birds are debilitated in some manner after their disorientated flight or by the subsequent stress of human handling.

Why are petrels attracted by lights?
Very little is known about why birds are attracted to artificial lights (Verheijen 1985), but some hypotheses have been proposed. Nocturnal seabirds often have larger eyes than diurnal ones, and their retinas have a preponderance of rods, thus enabling these species to be more sensitive to light (McNeil et al. 1993). Furthermore, species that consume bioluminescent prey appear to be affected to a greater extent by artificial light (Montevecchi 2006).

Inexperience may also play an important role. Petrel behaviour to reach the ocean from their nests must be innate, as they are abandoned by their parents some days before fledging (Warham 1990). They may be attracted to lights because this behaviour could increase their chances of finding food under natural conditions (Imber 1975, Klomp & Furness 1992). However, a more plausible explanation may be related to the fact that visual cues to reach the ocean during their first flight depend on moon or star light in a natural environment (Telfer et al. 1987). Young birds are attracted to illuminated areas because they need visual cues for navigation. Supporting this idea is the fact that many young petrels do not fly directly into lights, but rather circle illuminated areas, becoming disoriented over time, and finally landing stunned or exhausted (Telfer et al. 1987, A. Rodriguez and B. Rodriguez pers. obs.).

Conservation measures
Although research is urgently needed to develop effective mitigation measures for light attraction in birds (Verheijen 1985, Montevecchi 2006), several measures could be implemented immediately. These include reducing artificial lighting sources and changing light signatures. The current location of artificial light sources must be revised and some could be switched off if they are unnecessary. Furthermore, an amount of unused artificial lighting is projected into space due to inadequate orientation of light sources, and this should be eliminated. The peak concentrations of grounded birds are around the fledgling periods of the different species (Reed et al. 1985, Telfer et al. 1987, Le Corre et al. 2002, this study), so intensive light reduction could be undertaken during these periods. Some changes in light signature could reduce bird attraction to artificial lights (Reed 1987, Jones & Francis 2003, Baccetti et al. 2005, van de Laar 2007). Shielding lights to avoid upward radiation decreased the number of grounded petrels by > 40% on Kauai, Hawaii (Reed et al. 1985). More experimental studies testing light signatures and bird attraction
to lights are necessary to develop evidence-based management measures (Reed 1987, van de Laar 2007). On the other hand, awareness campaigns are necessary to help the public to become aware of light pollution and demand solutions from local and national governments. At least until light pollution is mitigated, rescue campaigns should be continued indefinitely. Great efforts must be made during the peak fledging periods of the most endangered species such as Macaronesian Shearwater and Manx Shearwater. In addition to these considerations, a monitoring program needs to be established to detect population changes on the Canary Islands.

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