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PERSPECTIVES AND NOTES

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Is seabird light-induced mortality explained by the visual system development?

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Abstract

Seabirds are impacted by coastal light pollution, leading to massive mortality events. Juveniles comprise the majority of affected individuals, while adults are only seldom grounded and reported in rescue programs. We propose a connection between visual system development of burrow nesting seabirds and the observed higher vulnerability to light pollution by a specific age group. We illustrate the need for multidisciplinary research to better understand and further mitigate light-induced mortality.

KEYWORDS

fallout, light attraction, light pollution, petrel, seabird vision, visual development

The anthropogenic use of artificial light at night and consequent light pollution are eroding natural nightscapes worldwide, resulting in unintended and negative consequences for biodiversity and ecosystems (Gaston, Davies, Nedelec, & Holt, 2017). While our understanding of how artificial light affects genes, individuals, species and communities, is still limited, the growing rate of urbanization and hence light pollution, represents an urgency for comprehensive multidisciplinary research (Gaston, Visser, & Hölker, 2015; Hölker et al., 2010).

Petrels and shearwaters (hereafter petrels) are highly adapted seabirds and one of the most threatened avian groups (Rodríguez et al., 2019). Petrels have the ability to navigate in the dark and to execute behaviors at various ambient light levels, from underwater foraging to colony visitation at night and underground nesting (Brooke, 2004). Consequently, they must possess anatomical and physiological adaptations to low-light levels, different optical media and rapid ambient light changes (reviewed in Martin, 2017).

In coastal areas, petrels are attracted to, and disorientated by, urban artificial lights. Following exhaustion or collision, individuals fall to the ground in fallout events becoming susceptible to lethal threats such as fatal injuries, vehicle collisions, predation, dehydration and inanition, or getting trapped (reviewed in Rodríguez et al., 2017). Grounded birds are sporadically observed throughout the year; however, fallouts are particularly severe during fledging season affecting thousands of juveniles during their first flights from nest to sea (Ainley, Podolsky, Deforest, Spencer, & Nur, 2001). Fallouts are aggravated by environmental drivers such as adverse weather (fog, rain), strong onshore winds and darker nights with reduced moonlight (Rodríguez et al., 2014; Syposz, Gonçalves, Carty, Hoppitt, & Manco, 2018; Telfer, Sincock, Byrd, & Reed, 1987). Without intervention fallouts are most likely fatal, increasing juvenile mortality rates and contributing to population declines (Fontaine, Gimenez, & Bried, 2011; Gineste et al., 2016).

Rescue campaigns are the most frequently employed mitigation measure worldwide, when citizens and organizations collect and release fallen birds. Data collected during such campaigns have shown that juveniles have a higher vulnerability to light pollution, making up from 68% to 99% of the rescued individuals (reviewed in Rodríguez et al., 2017).

The reasons for seabird attraction to lights remain unclear, currently resting upon three main hypotheses. First, foraging inexperience, where young individuals might confuse artificial light outputs with their naturally occurring bioluminescent prey (Imber, 1975). Second, associating light from the nests entrance with a food source, as chicks only feed whenever parents land and enter the nest to deliver sustenance (D. Ainley pers. comm. in Rodríguez et al., 2017). Third, interference of artificial light with navigation capabilities, either by outshining natural celestial cues or by interfering with vision-based magnetic navigation control mechanisms (Guilford, Padget, Bond, & Syposz, 2018; Telfer et al., 1987).

Chicks of burrow-nesting petrels spend most of their early life in the dark environment underground, only going out at night to practice flight motions during the end of the nestling period (Yoda, Shiozaki, Shirai, Matsumoto, & Yamamoto, 2017). Mitkus and colleagues have studied development of the visual system in a burrow-nesting seabird—Leach's storm-petrel (*Hydrobates leucorhous*) (Mitkus, Nevitt, & Kelber, 2018), a species affected by light pollution (Miles, Money, Luxmoore, & Furness, 2010). Leach's storm-petrel chicks spend 6–8 weeks in dark underground burrows before fledging. Their vision starts to function only around the third week post-hatching, however the retina is still immature and continues to develop, reaching adult-like state probably only sometime after fledging. In contrast, olfactory bulbs reach adult-like size before fledging, and can be used to identify burrows 1 week after hatching (Mitkus et al., 2018).

Two factors responsible for poor vision in recently fledged petrels were presented (Mitkus et al., 2018). First, a trade-off prioritizing olfaction over an energetically costly visual system. This underdevelopment of vision possibly reflects an adaptation to underground nesting where visual cues and necessity to use them are minimal. Second, a lack of visual stimuli prevents a growing eye to achieve emmetropia, that is, to produce a well-focused image. Dark underground burrows hinder visual experience due to the lack of visual cues, most likely resulting in severe focus deficiency upon fledging. Such handicap is expected to be corrected with urgency after fledging, allowing the juveniles to orientate and feed independently without parental care. While emmetropization was not tested in Leach's storm-petrel chicks in the aforementioned study, in other avian species (e.g., American Kestrel *Falco sparverius* and Common Barn-owl *Tyto alba*) juveniles achieve emmetropia after 1–2 weeks of visual exposure (Andison, Sivak, & Bird, 1992; Schaeffel & Wagner, 1996).

Assuming similar developmental mechanisms in all burrow-nesting petrel species, we suggest that untrained and undeveloped visual system coupled with innate behavioral inexperience at fledging could be one of the main drivers of the massive fledgling fallout events observed every year on oceanic islands, and the leading factor for the age disparity observed. This argument is supported by the observations that other non-petrel seabirds grounded by light pollution, such as puffins, are also burrow-nesters (Wilhelm et al., 2013). On the other hand, surface-nesting petrels such as fulmars or albatrosses have not been recorded at fallout events nor in light attraction events at sea, to the best of our knowledge.

While knowledge regarding vision in petrels is limited (Capuska, Huynen, Lambert, & Raubenheimer, 2011; Hart, 2004; Martin, & Brooke, M. de L., 1991; Mitkus, Nevitt, Danielsen, & Kelber, 2016; Reed, 1986), the fledglings versus adults and burrow-nesting versus surface-nesting species biases at fallout events suggests a connection between vulnerability to artificial lights and visual system development. Differential exposure to daylight during development could further suggest differences in light attraction between species and conspecifics. The depth and the tortuosity of the burrow greatly determines the amount of light coming into the nest, thus chicks from darker nests might have a higher visual handicap. Conversely, surface-nesters experience natural light cycles and should receive enough visual input for the eyes not to develop focus deficiencies. Additionally, fledging during the day versus night could influence immediate exposure to light pollution, and aggravate fallout for already vulnerable groups. Further research is needed to resolve these interactions, as well as ensuing questions, such as the potential role of artificial light and light pollution as a surrogate of sunlight in vision development.

Our hypothesis could also be valid for sea turtles, which show a reaction to light pollution similar to that of seabirds. Sea turtle hatchlings are misdirected by artificial lights when they emerge from their buried nests, leading to massive mortality events (Limpus & Kamrowski, 2013). Adult sea turtles are less vulnerable to artificial lights and are able to find their way to the ocean after laying their eggs in the same lit beaches. This age disparity has been attributed to increased experience and different visual perspective to the horizon due to higher height of adults (Limpus & Kamrowski, 2013). However, ontogenetic differences in visual systems could also occur in sea turtles (Horch, Gocke, Salmon, & Forward, 2008) and help to explain the disruption of the ocean finding behavior by artificial lights.

Conservation measures currently implemented, that is, rescue campaigns, already target fledging season and consequently the more vulnerable life-stages (Rodríguez et al., 2017), but such campaigns are palliative actions as they only rescue grounded birds. To reduce artificial light impact it is recommended shielding the lighting structures as well as turning off, or decreasing the use of, street and private lights during fledging season, which in some locations has reduced the fallouts (Reed, Sincock, & Hailman, 1985; Rodríguez et al., 2014). Changing the spectral composition of light can also reduce the number of grounded seabirds (Longcore et al., 2018). However, without knowledge on specific mechanisms that drive seabird attraction or disorientation by artificial lights, it is difficult to propose measures to effectively reduce, or eliminate, negative effects of this phenomenon. Future studies should investigate specific aspects of seabird vision across different life stages and species, for example, contrast sensitivity, flicker fusion frequency or innate color preferences, to better understand how and what seabirds can see.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

AUTHORS CONTRIBUTIONS

E. A. and A. R. conceived the idea. M. M., E. A., and A. R. contributed to the development of the argumentation and writing.

ETHICS STATEMENT

All ethical guidelines were met.

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