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Applied Studies of Raptor Sensory Ecology are Rare

Christopher J.W. McClure
Peregrine Fund

Simon Potier
Lund University

Jesse R. Barber
Boise State University

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APPLIED STUDIES OF RAPTOR SENSORY ECOLOGY ARE RARE

CHRISTOPHER J. W. MCCLURE[1]
Peregrine Fund, Boise, ID 83709 USA

SIMON POTIER
Department of Biology, Lund University, Lund, 221 00 Sweden

JESSE R. BARBER
Department of Biological Sciences, Boise State University, Boise, ID 83725 USA

ABSTRACT.—Light and noise often act as pollutants, but can also be used as tools for managing wildlife (e.g., sensory deterrents). Given that raptors are among the most threatened groups of birds, we expected there to be a moderate amount of applied research on their sensory ecology. We searched Web of Science and Google Scholar to quantify and classify the research that has been conducted on the applied sensory ecology of raptors. Of 32 studies assessing the effects of sensory pollution on raptors, we found that 10 studies examined effects of light pollution and 24 studies examined effects of noise pollution. Most of the studies regarding sensory pollution were of owls (21 studies). The United States was the site of the most noise pollution studies (seven studies) whereas Spain and Poland (two studies each) were sites of the most studies of light pollution. We found only seven studies that directly collected data regarding sensory deterrents. With so few studies examining applied aspects of the sensory ecology of raptors, we argue that effects of sensory pollution are poorly understood and the efficacy of sensory deterrents is largely unknown. Light and noise pollution are spreading across much of the globe. Applied research on the sensory ecology of raptors must be made a priority if wildlife managers are to conserve this imperiled group of birds.

KEY WORDS: *artificial light at night*; *bird of prey*; *deterrent*; *light pollution*; *noise pollution*; *raptor*; *sensory ecology*.

LOS ESTUDIOS APLICADOS DE ECOLOGÍA SENSORIAL DE RAPACES SON RAROS

RESUMEN.—La luz y el ruido a menudo actúan como contaminantes, pero también se pueden usar como herramientas para manejar la fauna salvaje (e.g., disuasores sensoriales). Dado que las rapaces se encuentran entre los grupos de aves más amenazados, esperábamos que hubiera una cantidad moderada de investigación aplicada sobre su ecología sensorial. Realizamos búsquedas en Web of Science y Google Académico para cuantificar y clasificar la investigación que se ha realizado sobre la ecología sensorial aplicada de las rapaces. De 32 estudios que evaluaron los efectos de la contaminación sensorial en las rapaces, encontramos que 10 estudios examinaron los efectos de la contaminación lumínica y 24 estudios examinaron los efectos de la contaminación sonora. La mayoría de los estudios sobre contaminación sensorial fueron de búhos (21 estudios). Estados Unidos fue el sitio con la mayor cantidad de estudios de contaminación sonora (siete estudios), mientras que España y Polonia (dos estudios cada uno) fueron los países con la mayor cantidad de estudios de contaminación lumínica. Solo encontramos siete estudios que tomaron datos directamente con respecto a los disuasores sensoriales. Con tan pocos estudios que examinan los aspectos aplicados de la ecología sensorial de las rapaces, argumentamos que los efectos de la contaminación sensorial son poco conocidos y que se desconoce en gran medida la eficacia de los

[1] Email address: cmcclure@peregrinefund.org

disuasores sensoriales. La contaminación lumínica y sonora se está extendiendo por gran parte del mundo. La investigación aplicada sobre la ecología sensorial de las rapaces debe ser una prioridad si los gestores de fauna silvestre quieren conservar este grupo de aves en peligro.

[Traducción del equipo editorial]

Introduction

Ambitious conservation action is needed to assuage the Earth's sixth mass extinction (Ceballos et al. 2010, 2015, Díaz et al. 2020). The science of sensory ecology can inform many actions needed to address threats to the world's biodiversity (Dominoni et al. 2020). For example, anthropogenic noise and artificial light are ubiquitous across much of the globe, and can affect the fitness of animals across continental scales (Senzaki et al. 2020). Such pollution is best understood through the lens of sensory ecology (Dominoni et al. 2020), which we define as the study of how organisms gather information from the environment and the effects of such information on evolution, physiology, behavior, and conservation. Other threats to biodiversity can be managed by exploiting the sensory systems of animals to accentuate or otherwise alter their perception. Loud noises, for instance, are often used to scare birds away from ponds contaminated with dangerous chemicals (Stevens et al. 2000, Ronconi and Cassady St. Clair 2006). Sensory ecology can thus inform the management of anthropogenic light and noise as pollutants in addition to informing the use of visual and auditory stimuli as wildlife management tools (e.g., sensory deterrents). This important nexus between sensory ecology and wildlife management, however, is understudied (Dominoni et al. 2020).

As a group, raptors (orders Accipitriformes, Cathartiformes, Falconiformes, Strigiformes, and Cariamiformes; Iriarte et al. 2019, McClure et al. 2019) are of conservation and research priority (McClure et al. 2018, Buechley et al. 2019). Indeed, raptors are more threatened and are declining more sharply than other groups of birds (McClure and Rolek 2020), with more than half of raptor species having declining global populations, and 18% (of 557 raptor species) threatened with extinction (McClure et al. 2018). Even among raptor species listed as Least Concern by the International Union for the Conservation of Nature, 38% are in decline (McClure et al. 2018). Raptors are also poorly studied, with just 10 species accounting for one-third of all raptor research and 20% of raptors remaining virtually unstudied (Buechley et al. 2019).

The sensory systems of raptors are especially adapted to predatory or scavenging lifestyles (Potier 2020), and these adaptations have conservation implications. For example, Martin et al. (2012) suggested that when some vulture species forage, they position their visual fields to scan the ground and to prevent the eye from imaging the sun. This positioning results in vultures being blind in the direction of travel and thus being subject to collision with objects including wind turbines (Martin et al. 2012). Given the conservation and research priority of raptors and the role that sensory ecology can play in their conservation, the sensory ecology of raptors is an especially important research topic.

Studies of the basic ecology and physiology of raptor vision are fairly common and well-reviewed (e.g., Mitkus et al. 2018, Potier 2020, Potier et al. 2020). Because some raptor species are well studied (Buechley et al. 2019), and sensory pollution has gained attention recently (e.g., Barber et al. 2010, Swaddle et al. 2015, Dominoni et al. 2020), we expected at least a moderate amount of research regarding applied sensory ecology of raptors (approximately 100 studies). The goal of this study was to conduct a literature review of research that has examined the effects of light and noise pollution on raptors, or has examined the effectiveness of sensory deterrents on birds of prey.

Methods

Web Searches. We searched Web of Science and Google Scholar for studies regarding the effects of sensory pollutants and deterrents on raptors. Web of Science searches the academic literature whereas Google Scholar also includes the "gray literature." We did not restrict the search by country, time period, or language. We used "Harzing's publish or perish" software (https://harzing.com/resources/publish-or-perish) to search Google Scholar. Haddaway et al. (2015) suggested the examination of the top 200–300 entries from Google Scholar to ensure the retention of mostly academic literature. We thus retained the first 250 entries returned by Google Scholar. We performed separate searches for sensory pollutants and deterrents on 7 November 2020. We used the same search strings for Web of Science and Google Scholar. These strings were adapted from McClure et al. (2021). For sensory pollutants the search string was: (raptor* OR "bird* of prey" OR vulture* OR eagle* OR hawk* OR owl* OR seriema*) AND ("light pollution" OR "artificial light at night" OR "noise pollution" OR "anthropogenic noise" OR "anthropogenic light"). For sensory deterrents the search string was: (raptor* OR "bird* of prey" OR vulture* OR eagle* OR hawk* OR owl* OR seriema*) AND (deterren* OR diversion OR repel*). For consistency and repeatability, we did not successively search for studies cited by other studies (i.e., "snowball searching"). We therefore only

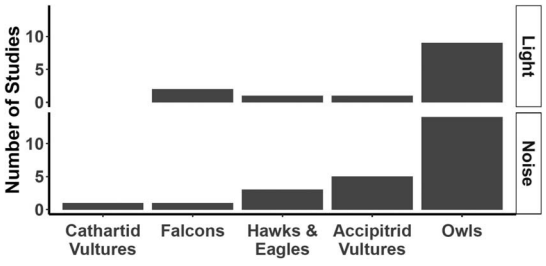

Figure 1. The number of studies examining light or noise pollution for different groups of raptors. Note that seriemas are not included because no study has examined them in relation to sensory pollutants.

considered the studies returned by the above search strings.

Processing. We used the R (R Core Team 2018) package *revtools* (Westgate 2019) to remove duplicate titles from search results. Next, we screened studies based on full texts. We used two criteria for screening: (1) the study addressed at least one raptor species, (2) the study addressed either light or noise pollution or, for the deterrent studies, either acoustical or visual deterrents. We considered studies to have passed the screening process if they met both criteria. So few studies addressed either acoustical or visual deterrents that we did not code them (see below). For pollutants, we coded studies according to the type of pollutant (light, noise, or both), the country in which the study was conducted, the year in which the study was published, and the type of raptor.

RESULTS

Our pollutant search returned 595 unique entries, of which 33 met our criteria. The majority of the studies that passed our criteria examined noise (24 studies) versus light (10 studies) pollution. Most of these studies were of owls (21 studies), followed by Accipitrid vultures (six studies; Fig. 1), with no studies of seriemas. The Unites States was the site of the most studies (seven studies) of noise pollution, followed by Spain (four studies) and then Poland (three studies; Fig. 2). Portugal and Poland were the site of the most studies (two studies; Fig. 2) of light pollution. Of the 534 studies returned by our search for sensory deterrents, only 12 studies met our criteria; seven of these reported directly collected data, and five provided reviews. Of the 12 studies of sensory deterrents, eight discussed visual deterrents and five discussed auditory deterrents. Visual deterrents included mirrors (Dixon et al. 2019) and short-wave light (Foss et al. 2017) and auditory deterrents included a hailing device (Schlichting et al. 2017) and harassment with pyrotechnics (Lowney 1999). See Supplemental Material for the results of the literature search and study coding.

DISCUSSION

There are few studies of the effects of sensory pollution on raptors (33 studies) and even fewer examining sensory deterrents (12 studies). Certain groups and types of sensory pollution are even less studied. For example, light pollution is less examined than noise pollution, and we were unable to find any studies of light pollution on Cathartid vultures, or studies of either light or noise pollution or deterrents on seriemas. There has been little research of seriemas on any topic (Méndez et al. 2022), so such lack of attention was perhaps to be expected. However, some raptor species are well studied (Buechley et al. 2019), so a lack of applied sensory ecology research across all raptors is especially salient in light of the current biodiversity crisis (Dirzo et al. 2014, Ceballos et al. 2017).

Owls are the most studied group of raptors regarding both noise and light pollution. Perhaps this focus on owls is because of their nocturnal lifestyle, which heightens their sensory needs. To see under low light conditions, owls have larger eyes than most birds and the largest eyes of the raptor groups (Potier et al. 2020). These nocturnal predators also have specialized ears, which accentuates their hearing abilities (e.g., Payne 1971, Dooling 2002, Krumm et al. 2017). Such well-known sensory capabilities might have led to more research compared to other raptor groups.

Although we were surprised by the low number of countries that were sites of applied research in raptor sensory ecology (Fig. 2), we did expect that North America would be overrepresented. Indeed, North America is the site of most of the research of anthropogenic noise (Sordello et al. 2020) and traffic noise in particular (McClure 2021). Such lack of spatial research coverage reflects not only a lack of overall attention to applied sensory ecology of raptors, but also highlights a need for raptor research in the Global South, where the bulk of raptor diversity resides (McClure et al. 2018, Buechley et al. 2019).

Noise and light exposure are both ubiquitous pollutants across much of the Earth's surface, with major ecological consequences (Senzaki et al. 2020). Given the sensory specialization of many raptor species, such pollutants are likely affecting raptors around the globe. Strasser and Heath (2013) suggested that reproductive failure of American Kestrels (*Falco sparverius*) was due to disturbance by traffic noise. Especially for owls, noise pollution seems to substantially reduce foraging success (Mason et al. 2016, Senzaki et al. 2016). More work therefore should be done elucidating the effects of sensory pollution on raptors, with a focus on developing and testing methods to mitigate such impacts.

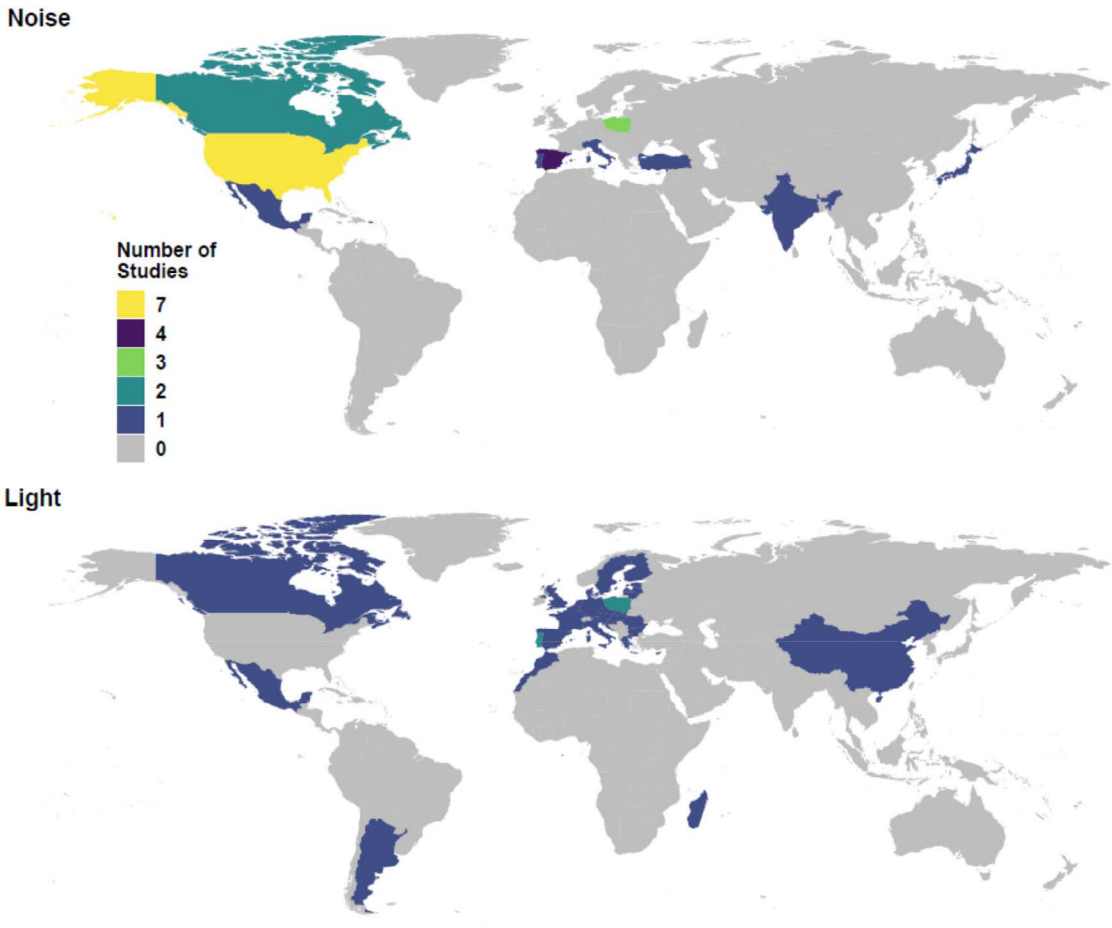

Figure 2. Map demonstrating the number of studies that have been conducted within each country regarding the effects of noise and light pollution on raptors.

Sensory deterrents are potentially powerful tools to repel raptors from dangerous hazards. Foss and colleagues (2017) demonstrated that short-wavelength light can repel Red-tailed Hawks (*Buteo jamaicensis*) from a migratory stopover site, and Allison and co-workers (2019) mentioned that acoustic deterrents are promising tools for repelling Golden Eagles (*Aquila chrysaetos*) from wind turbines. Such studies suggest that sensory deterrents are perhaps a fruitful, yet severely underresearched area of applied study.

We expected more research to have been conducted regarding applied sensory ecology of raptors. Given the expanse of light and noise pollution worldwide and the potential uses for sensory deterrents, much more applied research on raptor sensory ecology needs to be conducted, especially in the Global South. The sixth mass extinction is already upon us, and sensory pollutants are playing a role (Senzaki et al. 2020). Applied research on the sensory ecology of raptors must be made a priority if wildlife managers are to conserve this imperiled group of birds.

Supplemental Material (available online). Excel file: Output from the R package *revtools* for the literature search for sensory repellents, coded studies of sensory repellents, output from the R package *revtools* for the literature search for sensory pollution, coded studies of sensory pollution.

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