LuMinAves: cooperative research and mitigation of light pollution impacts in seabirds

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Abstract

Any efforts to conduct a sustainable management of urban and natural landscapes benefit from an interdisciplinary approach and active collaboration between actors, thus increasing the feasibility and effectiveness of the proposed actions. The emergent transition of urban lighting to white LED technology can bring a variety of negative effects to these environments, accordingly management actions should be applied taking into account as broad a knowledge set as available. Such knowledge is often fragmented and incoherent thus in need to be united and clarified into usable and common tools. In the North Atlantic, the region of Macaronesia has implemented a project which uses knowledge about the negative effects of light pollution on seabird populations as a baseline to effect changes in the regional lighting schemes, decreasing light pollution and increasing the sustainability of the current LED transition, improving practices and awareness, to the benefit of both seabird and human populations.

Keywords: sustainable lighting, collaborative actions, seabird ecology, urban light pollution, citizen-science

1 Introduction

Light pollution in urban coastlines often have conspicuous effects on biodiversity [1]. Juvenile seabirds when leaving their natal colonies for the first time, are disoriented and attracted by artificial light at night, frequently falling into urban areas. During these events juveniles can be injured or even perish during the fall, and once on the ground, they are further subjected to threats such as vehicle collision, predation or inanition [2]. Over 62 seabird species are known to be affected by light pollution [2;3]. In the Macaronesian archipelagos of the Azores, Madeira and the Canary Islands, light pollution impacts on seabirds are well known, with long-term rescue campaigns currently active. Such rescue campaigns, where volunteers and specialists search for, collect and release fallen juveniles, are a widely used mitigation tool and are crucial to reduce seabird light-induced mortality. Likewise, actions that prevent or reduce light pollution and thus their impacts, have been increasing in the region, mostly centred on the critical fledging periods, and have been hitherto unconnected between actors. To increase mitigation, reduction, and avoidance of light pollution in Macaronesia, the collaborative project 'LuMinAves' was designed, which unites current efforts by the different regions and provides a common platform for development of enhanced mitigation practices and improved protocols regarding urban lighting and management of light pollution impacts.

The project covers ten petrel species (Table 1) and spans across the three archipelagos. LuMinAves actions actively contribute to the implementation of European directives such as the Marine Strategy Framework Directive (Descriptor 1 – Biodi-

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versity) and comply with the Birds Directive from Natura 2000 network, furthering the reach of the project. Three main approaches aim to address current shortcomings and improve the overall management of light pollution: knowledge, dissemination, and mitigation & urban planning.

Table 1: Species affected by light pollution in Macaronesia and their respective historical fallout records availability, span of the rescue campaign when it exists and its respective description. Species covered by project's actions are in bold.

Archipelago	Family	Species	Historical Fallout Records	Years of campaign	General description of Rescue campaign
Azores	Procellariidae	***Calonectris borealis***	Yes. Dedicated Rescue campaign	1995 to current. Data collection since 2001	**SOS Cagarro**. Led by DRAM. Executed on all islands in partnership with Natural Island Parks and NGOs
	Procellariidae	***Bulweria bulwerii***	Yes. Anecdotal		
	Hydrobatidae	***Hydrobates castro***	Yes. Anecdotal		
	Hydrobatidae	***Hydrobates monteiroi***	Yes. Anecdotal		
	Hydrobatidae	*Hydrobates leucorhous*	Yes. Anecdotal		
	Procellariidae	***Puffinus lherminieri (baroli)***	Yes. Anecdotal	2010 to current	
	Procellariidae	***Puffinus puffinus***	Yes. Dedicated Rescue campaign	2009 to current.	**SOS Estapagado**. Led by SPEA and executed on Corvo Is. In partnership with Corvo Natural Island Park
	Procellariidae	*Ardenna grisea*	Yes. Anecdotal		
Madeira	Procellariidae	***Calonectris borealis***	Yes. Dedicated Rescue campaign	2009 to current.	**Salve uma ave marinha.** Led by SPEA Madeira in collaboration with Natural Island Parks. Executed on Madeira Is. and Porto Santo Is.
	Procellariidae	***Bulweria bulwerii***	Yes. Dedicated Rescue campaign	2009 to current.	
	Procellariidae	***Pterodroma madeira***	Yes. Dedicated Rescue campaign	2009 to current.	
	Procellariidae	***Pterodroma deserta***	Yes. Dedicated Rescue campaign	2009 to current.	
	Hydrobatidae	***Hydrobates castro***	Yes. Dedicated Rescue campaign	2009 to current.	
	Procellariidae	***Puffinus lherminieri (baroli)***	Yes. Dedicated Rescue campaign	2009 to current.	
	Procellariidae	***Puffinus puffinus***	Yes. Dedicated Rescue campaign	2009 to current.	
	Oceanitidae	***Pelagodroma marina***	Yes. Dedicated Rescue campaign	2009 to current.	
Canary Is.	Procellariidae	***Calonectris borealis***	Yes. Dedicated Rescue campaign	1990 to current	Local campaigns are led by Municipalities in collaboration with NGOs varying among islands
	Procellariidae	***Bulweria bulwerii***	Yes. Admissions to rehabilitation centre	1990 to current	
	Procellariidae	***Puffinus lherminieri (baroli)***	Yes. Admissions to rehabilitation centre	1990 to current	
	Procellariidae	***Puffinus puffinus canariensis*** [4]	Yes. Admissions to rehabilitation centre	1990 to current	
	Oceanitidae	***Pelagodroma marina***	Yes. Admissions to rehabilitation centre	1990 to current	
	Hydrobatidae	***Hydrobates pelagicus***	Yes. Admissions to rehabilitation centre	1990 to current	
	Hydrobatidae	*Hydrobates leucorhous*	Yes. Admissions to rehabilitation centre	1990 to current	
	Hydrobatidae	*Hydrobates castro*	Yes. Admissions to rehabilitation centre	1990 to current	
	Procellariidae	*Ardenna gravis*	Yes. Admissions to rehabilitation centre	1990 to current	

Here we present a general overview of the methods and current results from the main actions executed during the project and generally discuss its effectiveness and implications to the region.

1.1 Knowledge

Monitoring seabirds in situ can be challenging due to the burrow-nesting habits of these species, the inaccessibility of their colonies' selection and their nocturnal behaviour on land [5]. To provide more accurate knowledge on such species it is beneficial to use multiple methods and data sources [6]. The project integrates data collection at breeding colonies and during rescue campaigns, to estimate the effectiveness of conservation actions (e.g., by evaluating changes in demographic parameters or calculating population recruitment), and to provide more accurate data regarding several aspects of fallout events (e.g., geographical distribution of fallout or citizens' rescue effort).

1.2 Dissemination.

Clear communication, exchange of knowledge and cooperative approaches enhance the response capacity of conservation actions [7]. LuMinAves was designed so that all partners directly and continuously exchange information on past experience (e.g., practices of active rescue campaigns) and of knowledge gathered during the project's actions (e.g., pilot projects or rescue protocols), thus guaranteeing the exchange of information amongst partners (e.g., unified databases) and towards the public (e.g., public workshops and talks). These actions aim to improve light pollution awareness and response capacity of all actors.

1.3 Mitigation & Urban Planning.

Key measures to mitigate the effects of light pollution include the rehabilitation of individuals affected by the impact (i.e., via rescue campaigns), the reduction of the spatial and temporal use of artificial light at night (e.g., via lighting scheduling and identification of critical areas), and the manipulation of light components (i.e., via shielding of light structures, selection of spectral composition and reduction of light intensity) [2]. Coalesced results from Knowledge and Dissemination chapters help to estimate seabird ecological indicators (e.g., changes in population size or distribution), characterize spatial and temporal aspects of light pollution, and generate protocols and best practices guides in regards to both urban lighting schemes and light pollution impacts.

2 Methods

The project began in 2016 and finished at the end of 2020. Lead by SEO (Sociedad Española de Ornitología), it is conceptualized, managed and implemented by the operational partners: SEO, IFCN IP-RAM (Instituto das Florestas e Conservação da Natureza IP-RAM), DRAM (Direção Regional dos Assuntos do Mar) and FRCT (Fundo Regional para a Ciência e Tecnologia) in the Azores, SPEA (Sociedade Portuguesa para o Estudo das Aves) Açores and SPEA Madeira. Development of the project actions are conducted in collaboration with non-operational partners, which provide platforms for urban lighting change and logistical support: Viceconsejería Medioambiente del Gobierno de Canarias, Cabildo Insular de Tenerife, Cabildo Insular de Fuerteventura, Cabildo Insular de Gran Canaria, IAC (Instituto de Astrofísica de Canarias), Câmara Municipal de Santa Cruz, Câmara Municipal do Corvo, EEM (Empresa da Electricidade da Madeira) and EDA (Electricidade dos Açores).

2.1 Knowledge

Systematic monitoring was conducted on selected colonies to estimate seabird ecological indicators: demographic parameters (breeding success and survival rate), abundance (breeding population size estimates and global census) and distribution (active breeding colonies). Data were collected using different methods, including traditional nest-checking (regular visits to the nest to record presence of adults, chicks or eggs) and automatic recording units (used to estimate population size based on vocalizations when seabirds return to the colonies). Known colonies were monitored and prospecting efforts were made to identify new ones. Whenever possible, LuMinAves integrated its monitoring actions within ongoing monitoring schemes, in collaboration with universities and synergetic projects, thus ensuring the best datasets and use of resources. The ten target species were selected based on established monitoring schemes at known colonies, and based on these species occurrence during past rescue campaigns, thus increasing the quality of data collected by building on previous knowledge, and optimizing field operations, a crucial aspect of the project planning due to its short duration (i.e., 3 to 4 years of data collection and organization).

Massive ringing sessions of chicks were organized in two phases. First, chicks were ringed at colonies a few weeks to days before fledging, to determine source colonies of the affected juveniles [8]. Fledged chicks rescued during campaigns were also ringed before being released at sea.

Rescue campaigns are the main tool used to reduce light induced mortality [9] and can increase knowledge on cryptic or data poor species [3;4] as well as supply knowledge on these species ecology and on environmental state [2]. Thus, data collection protocols were standardized: implementation of ringing actions on rescued juveniles where lacking, systematization of the handling and release methods, and collection of standardized biometrics (e.g., weight, wing length, tarsus, etc.). The latter can be used to inform on the health condition of affected individuals providing information to enhance and improve rescue protocols (i.e., increase focus and effort on critical dates and on individuals with higher probability of survival) [10].

Participants in rescue campaigns conduct searches for grounded birds in areas of easy access, close to their habitual daily routes, or in locations previously known to have higher fallout numbers, which can lead to location bias. To improve the quality of rescue data, pre-determined routes were implemented. As the campaigns are highly dependent on and organized by different groups throughout each island and archipelago, each pre-determined route was defined locally, however, all focused on covering both lighted and dark areas, as well as lighted areas previously overlooked, to increase geographical coverage.

Lastly, the registration of fallout location in GPS format was encouraged. Traditionally, fallout location has been recorded using descriptive text and often contained local references (e.g., 'dirt road' or 'person X's yard'). To increase usability and accuracy of the data, rescue forms now include a 'GPS' field where participants can write down the coordinates of where the rescued juvenile was found (currently this information can be easily extracted using a smartphone). However, this is time consuming especially at night, handling wild birds, thus digital tools for automated recording of GPS location are also being developed (e.g., currently a user-friendly mobile device application (App) is being tested by DRAM, to be available to any participant allowing them to automatically register GPS positions and append other rescue information more accurately, quickly and directly feeding an archipelago wide online database).

2.2 Dissemination

Operational partners met during scheduled meetings and workshops to coordinate efforts and to manage the progress of ongoing actions.

The high number of citizen participation and organized data collection during Macaronesia's rescue campaigns has already generated a large dataset, albeit fragmented amongst different organizations, islands and archipelagos (Table 1). All available historic data were collected and coalesced into a common database, detailing location of rescue, health condition, ringing and biometric data of rescued individuals, as well as information on volunteers and rescue effort.

Educational and outreach materials were produced, including a website, posters, fliers and videos with information on the species ecology, light pollution and rescue procedures for fallen birds. To increase citizens' awareness and the reach of the project, the partners organized public talks and events with varied target audiences.

2.3 Mitigation

All available fallout locations were extracted from the coalesced database, subsequently mapped then analyzed against light pollution and urban layers. Geographical mapping was conducted in QGIS version 3.8.2-Zanzibar (QGIS Development Team, 2009. QGIS Geographic Information System. Open Source Geospatial Foundation. URL http://qgis.org). For each island, available data were totaled and plotted in two ways: individual GPS fallout locations (e.g., Fig. 2 left) and totals by municipality (e.g., Fig. 2 right). Due to differences in rescue efforts between islands and archipelagos, maps can represent data from distinct time spans, and can have distinct geographical accuracies (i.e., there are islands where reduced technology and low number of citizens' participants do not allow for the collection of specific location data per individual, rather they are grouped in the small number of places where juveniles are delivered to). Kernel density maps for individual fallout locations were generated at 5 km and 2 km depending on the relative size of the island. Light pollution layers (vcm monthly averages) were extracted from the VIIRS satellite information at NOAA (National Oceanic and Atmospheric Administration) Earth Observation Group (https://eogdata.mines.edu/download_dnb_composites.html) [11], for the periods corresponding with the peak fallout in each region (e.g., October for Cory's shearwater in the Azores), averaged between 2016-2019, and finally displayed with a stretched and clipped scale of 0-50 or 100 nanowatts/cm2/sr depending on the islands' scale (e.g., Fig. 2 bottom).

To begin assessing social effects of implementing changes in urban lighting schemes, a blackout pilot project was set up on Corvo Island, Azores. From 2017 to 2019 Corvo's local municipality turned off public lights at two areas (main streets and old town) for distinct time periods, during the fledging period of Cory's shearwater, between October and November (Table 2). The municipality also executed a total blackout for one night in 2019 in an awareness event led by SPEA-Açores in partnership with Corvo Natural Park.

Finally, combining the interdisciplinary knowledge gathered during the project, the partners are elaborating best practices guides and a comprehensive action-plan to tackle light pollution in Macaronesia. These documents will be distributed amongst stakeholders and used as a base to integrate reducing light pollution in urban planning and to help implement realistic and effective strategies to tackle light pollution.

3 Results

3.1 Knowledge

Two new colonies for *Calonectris borealis*, one breeding confirmation for *Bulweria bulwerii* and a new colony for *Hydrobates castro* were identified. At the monitored colonies, over 1000 nests were followed leading to updated population estimates for *H. castro, H. monteiroi* and *B. bulwerii*, and to the estimate of breeding success for all species.

Over 900 chicks were ringed at their colonies, prior to fledgling. Of these, <1% were re-sighted (and rescued) during the rescue campaigns.

From 2016 to 2019, 25% of rescued birds were ringed before release (over 5600 Cory's shearwater juveniles), and their respective biometrics recorded. Recovery of these individuals remains anecdotal, due to the deferred sexual maturity of these species (e.g., Cory's shearwaters return to their natal colonies 5-9 years after fledging) [12]. The estimation of the rescue campaign's effectiveness has to rely on the long-term and continuous aspect of these actions and these data are still being processed.

Multiple organizations integrated pre-determined routes during the rescue searches. From 2016 to 2019, ~27% of rescued individuals had GPS coordinates associated with their rescue location, a notable increase from the 1% in all previous years combined (2001-2015).

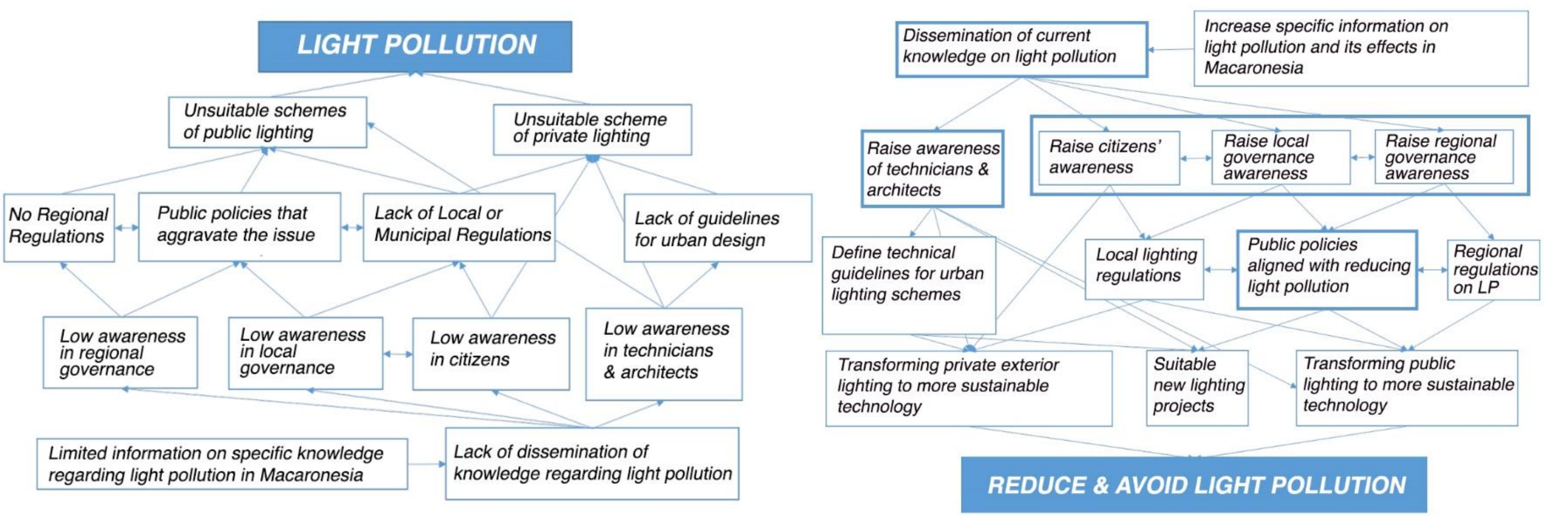

Figure 1: Outcome of the Regional SWOT analysis. Tree of the problem (left). Tree of the objectives (right).

3.2 Dissemination

The coalesced database is the result of a permanent ongoing effort with contributions from all archipelagos, and currently contains over 50,000 records of fallen fledglings. Around 6% of the individuals found were injured or dead, the former sent to recovery centers and the latter used for associated studies e.g., plastic ingestion research [13].

At least three online meetings were conducted each year, where partners exchanged updates on the actions progress, identified issues and reasserted tasks division. With a high number of partners and interdisciplinary actions, these meetings were crucial to maintain effective communication between actors, and to continuously structure milestones and deadlines for each action. In addition, each year, one of the archipelagos hosted a joint session, where all partners met to summarize the year's progress and to actively execute selected actions. These sessions were particularly useful for the elaboration of joint materials (e.g., defining the structure of the shared database or define the content of the various educational products), and greatly increased coordination and scheduling of the projects actions.

At the last joint session, the partners held a workshop on light pollution management with relevant stakeholders from each archipelago. Participants presented and discussed the currently active conservation measures (within and outside of LuMinAves) and developed a SWOT (strengths, weaknesses, opportunities, and threats) analysis for the light pollution problematic. This analysis was initially prepared for each archipelago and then merged into a general analysis for the region, identifying current shortcomings in light pollution management, limiting factors, priorities and goals for future work (Fig. 1). The presence of the stakeholders, as the primary organizations responsible for the actual implementation of any lighting management measure, was crucial and this analysis will act as a basis for a joint strategy on the reduction of light pollution in Macaronesia.

Practical training sessions were also organized as capacity building events, for example in seabird veterinary care, which capacitated partners and volunteers to improve protocols and handling of rescued seabirds.

Over 100 public dissemination events, totaling over 2600 attendees, were successfully conducted. The project was also able to produce over 70 publications in various media (Twitter, local newspapers, regional TV, online magazines), and was represented at six environmental themed festivals. Outreach and educational materials are concluded and were already used in such events to represent the project and disseminate knowledge (e.g., informative calendars that contain fledging periods for each species or flyers containing instructions on how to rescue a fallen bird and helpful contacts). The project has surpassed the estimated number of visualizations (available at http://www.luminaves.com/index.php/es). In this platform other outreach tools produced by the project can be consulted, including the project's mascot, bilingual informative fliers and best practices videos.

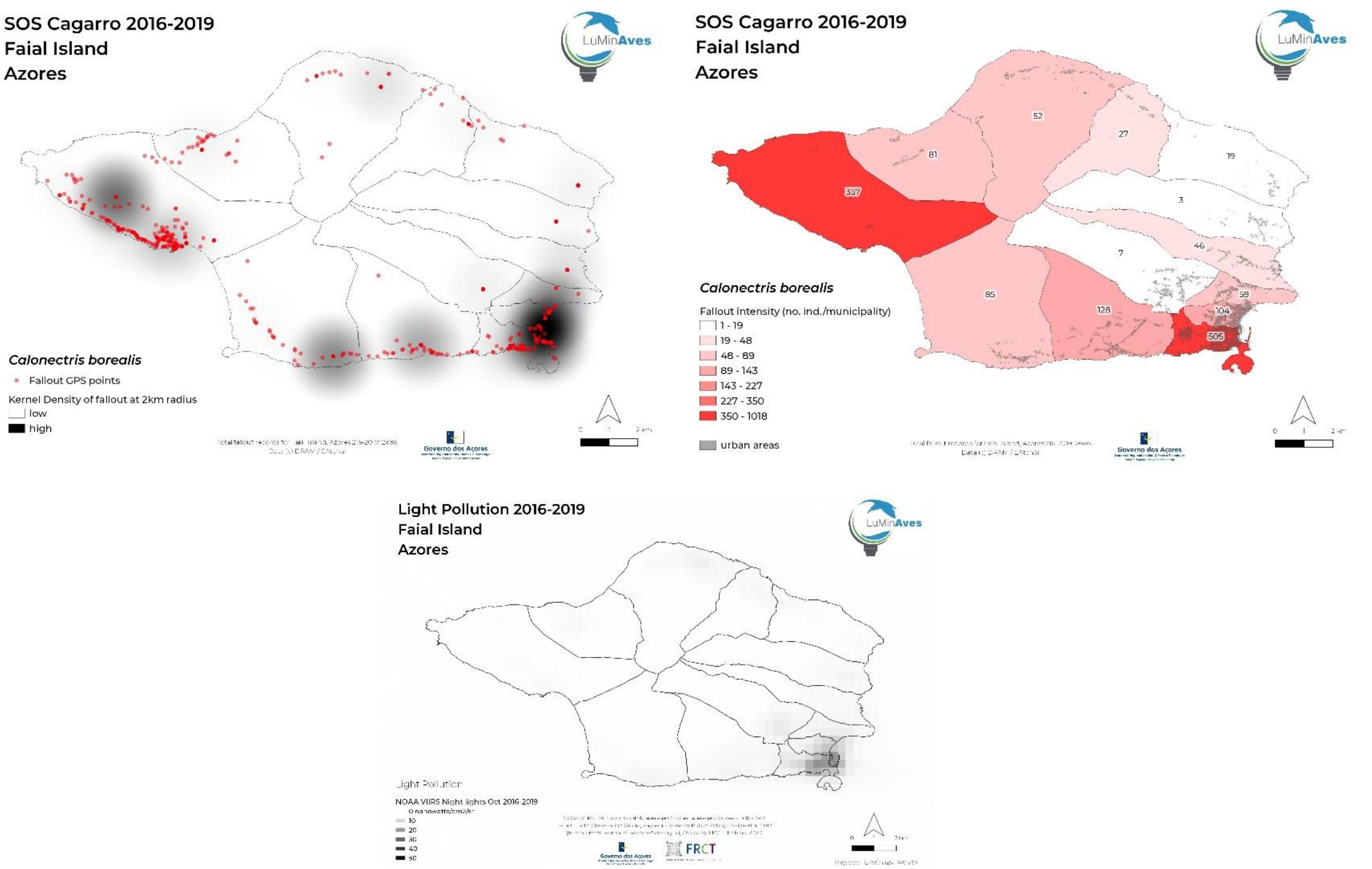

Figure 2: Fallout maps from Faial, Azores, PT. Left. Heatmap and fallout points from rescue birds with GPS location of collection. Right. Total number of fallouts per municipality (red gradient) overlaid with urban areas (grey). Data from SOS Cagarro campaign detailing Cory's Shearwater (*Calonectris borealis*) fallout from 2016 to 2019. Bottom. Light Pollution from VIIRs satellite layers, monthly average for October 2016 to 2019.

3.3 Mitigation

Maps depicting the spatial distribution of fallout were created for each island of each archipelago (e.g., Fig 2), allowing for the preliminary identification of lit areas with higher seabird fallout, generating an initial list of critical locations to be used during meetings and interventions with local authorities. While the collection of GPS data on fallout locations has substantially increased (from the aforementioned ~1% to ~27%) after the project started, marked differences still persist between islands. Thus, further consultations with stakeholders and organizations involved with the rescue campaigns are being organized, to better identify areas not reflected by the GPS data. Such collaborations also help to resolve inconsistencies found between fallout and light pollution maps, where in some cases such as on the northern area of Faial Is., areas of large fallout show low values of light pollution from the satellite layers. In this example, a single fishing boat marina with a high-powered light affects a substantial breeding colony of Cory's shearwaters in the surrounding cliffs, leading to large fallout records even though the light pollution is not represented within the satellite layers.

On Corvo Is., where the lighting pilot project was implemented, the overall perception and reaction of the citizens was positive, with more acceptance of total blackout in the later hours of the night (2-6 AM). This was the first step to initiate structural changes to the public lighting scheme which has been reviewed by partners and will be implemented presently by the city hall in collaboration with the electric company. Total blackouts will continue to be implemented in 2020 with proposals to expand their extent (more days) and geographical reach (other islands).

The 'best practices guide' is complete and includes the preliminary critical locations lists (by island) and current recommendations to reduce light pollution (i.e., lamp types, shields and timers).

Table 2: Results from the blackout project on Corvo Island. Data for 2017, 2018 and 2019, during the months of October & November.

Schedule	Location	Total Hours (2017-2019)
21PM to 6AM	Main streets Vila do Corvo	810 h
2AM to 6AM	Old town	330 h

In collaboration with local authorities (local governance, institutes, electric companies and port authorities), a series of operational meetings are being organized, where using the outcomes of the project as a guide, municipalities will begin to plan the implementation of specific measures regarding lighting schemes (lamp types, lighting schedules and removal of light structures), taking into account the specificity of each area and the reduction of the impacts on seabird populations.

4 Discussion

The main goal of LuMinAves was to better understand light pollution in Macaronesia and to improve its management. By structuring itself as a scheme of regional cooperation and cross-sector policy integration, the project was able to successfully launch an interdisciplinary strategy to reduce light pollution, extending the project's reach beyond the impacts on seabirds, and has created momentum within local and regional authorities, to effectively and realistically improve urban design with regards to artificial light at night.

Mitigation actions which pre-date the project have been progressively applied throughout the region. For example, on Madeira, a pilot project integrated sustainable smart lighting to a municipality urban plan [14]. Here, in Santa Cruz county, the main stakeholders partnered with SPEA-Madeira to identify critical areas for seabird fallout, and enable this municipality to transition to a sustainable lighting scheme, decreasing overall costs of public illumination and reducing the impact of light pollution. In the Azores the rescue campaign, SOS Cagarro, partners with many private and public entities every year, and together they apply turning off public lights in specific areas known for higher fallout (e.g., airport, churches and industry buildings). The same occurs on the Canary Islands, where some municipalities in partnership with Island Councils organize blackouts during critical periods of the year but which do not follow a constant or systematic approach. LuMinAves enabled the sharing of these actions, specifically their procedures and outcomes, with all partners for their mutual gain, allowing direct learning and connectivity between actors, and forming a cohesive network of mitigation actions, increasing their effects and their potential for a broader implementation.

Comprehensive and long-term databases are key to allow stakeholders to quantify the effects of light pollution on ecological indicators and to assess the effectiveness of conservation actions [1]. The project successfully gathered data on seabird parameters via monitoring schemes, coalesced historical rescue data from all three archipelagos into a common database, and has uniformed data collection and protocols within rescue campaigns. These databases are continuously updated, shared and accessed by all partners. For example, they are currently feeding several chapters of an ongoing PhD study, where fallout parameters will be analysed against environmental and oceanographic variables, and has already allowed a preliminary analysis of the health condition of rescued individuals framed within a master thesis.

Such knowledge databases are also used to inform on the current design of light pollution management strategies, for example, following the critical locations lists obtained from the common database, it has been possible to accurately identify areas where fallouts are more severe. Regional electrical companies have halted the substitution of older lamps (to white LED) in these areas until a more sensible and feasible solution is determined. Transitioning urban lighting from older technology, e.g., high-pressure sodium lamps, to energy saving LEDs, is increasingly widespread [15], however this can potentially increase negative effects if the light characteristics, such as spectrum, intensity or structure, are not taken into account [16].

Public lighting designers, decision makers and ultimately the general public could benefit from collaborating with expert in different fields (i.e., light pollution, ecology, health or astronomy) to increase the feasibility and effectiveness of illumination changes towards energy efficiency and light pollution reduction. For example, using emblematic species and a known event such as seabird fallouts, which the citizens have been aware of and where they have been actively invested in the rescue efforts, enabled the partners to access dissemination platforms already in place (e.g., media coverage of the rescue) expanding the issue from mitigation to reduction and avoidance of light pollution. This in turn enabled the regional electrical companies and local governance to associate a certificate of good environmental practices to their urban lighting plans, facilitating the implementation of new measures.

Collaborative efforts have proven valuable to compensate for knowledge gaps. For example, while attempting to identify the colonies most affected by light pollution, only 1% of individuals ringed at colonies were recovered during rescue campaigns along the project, thus preventing the categorization of at risk natural areas. But by annexing concurrent research conducted by partners, e.g., data from chicks tagged with GPSs at their colonies indicate that the main proportion of fledglings in fallouts originate from colonies closer to light polluted areas, and that fallout tends to occur less than 16km from source colonies [8], has allowed for preliminary designs regarding urban planning efforts, decreasing light pollution near known colonies.

The project ended in December 2020, however its actions and goals extend beyond its time frame, and following the interdisciplinary and cross-sector approach, partners are implementing actions that enable the prolongation of its goals. For example, partners formed a working group which, together with regional governance, is working on regional regulatory legislation regarding lighting protocols. Likewise, a sequential INTERREG project has been granted and will be building upon LuMinAves actions to continue the efforts towards light pollution reduction and research in Macaronesia. With these follow up actions and projects, the partners aim to ensure the long-term quality of the previous actions and the reaffirmation of the ongoing commitment from partners and stakeholders alike.

5 Conclusion

Without the collaborative, cumulative and interconnected approach of the project, it would not have been possible to advance the management of urban lighting schemes in Macaronesia in such a quick and effective fashion. LuMinAves has been instrumental in incentivizing local and regional authorities to redesign urban lighting, maximize the use of current knowledge and apply the outcomes to the reduction of light pollution. Ultimately such collaborative initiatives and resulting actions provide a source of common tools and guidelines which facilitate the implementation of new concepts of sustainable lighting, improving public lighting schemes and associated policies, returning Macaronesia to its natural nightscapes.

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References

[1] Davies, T. W., Duffy, J. P., Bennie, J., & Gaston, K. J. (2014). The nature, extent, and ecological implications of marine light pollution. *Frontiers in Ecology and the Environment*, *12*(6), 347–355. https://doi.org/10.1890/130281

[2] Rodríguez, A., Holmes, N. D., Ryan, P. G., Wilson, K. J., Faulquier, L., Murillo, Y., Raine, A., Penniman, J. F., Neves, V., Rodríguez, B., Negro, J. J., Chiaradia, A., Dann, P., Anderson, T., Metzger, B., Shirai, M., Deppe, L., Wheeler, J., Hodum, P., … Corre, M. Le. (2017). Seabird mortality induced by land-based artificial lights. *Conservation Biology*, *31*(5), 986–1001. https://doi.org/10.1111/cobi.12900

[3] Silva, R., Medrano, F., Tejeda, I., Terán, D., Peredo, R., Barros, R., González, P., González, V., Guerra-Corre, C., Hodum, P., Keitt, B., Luna-Jorquera, G., Malinarich, V., Mallea, G., Manríquez, P., Nevins, H., Olmedo, B., Paéz-Godoy, J., de Rodt, G., … Toro-Barros, B. (2020). Evaluación Del Impacto De La Contaminación Lumínica Sobre Las Aves Marinas En Chile : Diagnóstico Y Propuestas. *Ornitologia Neotropical*, *31*(1), 13–24.

[4] Rodríguez, A., Rodríguez, B., Montelongo, T., Garcia-Porta, J., Pipa, T., Carty, M., Danielsen, J., Nunes, J., Silva, C., Geraldes, P., Medina, F. M., & Illera, J. C. (2020). Cryptic differentiation in the Manx Shearwater hinders the identification of a new endemic subspecies. *Journal of Avian Biology, 51*(11). https://doi.org/10.1111/JAV.02633

[5] Schumann, N., Dann, P., Hoskins, A. J., & Arnould, J. P. Y. (2013). Optimizing survey effort for burrow-nesting seabirds. *Journal of Field Ornithology*, *84*(1), 69–85. https://doi.org/10.1111/jofo.12007

[6] Orben, R. A., Fleishman, A. B., Borker, A. L., Bridgeland, W., Gladics, A. J., Porquez, J., Sanzenbacher, P., Stephensen, S. W., Swift, R., McKown, M. W., & Suryan, R. M. (2019). Comparing imaging, acoustics, and radar to monitor Leach's storm-petrel colonies. *PeerJ*, *2019*(4), 1–28. https://doi.org/10.7717/peerj.6721

[7] Curry, O. S., Hare, D., Hepburn, C., Johnson, D. D. P., Buhrmester, M. D., Whitehouse, H., & Macdonald, D. W. (2020). Cooperative conservation: Seven ways to save the world. *Conservation Science and Practice*, *2*(1), 1–7. https://doi.org/10.1111/csp2.123

[8] Rodríguez, A., Rodríguez, B., & Negro, J. J. (2015). GPS tracking for mapping seabird mortality induced by light pollution. *Scientific Reports*, *5*, 10670. https://doi.org/10.1038/srep10670

[9] Fontaine, R., Gimenez, O., & Bried, J. (2011). The impact of introduced predators, light-induced mortality of fledglings and poaching on the dynamics of the Cory's shearwater (*Calonectris diomedea*) population from the Azores, northeastern subtropical Atlantic. *Biological Conservation*, *144*(7), 1998–2011. https://doi.org/10.1016/j.biocon.2011.04.022

[10] Rodríguez, A., Rodríguez, B., Curbelo, Á. J., Pérez, A., Marrero, S., & Negro, J. J. (2012). Factors affecting mortality of shearwaters stranded by light pollution. *Animal Conservation*, *15*(5), 519–526. https://doi.org/10.1111/j.1469-1795.2012.00544.x

[11] Elvidge, C. D., Baugh, K., Zhizhin, M., Hsu, F. C., & Ghosh, T. (2017). VIIRS night-time lights. *International Journal of Remote Sensing*, *38*(21), 5860–5879. https://doi.org/10.1080/01431161.2017.1342050

[12] Mougin, J. L., Jouanin, C., Despin, B., & Roux, F. (1986). The age of first breeding of Cory's shearwater on Selvagem Grande and problems of ring loss. *Ringing and Migration*, *7*(3), 130–134. https://doi.org/10.1080/03078698.1986.9673891

[13] Rodríguez, A., Rodríguez, B., & Nazaret Carrasco, M. (2012). High prevalence of parental delivery of plastic debris in Cory's shearwaters (*Calonectris diomedea*). *Marine Pollution Bulletin, 64,* 2219-2223. https://doi.org/10.1016/j.marpolbul.2012.06.011

[14] Aura Light. (2019). *A iluminação pública como base para a sensorização de um municipio – Santa Cruz Smartcity*. 18–19.

[15] Kyba, C. C. M., Kuester, T., De Miguel, A. S., Baugh, K., Jechow, A., Hölker, F., Bennie, J., Elvidge, C. D., Gaston, K. J., & Guanter, L. (2017). Artificially lit surface of Earth at night increasing in radiance and extent. *Science Advances*, *3*(11), 1–9. https://doi.org/10.1126/sciadv.1701528

[16] Longcore, T., Rodríguez, A., Witherington, B., Penniman, J. F., Herf, L., & Herf, M. (2018). Rapid assessment of lamp spectrum to quantify ecological effects of light at night. *Journal of Experimental Zoology Part A*, *329*(8–9), 511–521. https://doi.org/10.1002/jez.2184