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Samuel Challéat, Johan Milian, Matthieu Renaud, L. Godet, Rémi Bénos, Magalie Franchomme, Marion Maisonobe, Igor Babou, Caroline Parvaty Marimoutou, Léa Tardieu, et al.

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The nocturnal social-ecological systems of Réunion Island: challenges in knowledge and perspectives for action

I. Pre-proposal's context, positioning and objectives

A. Context

On Réunion Island, more than anywhere else, the challenges of combating light pollution are particularly acute, given the high level of friction between artificial light at night (ALAN) and areas of high naturalness (Guetté et al., 2018), where major ecological issues are at stake. Classified as one of the world's 36 biodiversity hotspots and considered a conservation priority due to its extreme biological diversity, the island has seen its urban population grow significantly. In direct correlation with the dynamics of urbanization, the light footprint of La Réunion has undergone a radical change in recent years: its range and its pressure have increased considerably from the coast to the upper reaches of the island, the core zone of La Réunion National Park (Babou, 2015). The ecological impact of artificial lighting has been of concern to environmental associations and scientists since the 1990s (Le Corre et al., 2002; Chevillon et al., 2022). Launched in 2008, the 'Nuits sans lumière' initiative mobilizes the Park and a number of associations to promote public campaigns against lighting, accompanied by awareness-raising campaigns on the consequences of ALAN on endemic avifauna — Barau and Mascarene Petrels. However, by focusing on these flagship species and being limited in time (to the period of juvenile dispersal), these actions may have paradoxically contributed to hamper the emergence of less ecocentric approaches to light pollution control that could enable a lasting change in lighting practices (Challéat, Milian et al., 2022). Without abandoning naturalistic expertise, we now need to place it within a unifying framework, at the interface between environment and society, that is better able to grasp the complex real-world problems and provide keys for prioritizing actions and informing decisions whenever a trade-off between antagonistic needs for light and darkness appears necessary.

B. Research objectives and hypotheses

In this context, the FENOIR project aims at producing situated knowledge that will enable public action to overcome the aporias of the ecocentric approach to the 'ALAN problem' and to respond to the challenge — particularly acute on Réunion Island — of territorializing a holistic preservation of the nocturnal environment (Challéat, Lapostolle et al., 2023). Achieving such an objective requires an effort to converge knowledge — vernacular, usage, scientific and technical knowledge — or, in other words, the conjugation of different systems and repertoires of knowledge about the nocturnal environment (Tengö et al., 2014). To this end, the FENOIR project mobilizes the framework of nocturnal social-ecological systems (Challéat, 2018; Challéat, Barré et al., 2021). This holistic approach to the nocturnal environment is particularly relevant for an island territory where public action is now obliged to promote transformations under strong ecological constraints (Nadaï & Wallenborn, 2019). This change in the frame of reference for public action — from an ecocentric one, based on *the fight against* light pollution and reflected in the 'Nuits sans lumière' action, to a holistic one, based on *the preservation of* the nocturnal environment and reflected in the 'Jours de la Nuit' action program — was initiated by La Réunion National Park in 2020, following initial work by our team, which has since supported the Park and several other territorial actors in this approach (Challéat, Milian et al., 2022; Challéat, Lapostolle et al., 2023). In order to take this initial work a step further, the FENOIR project will pursue two objectives, with the aim of overcoming the main obstacles related to the lack of a sufficiently broad and well-founded repertoire of knowledge to create the conditions for deliberation between the needs of darkness and the needs of ALAN, and hence committing in an effective public environmental action for the preservation of the nocturnal environment of La Réunion.

1. To study, at different socio-spatial scales, (i) the socio-cultural practices and representations of the Reunionese night, (ii) the attachment and sensitivity to the components of the island's nocturnal environment, and (iii) the modes of governance of the territorial system that establishes darkness as a resource. The research will be based on the intersection of approaches from the socio-anthropology of relations between nature, knowledge and society, ethnography, the geography of knowledge and understanding, linguistics and literary studies, environmental geography and economics, regional planning and political science. The work will be organized in order to put into perspective, at different socio-spatial scales, the changes in cultural and social representations linked to the transformation of the nocturnal landscapes of La Réunion by ALAN, in order to identify the determining factors. The aim is also to gain a better understanding of the values associated with these landscapes and with darkness, and to unravel and understand the networks and interactions of the stakeholders involved in the regulation of lighting and the preservation of the island's nocturnal environment. Three hypotheses will guide our work here. *Our first hypothesis* is that the relationship with the night, in terms of representations and social relations, has undergone a significant change since the recent past, when Reunionese society was essentially rural and darkness was very present. The penetration of artificial lighting infrastructures was also much faster than in metropolitan France, where the process took more than a century. Consequently, the aim here is to understand how people's nocturnal lifestyles may have been affected by these changes. *Our second hypothesis* is that this rapid transformation of the Reunionese night is profoundly reconfiguring relations with the *fénoir* (the 'obscure fact' in Creole culture, the darkness in which our project was born and from which it takes its name) — the living memory of the 'natural' night, accompanied by practices that testify to the importance of darkness in the lives, uses, and imaginations of Creole populations, as well as to a unique relationship with non-human beings. The goal here is to continue to explore the thickness of darkness, from its magico-religious dimension to its environmental dimension, while taking care to avoid the pitfalls of folklorization and environmental declinism (Banos et al., 2021). *Our third hypothesis* is that, for the territorialization of the preservation of the nocturnal environment to function properly, the tools of public action in this field must become vehicles for the socialization of the fight against light pollution, and not vehicles for a cognitive confiscation through the technicization of the problem. The aim here is to bridge the gap between scientific knowledge and action, and to deepen the links between multilevel governance and participatory processes.

2. To study, at different spatio-temporal scales, (i) the structures and dynamics of light pressure, (ii) the vulnerability of natural environments (biodiversity patterns and processes) to ALAN and (iii) the uses of darkness by wildlife and how these uses are affected by artificial light. Research here will be based on the intersection of environmental metrology, spatial modeling, biogeography, and nocturnal ecology, supported by environmental physics, scientific computing, bioacoustics, and artificial intelligence. The work will be organized to initiate the construction of a repertoire of knowledge on different spatio-temporal scales about ALAN and its fine interactions with meteorological and orographic conditions, about interactions between light pressure and other anthropogenic pressures on the environment, and about the effects of light pressure on the activity patterns of birds. Two hypotheses will guide our work here. *Our first hypothesis* is that Réunion Island is a prime area for a better understanding, based on ground observations, of the multiscale mechanisms that control the diffusion of artificial light and directly influence changes in the shape and intensity of the light footprint. Approaching the ‘ALAN problem’ on La Réunion exclusively through satellite imagery ignores the atypical nature of this island, which covers an area of 2,512 km² and has a relief that is both high and extremely fragmented, with extreme contrasts in meteorological conditions. Based on ground observations (network of photometric sensors), the goal is to model the light pressure in detail, taking into account the meteorological and orographic conditions. *Our second hypothesis* is that the lack of fundamental knowledge of nocturnal biogeography and ecology, generated in situ and focusing on the effects of light pressure on natural environments and on the activity rhythms of wildlife in all its diversity, prevents public authorities from prioritizing their actions in time and space. This calls for a pragmatic approach that takes into account the vulnerability of ecosystems to light pressure and its interactions with other forms of anthropogenic pressures. However, to further answer the question of ‘what, where and when to put on the political agenda’, it is necessary to meet the ecological stakes of preserving the nocturnal environment on the one hand, and the situated socio-technical possibilities for planning and action on the other (Challéat & Lapostolle, 2014). In other words, the aim is to install, through our interdisciplinary experimental set-up, the conditions for a socio-ecosystemic negotiation of the modalities of intervention on the island’s lighting points network following the needs for both darkness and light.

C. Work packages and methodology

In order to achieve these objectives, we adopt a broad interdisciplinary approach, combining knowledge from social and territorial sciences, natural sciences, universe sciences, engineering and environmental physics. By combining these disciplines and different research methods (fundamental research, action research, participatory research), and by creating ‘bridging objects’ (BO) to promote the circulation of diverse knowledge, the FENOIR project will enable an unprecedented socio-ecosystemic approach to the nocturnal environment. **The project is divided into five work packages**, which will be further detailed into sub-packages in phase 2:

WP1. Practicing & inhabiting darkness: an ethno-geography of the Reunionese nights. This WP focuses on investigating nocturnal territorialities in order to characterise nocturnal social-ecological systems. The aim is to understand how people live with the darkness and what specific features the *fénoir* can reveal in the construction of these territorialities (Franchomme et al., 2023). Operative actions therefore focus on dwellers and use methodologies to study in depth the processes that feed these territorialities, through two fundamental components. **(i) Frequenting the nocturnal places.** The first part of the research will be to explore and map Réunion’s nightlife (the history and development of nighttime recreational activities) and to link it to the different types of nocturnal practices. The second part will mobilize ethnographic methods to describe the places of the *fénoir* and the relationships between inhabitants, darkness and ‘nightscapes’. **(ii) Frequenting the nocturnal rhythms and temporalities.** We will study the place occupied by nightlife in island cultural practices through the analysis of a literary corpus and music listening data from users of the music streaming platform Deezer, which reveals the local and territorial specificities of Réunion Island (Cura & Maisonobe, 2023). **BO produced** for WP2: detailed knowledge of nocturnal territorialities, elements on the meaning of places and relationships to lived spaces. For WP4: implementation of researcher-inhabitant workshops around nocturnal soundscapes (whose methodology was designed during the CNRS-funded **OUTRENOIR** program — 2022-2023).

WP2. Governing & territorializing darkness: public action to preserve the nocturnal environment of La Réunion. From the island scale to the micro-local scale, this WP will focus on the existing arenas of territorial governance around the issue of artificial lighting, and will seek to produce elements that will allow their grammar to be adapted in order to promote their widening. **(i) Understanding the interplay of actors involved in the preservation of the nocturnal environment.** A survey will be carried out to pay close attention to the discourses, arenas and places where decisions are made, and to question the political inequalities of participation in the development of public policies and decision making. **(ii) The multiple values of darkness and its effects on framing public action.** By comparing stated preferences (Glenk et al., 2020) the aim here consists to assess the effects of a change in public action frame of reference on the preferences and different values expressed by residents in relation to the issues of preserving the nocturnal environment. **(iii) Issues and challenges for territorializing nocturnal environment.** The construction of grassroots innovations towards transition in lighting practices and the setup of associated local action communities will both be surveyed through a few case studies. This work will seek to implement collective intelligence based on the plurality of viewpoints, perspectives, scientific and vernacular knowledge, and life experiences. **BO produced** for WP3: installation of local action communities related to the implementation of educational projects on the nocturnal environment. For WP4: installation of local workshops to build socio-ecosystemic scenarios for mitigating light pressure with inhabitants and public lighting managers.

WP3. Modelling & mapping darkness: the Light Pressure Monitoring Network on Réunion Island (LPMN-Run). This WP will focus on continuing the deployment of TESS-W photometers (Zamorano et al., 2016) across the island, then implementing the organization, FAIRization and exploitation of the collected data, up to the fine modeling of the light pressure on Réunion. **(i) Completion of the LPMN-Run, already under construction since 2021:** the aim is to increase the density of this network by installing about 100 photometers, making La Réunion the most densely equipped

territory in the world. We will also work to make some of the sensors autonomous, as several of the proposed sites are located in isolated areas. (ii) Light pressure modeling and mapping. The natural brightness of the night sky will be modeled (Masana et al., 2022) to characterize its evolution at photometer installation sites and thus extract the artificial component from ground-based measurements. Enriched with satellite and ground-based data (DTM, GIS database of lighting points), the LPMN-Run will allow us to produce the first high-resolution mapping of Réunion's light footprint, integrating meteorological and orographic variability (Aubé et al., 2020). (iii) Use the LPMN-Run as a vehicle for local projects to educate the public about the nocturnal environment. The development of participatory science projects (Kyba et al., 2023) to build local action communities around the public data produced by LPMN-Run will be pursued, with a particular emphasis on school audiences (Barré et al., 2023). **BO produced** for WP2: multimodal dashboard (under development) for use by naturalist and astronomer experts, decision makers, and inhabitants-citizens. For WP4: mapping of light pollution, helping to define areas of ecological concern with respect to this pollution.

WP4. Monitoring & understanding wildlife in darkness: a nighttime biogeography of Réunion Island. This WP aims to investigate the impact of light pressure on wildlife activity rhythms, particularly on the island's passerines, using bird calls and songs as indicators. (i) A comprehensive island-wide comparison of light pressure with other anthropogenic factors. The goal is to identify spatial correlations and discrepancies between light pressure and other anthropogenic pressures across the island, using cartographic methods developed by Guetté A. and the IUCN in metropolitan France to map landscape anthropization (Guetté et al., 2021). (ii) Assessment of bird vocal activity across the island, examining how light pressure affects temporal changes in bird vocalizations. Birdsong extraction based on acoustic sensors next to photometers, and using AI (Moummad et al., 2023) combined with manual listening and annotation, will allow us to understand the impact of light and sound pressures along with other anthropogenic indicators on birdsong chronology. (iii) Focusing on sites with varying light and anthropogenic pressures, the WP will focus on the temporal behavioral parameters of an endemic species in decline (Mascarene Paradise-Flycatcher) and an invasive species (Red-whiskered bulbul) using AI. Different vocalizations such as songs, contact calls, and alarm calls will be analyzed to disentangle the influence of light and other anthropogenic pressures on the temporal behavior of these species. **BO produced** for WP1: acoustic recordings enabling the installation of workshops around nocturnal soundscapes. For WP2: inputs for workshops with stakeholders of lighting governance, aiming at the construction of socio-ecosystemic ALAN-mitigating scenarios.

WP5. Coordinating & disseminating research and its results. This transversal WP will organise the interdisciplinary seminars structuring the project. It will be in charge of the partnership coordination and logistics with the 4 research partner teams. Finally, it will focus on the transfer of results in two ways: the scientific publications, and the production of (i) a photographic exhibition, (ii) an illustrated book for the general public, and (iii) a film showing an interdisciplinary approach 'in effect'. Led by the coordinator, this WP will involve all project members and two service providers.

D. State-of-the-art positioning and scientific innovation

This project is in line with the perspectives opened up by studies on the night (Galimier, 2010; Edensor, 2013; Shaw, 2018) and, more precisely, on the *nocturnal environment* (Challéat, 2018; Milian et al., 2023). Through the case of La Réunion, the FENOIR project will fill a gap in the rich field of Night Studies (Gwiazdzinski et al., 2020), where few works have managed to move away from the Northern countries, to decentralize their focus in the nights of tropical spaces (Fouquet, 2011; Kouadio & Kouakou, 2021). These latter, however, have been studied by anthropology and cultural geography — more specifically, from the point of view of festive practices and economic activities (Morelle & Fournet-Guérin, 2006; Fouquet, 2016) — or by history, from the point of view of the recomposition of meanings, perceptions and atmospheres that they generate (Nativel, 2016). Regarding the monitoring of light pressure, it is now necessary to “gather more information from measurement data [...], for example through long-term observations of night sky brightness” (Kocifaj et al., 2023). Thus, the LPMN-Run will allow the FENOIR project to feed several scientific fronts in this field: analysis of long-term trends in light pressure (Fiorentin et al., 2022), of the links between the night sky brightness and atmospheric aerosols (Kocifaj & Bara, 2021), and discussions on the production of holistic indicators to harmonize light pressure measurement methods across disciplinary boundaries (Hölker et al., 2021). From the point of view of the natural sciences, the FENOIR project will generate knowledge that will enable our team to play a major role in constructing answers to several of the “11 pressing research questions on how light pollution affects biodiversity” proposed by Franz Hölker *et alii* (2021).

This project claims to be innovative and original on several levels. *i) For the proposed combination of disciplines and research methods*, and for the interdisciplinary framework, which both make it possible to bring together a variety of complementary points of view on ‘the obscure fact’. *ii) For the central place given to the focal object ‘nocturnal environment’*, both as a framework for the integration and mesological analysis (Berque, 2014) of disciplinary contributions, and as a mediating tool. *iii) For its pioneering role in Réunion Island*, where the Night Studies have yet to take root. The FENOIR project will provide the scientific community with a valuable point of comparison, at the scale of the Indian Ocean and beyond. *iv) Finally, from the point of view of the methods and bridging objects deployed* to circulate and translate the results obtained — from one WP to another, but also in terms of public action — and to ensure the dissemination of research far beyond the academic sphere alone.

II. Partnership (consortium or team)

The scientific coordinator of the project, Samuel Challéat, Research Fellow in Environmental Geography at the UMR GÉODE (CNRS-InEE), will dedicate 70% of his working time to the project — i.e. 33.6 months of the project's 48 months. He has experience in scientific management and coordination of several interdisciplinary research programs, as well as of the Nocturnal Environment Observatory (NEO, CNRS). The consortium is strongly consolidated by the working habits acquired within this multidisciplinary structure, as well as by the joint participation of several of its members in various programs, including two concerning La Réunion. The mobilization of skills present on the island, already in

place within the NEO since 2022, has been reinforced. This criterion will also be a priority for the proposed recruitment of 3 temporary contracts. The team consists of researchers in Geography and Land Use Planning (Challéat S., Milian, J., Maisonobe M., Franchomme M.), Anthropology, Ethno-Geography and Linguistics (Babou I., Bénos R., Parvaty Marimoutou C.), Environmental Economics (Tardieu L.), Ecology and Biogeography (Gaudet L., Froidevaux J., Le Corre M., Guetté A.), Environmental & Engineering Physics (Morvan S., Morel B., Brouat C., Delsaut M., Renaud M.) and Artificial Intelligence (Farrugia N.). The requested funding, to cover the whole team missions, support the purchase of equipment and recruit contractual researchers, is spread over four laboratories. The UMR GÉODE will support the project. It provides expertise in the analysis of complex human-environment interactions and socio-environmental dynamics, as well as in Physical Environmental Metrology. It hosts the NEO and makes its Environmental Metrology platform available to the project. The UMR LADYSS brings skills in understanding changes in contemporary societies and in analyzing processes of territorialization of individual and collective actions to preserve the environment. The Observatoire des Sciences de l'Univers de La Réunion (OSU-Réunion) provides expertise in universe and atmospheric sciences, engineering sciences, metrology and environmental physics. The UMR LETG provides expertise in conservation ecology, analysis of landscape anthropization processes and their impact on biodiversity, and bioacoustics.

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