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Cover: Long-tailed Shrike *Lanius schach* resting on a dry branch after courtship. Digital illustration on Procreate. © Aakanksha Komanduri.

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ARTICLE

Altered nocturnal vocal activity patterns in Tropical Kingbird *Tyrannus melancholicus* (Passeriformes: Tyrannidae) at a site with artificial lighting

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Abstract: Artificial lighting at night (ALAN) modifies the vocal activity patterns of numerous birds. In this study, we evaluated the impact of ALAN on the vocal activity patterns of the Tropical Kingbird *Tyrannus melancholicus* on María Madre Island, located in the state of Nayarit, Mexico. Vocalizations were recorded using autonomous Song Meter Micro recorders at one site with ALAN and another without. We analyzed sound spectrograms to quantify vocalizations and performed behavioural observations. Our results showed differences in vocal activity between the ALAN site and the non-illuminated site. The ALAN site had higher total vocal activity, producing 3,947 vocalizations with at least one vocalization in every recording, compared to 228 distributed across 40% of the recordings at the non-ALAN site. Tropical Kingbirds at the ALAN site also had a substantially longer and earlier-shifted period of pre-dawn vocalization activity, from 0200 h to 0500 h, compared to a very brief period around 0500 h at the site without ALAN, as well as vocalizations throughout the night compared to a brief peak around twilight with no nocturnal vocalizations. Finally, we observed that individuals at the ALAN site continued to forage into the night, displaying increased agonistic interactions such as chases, wing-fluttering, and physical confrontations. Our results suggest that artificial light significantly alters the activity pattern of the Tropical Kingbird, extending its vocal and foraging activity. Our study could contribute to understanding the effects of light pollution on insectivorous birds in island environments and shows the importance of reducing the impacts of artificial light in natural habitats.

Keywords: ALAN, behaviour, insectivorous birds, islands, light pollution, nocturnal foraging, vocalization.

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INTRODUCTION

Increasing urbanization in economically developing regions has often resulted in substantial increases in artificial lighting at night (ALAN) (Cinzano 2003; Hölker et al. 2010). ALAN adversely affects ecosystems by modifying natural light regimes, a phenomenon called "ecological light pollution" (Longcore & Rich 2004). This affects terrestrial and marine habitats globally through both direct illumination and indirect reflection of sky glow (Spoelstra & Visser 2013). However, the effects and consequences of light pollution on biodiversity, ecosystems, and ecological and evolutionary processes remain poorly understood (Dominoni 2015).

Most organisms are subject to circadian cycles that are regulated by natural light cycles (Arendt 1998; Bell-Pedersen et al. 2005). Light pollution alters these cycles in numerous species by interfering with the natural light regimes that regulate their biological rhythms (Cassone 2014). Beyond disrupting sleep and activity patterns, ALAN can also have detrimental effects on behaviour, reproduction, and even survival (Raap et al. 2015). Desynchronization of the circadian clock due to artificial light can have consequences at the physiological and biochemical levels, altering processes such as hormone secretion and immune responses, which potentially compromises organisms' ability to adapt to their environment and perform activities that are essential for their survival (Gaston et al. 2013).

In addition to the direct negative effects of artificial night-time lighting, ALAN can alter the foraging activity of insectivorous by attracting arthropods, thereby providing a consistent food source for insectivorous species. Opportunistic nocturnal feeding has been observed at locations where ALAN leads to nighttime arthropod activity, primarily in some species of amphibians (Perry et al. 2008), reptiles (Garber 1978; Amadi et al. 2021; Baxter-Gilbert et al. 2021), and birds (Santos et al. 2010; Ortiz 2013).

In avian species, one of the most frequently reported effects of light pollution is the alteration of vocal activity patterns and feeding behaviour, which in some instances has been found to impact reproduction and survival (Longcore & Rich 2004; Dominoni et al. 2013; Dominoni 2015). While birds commonly exhibit marked vocal peaks at dawn and dusk (Gil & Llusia 2020), ALAN can substantially modify these vocalization rhythms. In species such as Eurasian Blue Tit *Cyanistes caeruleus*, European Robin *Erithacus rubecula*, Eurasian Blackbird *Turdus merula*, Great Tit *Parus major*, and American Robins *Turdus migratorius*, an advancement in the onset of morning song and an extension of vocal activity after dusk have been observed in illuminated environments (Miller 2006; Kempenaers et al. 2010; Da Silva et al. 2014). However, most of these studies have focused solely on identifying the first and last vocal events of the day, without examining song patterns across the full 24-hour cycle, limiting our understanding of continuous vocal activity (Dominoni 2015). Moreover, ALAN has been shown to affect not only vocal rhythms but also foraging behaviours. Although some species are typically diurnal, the Northern Mockingbirds *Mimus polyglottos* have been observed utilizing the visibility provided by ALAN to continue to feed their offspring after dusk (Stracey et al. 2014), and the Eurasian Blackbird has been observed using artificial lighting to forage at night in urban areas (Russ et al. 2015). It has been documented that in anthropogenically altered locations, some visual-hunting waders demonstrate increased activity in illuminated areas, increasing their ingestion rate by 83% (Santos et al. 2010). Illuminated areas may also attract avian species to degraded habitats near urban areas where they may be subject to fitness costs such as increased predation by domestic & feral dogs and cats, lower quality nesting habitats, and noise & chemical pollution, among others.

The Tropical Kingbird *Tyrannus melancholicus* (Image 1), a passerine bird of the family Tyranidae, is widely distributed, ranging from the southwestern United States to southern Argentina (Stouffer et al. 2024). In Mexico, this species is resident from southern Sonora, including the Islas Marías on the west coast and from central Tamaulipas on the east coast extending southward along both coasts, including the Yucatán Peninsula, and inland throughout the central region of the country (Stager 1957; Howell & Webb 1995). Both sexes vocalize throughout the day, mostly while perched but also occasionally during flight. A distinctive dawn song, characterized by a series of brief notes and delicate ascending trills, is typically performed from shortly before dawn until sunrise and does not resume for the remainder of the day (Skutch 1965; Smith 1966). Additionally, these birds emit social calls that are perceived as high-pitched, thin warbles that exhibit contextual variations (Skutch 1965). The Tropical Kingbird feeds primarily by aerial hunting of flying insects, with frequent returns to the same perch after capturing prey (Fitzpatrick 1980). While foraging habits are predominantly diurnal, there are anecdotal reports of Tropical Kingbirds hunting insects at night in artificially illuminated areas in Brazil (Sick & Teixeira 1981; Stouffer et al. 2024). Nevertheless, the influence of ALAN on the

Image 1. Tropical Kingbird *Tyrannus melancholicus* perched while searching for food at night (~0200 h) in the Islas Marías Biosphere Reserve, Mexico. © David Ramírez Adame.

activity patterns of this species remains unclear, and the specific effects on vocal activity in less anthropized insular populations, such as those inhabiting isolated regions like Islas Marías, have yet to be elucidated.

Given that artificial illumination continues to expand into remote regions, it is crucial to understand its effects on avian populations. To address this, we compared the vocal activity of the Tropical Kingbird at locations with and without artificial nocturnal lighting in an island population that is not exposed to other aspects of urbanization. We hypothesized that ALAN induces an extension of vocal activity during nighttime hours, thereby altering the natural activity patterns of this species.

METHODS

During July and August 2024, we conducted field research on María Madre Island (21.634° N, 106.541° W; Image 2) with the main objective of studying the Elf Owl *Micrathene whitneyi*. María Madre is the largest island in the Islas Marías archipelago, situated within the Islas Marías Biosphere Reserve in Nayarit, Mexico. The climate is arid, with moderate precipitation occurring from June to October and an average annual temperature of 24.9°C. In the Islas Marías, during the sampling period, sunrise occurred at approximately 0500 h and sunset around 1900 h. The island exhibits four distinct vegetation types: medium sub-deciduous forest, low deciduous forest, crassicaulous scrub with low thorny forest, and coastal dune associations (Sánchez-Mejorada 1984; CONANP

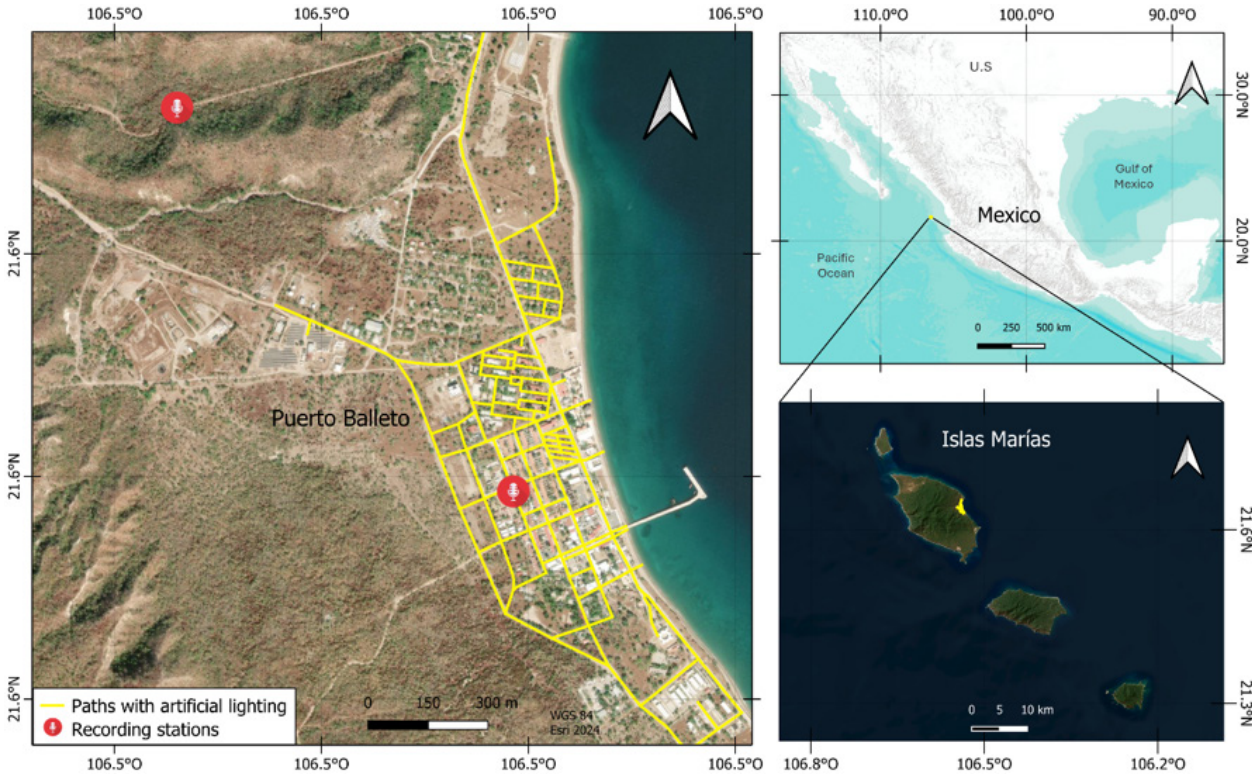

Image 2. Location map of the study site on María Madre Island, Nayarit, Mexico.

2021). Furthermore, the island has an urbanized area, consisting of paved roads, houses for tourists and island personnel, as well as some areas designated for naval bases.

During our field trips on the island, we noted that individuals of Tropical Kingbird inhabiting the urbanized area exhibited nocturnal activity. Consequently, we designed an observational study to be conducted at two sites with contrasting lighting conditions. The first site was situated in an area with consistent ALAN, where multiple lamps are activated at dusk and remain on until dawn, providing approximately 10 hours of continuous artificial illumination each night. These lamps are positioned at 30 m intervals. The second recording location was established in the territory of a Tropical Kingbird, approximately 410 m from the nearest lamp in an area without ALAN (Image 2). We implemented the same recording protocol at both sites using autonomous Song Meter Micro recorders model SM-MIC (Wildlife Acoustics, Inc., Maynard, USA) with built-in omnidirectional microphones. Recorders were mounted at 2 m height on tree branches within Tropical Kingbird territories, carefully positioned to avoid disturbance. The recording protocol consisted of 10 min recording periods followed by 10 min intervals without recordings, continuing until a complete 24-hour cycle was achieved at both sites. The recordings were made continuously, with one day of separation between both recording sets and a similar lunar phase (last quarter) at both sites. All recordings were made in WAV format at 44.1 kHz/16-bit resolution.

The vocal activity pattern of Tropical Kingbird was characterized by quantifying the number of vocalizations from 72 recordings per site, corresponding to a complete 24-hour recording cycle. Data were extracted through systematic visual inspection of spectrograms configured with a Hann window, 256 points, 90% overlap, and a discrete Fourier transform size of 512 samples, using Raven Pro 1.6 software (Yang 2024). Vocalizations were identified and counted by manually selecting all clear acoustic events across the 24-hour cycle. Each detection was verified aurally and visually by two independent observers to minimize false positives. Vocalizations were manually identified and categorized as either dawn songs or social calls (Figure 1; Audio 1; Audio 2). Dawn songs are apparently produced only by males and defined as long, ascending trills composed of stereotyped sequences of multiple syllables, typically emitted during pre-dawn hours, and characterized by slightly longer and more grating notes. Social calls are high-pitched, thin, and emitted by both sexes, consisting of short, repeated notes (Howell & Webb 1995; Stouffer et al. 2024). Circular charts were constructed utilizing the "ggplot2" package (Wickham 2016) of R Software R 4.4.2 (R Core Team 2024) to visualize the frequency distribution of dawn songs and social calls over a 24-hour cycle. Subsequently, acoustic activity patterns were statistically compared using the Mardia-Watson-Wheeler circular nonparametric test (Zar 1998) using Oriana 4.02 software (Kovach 2013).

In addition to the recordings, to document the nocturnal behaviour of Tropical Kingbirds, direct observations were conducted during six nights at sites with ALAN, simultaneously, were performed these six same nights walks at sites without ALAN, between 1800 h and 0200 h, with a single walk conducted per site.

RESULTS

At the site with ALAN, 100% of recordings contained at least one Tropical Kingbird vocalization, totaling 3,947 vocalizations, of which 1,040 were dawn songs, and 2,907 were social calls. In contrast, at the site without ALAN, 40% of recordings contained vocalizations, for a total of 228 vocalizations, of which 13 were dawn songs and 215 were social calls. During the sampling period, we observed that the territories were generally occupied by a single individual; however, at the site with ALAN, more agonistic interactions between individuals were observed, including chases, wing-fluttering, and physical confrontations.

At the site with ALAN, dawn songs were recorded from 0200–0500 h, exhibiting a peak around 0300 h (Figure 2A). In contrast, at the site without ALAN, dawn song activity was more temporally concentrated, occurring primarily near dawn at approximately 0500 h (Figure 2B). Statistical analysis revealed significant differences in dawn song emission patterns between the site with ALAN compared to the site without ALAN ($W = 26.145$, $P < 0.001$).

Social call patterns exhibited notable differences between the sites with and without ALAN. At the artificially illuminated location, social calls occurred throughout the 24-hour cycle, with heightened activity during nighttime hours and a peak after sunset (1900 h; Figure 2C). In contrast, in the site lacking artificial light, social calls were less frequent, limited to daytime hours, and primarily concentrated around twilight periods, with peak activity observed before sunset at 1800 h (Figure 2D). Statistical analysis revealed significant differences between the two sites ($W = 56.456$, $P < 0.001$).

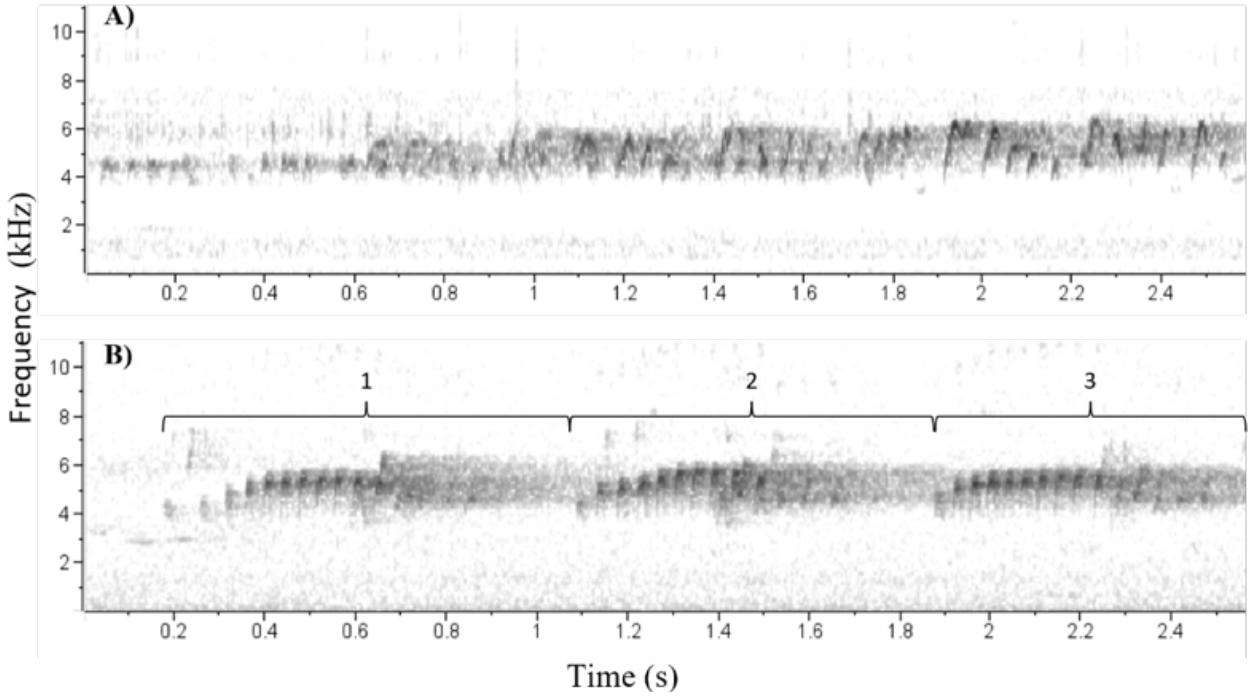

Figure 1. Spectrograms of the Tropical Kingbird vocalizations recorded during study period: A—One dawn song vocalization | B—Three social calls.

Our field observations at ALAN site revealed that Tropical Kingbirds foraged at night, frequently pursuing insects drawn to the light sources (Video 1). These feeding behaviours were recorded from dusk until 0200 h, covering the entire period during which field surveys were conducted. Additionally, these birds displayed agonistic behaviours towards conspecifics. In contrast, during six nighttime surveys at locations without ALAN, we did not observe feeding behaviours or detect any vocalizations of Tropical Kingbird after nightfall.

DISCUSSION

The results of this study show clear differences in vocalization patterns, both in dawn songs and in social calls, of the Tropical Kingbird between a site with ALAN and a site without ALAN. At the site with ALAN, an earlier onset of dawn singing and a longer duration of vocal activity were observed, in contrast to the site without ALAN, where vocal activity was more concentrated at dawn. This difference was statistically significant. Such shifts in the timing of morning song in the presence of ALAN have been reported in other bird species exposed to similar conditions. For instance, previous studies have documented that artificial light can advance the onset of vocal activity and extend its duration in urban birds, which can in turn affect key processes such as reproductive success and disrupt circadian rhythms (Kempenaers et al. 2010; Da Silva et al. 2015).

Regarding social calls, we observed significantly higher activity at the site with ALAN, with calls recorded throughout the 24-hour cycle, including a peak in vocal activity after sunset and a high concentration of calls during the night. In contrast, at the site without ALAN, social calls were considerably less frequent and were only recorded during daylight hours, peaking before sunset. This difference in the temporal pattern of social calls was statistically significant, reinforcing evidence that artificial night lighting substantially alters vocal communication in this species on María Madre Island. While our findings partially align with previous studies that have documented increased nocturnal vocalizations in birds exposed to artificial light (Da Silva et al. 2014; Dominoni et al. 2015; Ursino et al. 2022), most of those studies report this phenomenon only within narrow time windows, shortly before or after sunset. In contrast, the present study documents extended nocturnal vocal activity lasting throughout the night.

Furthermore, we observed nocturnal foraging behaviour at the site with ALAN, including active pursuit of insects attracted to the light and increased agonistic interactions between individuals, such as chasing, fluttering, and physical confrontations. These

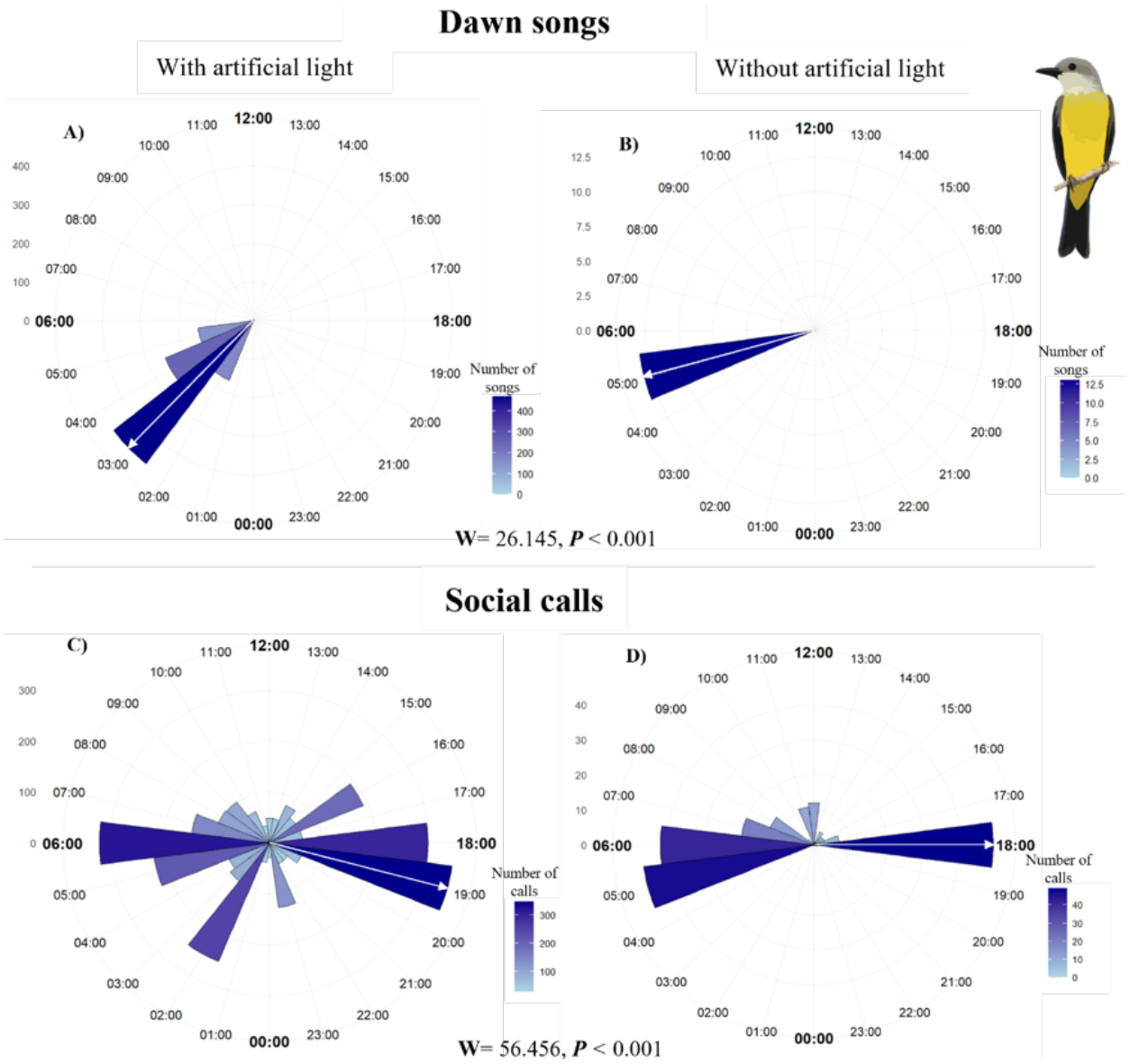

Figure 2. Vocal activity patterns of the Tropical Kingbird in a continuous 24-hour cycle. The color intensity represents the relative frequency of vocalizations, and the white arrow indicates the peak of vocal activity: A—Dawn songs with artificial light | B—Dawn songs without artificial light | C—Social calls with artificial light | D—Social calls without artificial light.

behaviours were not observed during nighttime hours at the site without ALAN, where individuals remained vocally and behaviourally inactive after sunset. This type of behaviour is consistent with observations in other bird species, in which opportunistic nocturnal foraging induced by ALAN has been documented, facilitated by the attraction of insects to light sources (Santos et al. 2010; Stracey et al. 2014; Russ et al. 2015). These studies indicate that ALAN can extend birds' foraging activity beyond the daytime period, altering natural foraging patterns.

Although the Tropical Kingbird is widely distributed across the American continent and is common even in urban areas with high levels of artificial light (Stouffer et al. 2024), records of nocturnal vocal activity in this species are scarce in the literature. To date, there is only a single isolated report of nocturnal vocal activity from a continental population, where individuals were observed feeding on insects and emitting social calls from 2300 h to 2400 h (Sick & Teixeira 1981). Therefore, the more pronounced and extended response to ALAN observed in this study could potentially be intensified by the ecological conditions of an insular environment.

Previous work has shown that island species

often exhibit greater behavioural plasticity and niche expansion (Scott et al. 2003; Losos & Ricklefs 2009; Dufour et al. 2024). These traits have been associated with the evolution of relatively larger brains in island populations, which facilitates the adoption of new foraging strategies and space use (Sol et al. 2005; Cnotka et al. 2008; Sayol et al. 2018). In this context, the high levels of nocturnal activity recorded in our study could be interpreted as an adaptive strategy by which birds exploit the abundance of insects attracted by artificial light, a resource that would otherwise be unavailable under natural conditions.

A potential limitation of the study is the limited sampling effort, the lack of quantification of the number of individuals per site, along with the absence of data on the reproductive status of the birds during the brief sampling period, which could influence vocal activity and foraging patterns of the individuals. Furthermore, our results establish a foundation for developing conservation strategies aimed at mitigating the impact of artificial illumination on species susceptible to human-induced environmental changes.

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Spanish Resumen (español): La iluminación artificial nocturna (ALAN, por sus siglas en inglés) modifica los patrones de actividad de numerosas especies de aves, alterando su comportamiento y actividad vocal. En este estudio, evaluamos el impacto de la ALAN en los patrones de actividad vocal del Tirano Pirirí (*Tyrannus melancholicus*) en la Isla María Madre, ubicada en el estado de Nayarit, México. Las vocalizaciones de esta especie se registraron en un sitio con ALAN y otro sin ALAN, utilizando grabadoras autónomas Song Meter Micro. Analizamos los espectrogramas para cuantificar las vocalizaciones y realizamos observaciones de comportamiento. Nuestros resultados mostraron diferencias claras en la actividad vocal en el sitio con ALAN en comparación con el sitio no iluminado. El sitio con ALAN presentó una mayor actividad vocal total, con 3,947 vocalizaciones con al menos una en cada grabación, en contraste con 228 vocalizaciones distribuidas en el 40% de las grabaciones en el sitio sin ALAN. Los Tiranos Piriríes en el sitio con ALAN tuvieron un período de vocalización previo al amanecer sustancialmente más prolongado y adelantado, de 0200 h a 0500 h, en comparación con un período muy breve alrededor de las 0500 h en el sitio sin ALAN, así como vocalizaciones a lo largo de toda la noche, en contraste con un breve pico al anochecer sin vocalizaciones nocturnas. Finalmente, observamos que los individuos en el sitio con ALAN continuaron forrajeando durante la noche, mostrando también un aumento en las interacciones agonísticas, como persecuciones, aleteos y confrontaciones físicas. Nuestros resultados sugieren que la luz artificial altera significativamente el patrón de actividad del Tirano Pirirí, extendiendo su actividad vocal y de forrajeo. Este estudio podría contribuir a comprender los efectos de la contaminación lumínica en aves insectívoras en ambientes insulares y muestra la importancia de reducir los impactos de la luz artificial en los hábitats naturales.

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