LIFE ilhas barreira

REPORT

Monitoring human disturbance on breeding seabirds on Barreta island

Lisboa | January | 2025

COFINANCIAMENTO COORDENAÇÃO PARCEIROS

Report of the Action D3 of the project Ilhas Barreira

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Reference

Nascimento T., Oliveira N., Werling E, Rossi M., Welzel S., & Andrade J. 2025. Monitoring human disturbance on breeding seabirds on Barreta island. Report of the Action D3 of the project Ilhas Barreira. Sociedade Portuguesa para o Estudo das Aves, Lisboa (unpublished report).

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Summary

Colonial seabirds are highly sensitive to human disturbance, yet they frequently face significant pressure from tourism and other human activities. Barreta Island hosts the largest breeding colony of Audouin's Gulls (Larus audouinii), along with breeding populations of Yellow-legged Gulls (Larus michahellis), Lesser Black-backed Gulls (Larus fuscus), and occasional Little Terns (Sternula albifrons). The rapid rise in tourism in the Algarve has increased human presence on Barreta Island, heightening the potential for disturbance to breeding seabirds.

As part of the LIFE Ilhas Barreira project, awareness measures were implemented to mitigate human intrusion and disturbance. This study evaluates the effectiveness of these measures by analyzing human activity patterns before and after the intervention. Using camera traps, we quantified the Relative Abundance Index (RAI) of human presence across different locations and seasons on the island.

Results indicate that while overall human activity decreased post-intervention, variability increased, with disturbance becoming more localized near the boardwalk. In non-boardwalk areas, human presence significantly declined, suggesting that the management actions were effective in reducing disturbance, particularly in the most remote colonies. However, all gull colonies on the island experienced some level of disturbance. The widespread human presence across the island and throughout all seasons suggests that disturbance is not solely caused by tourists; local residents, fishermen, and small boat users also contribute to habitat disruption.

Despite the intervention, the boardwalk area experienced high levels of human activity, potentially leading to increased trampling and habitat degradation. The lack of formal boardwalk access to the northeastern bay, combined with visitor disregard for awareness signs, has likely contributed to the use of informal paths, further disturbing sensitive habitats.

To enhance conservation efforts, strengthening patrolling and surveillance, could help deter unauthorized access and promote compliance. Additionally, targeted educational campaigns for local residents could increase awareness of the ecological importance of dune habitats, encouraging responsible behavior to minimize human impact.

Resumo

As aves marinhas coloniais são altamente sensíveis à perturbação humana, mas frequentemente enfrentam pressões significativas do turismo e de outras atividades humanas. A Ilha da Barreta abriga a maior colónia reprodutora de gaivotas-de-audouin (*Larus audouinii*), juntamente com populações nidificantes de gaivotas-de-patas-amarelas (*Larus michahellis*), gaivotas-d'asa-escura (*Larus fuscus*) e, ocasionalmente, chilreta (*Sternula albifrons*). O rápido crescimento do turismo no Algarve tem aumentado a presença humana na Ilha da Barreta, elevando o risco de perturbação das aves marinhas durante a reprodução.

No âmbito do projeto LIFE Ilhas Barreira, foram implementadas medidas de sensibilização para reduzir a perturbação humana. Este relatório avalia a eficácia destas medidas através da análise dos padrões de atividade humana antes e depois da intervenção. Com recurso a câmaras

automáticas de monitorização, quantificámos o Índice de Abundância Relativa (RAI) da presença humana em diferentes locais e estações do ano na ilha.
Os resultados indicam que, apesar da redução da atividade humana após a intervenção, a variabilidade aumentou, com a perturbação a tornar-se mais localizada junto ao passadiço. Nas áreas fora do passadiço, a presença humana diminuiu significativamente, sugerindo que as medidas de gestão foram eficazes na redução da perturbação, particularmente nas colónias mais remotas. No entanto, todas as colónias de gaivotas na ilha sofreram algum nível de perturbação.
A presença humana generalizada na ilha ao longo de todas as estações do ano sugere que a perturbação não é causada apenas por turistas, mas também por residentes locais, pescadores e utilizadores de pequenas embarcações, que contribuem para a degradação do habitat.
Apesar das intervenções, a zona em redor do passadiço manteve níveis elevados de atividade humana, o que pode levar a um aumento do pisoteio e da degradação do habitat. A falta de um passadiço até à baía a nordeste da ilha, aliada à desconsideração dos visitantes pelos sinais de sensibilização, parece ter contribuído para o uso de trilhos informais, agravando a perturbação em habitats sensíveis.
Para reforçar os esforços de conservação, o aumento da patrulha e da vigilância, poderia dissuadir acessos não autorizados e promover o cumprimento das normas. Além disso, campanhas educativas direcionadas aos residentes locais poderiam aumentar a consciencialização sobre a importância ecológica das dunas, incentivando comportamentos responsáveis para minimizar o impacto humano.

1 | Introduction

1.1 Effects of disturbance

For birds, human disturbance can generally trigger an increase in heart rate (Ackermann et al., 2004; Weimerskirch et al. 2002), reduce immunity (Palacios et al., 2018) and change core body temperature (Regel & Pütz, 1997). This leads to a loss of energy and increased levels of stress-induced corticosterone in the body, which can affect breeding success (Romero & Romero, 2002; Saino et al. 2005). During the breeding season, the concentration of human activity in sensitive areas, can result in significant direct impacts on bird populations. Trampling can lead to the destruction of nests, egg breakage, and even the death of newly hatched chicks, especially for ground-nesting species. Disturbance can disrupt incubation patterns, increase the number of nest failures and chick mortality due to inter-and intraspecific predation, intraspecific aggression, and lower parental care or abandonment (Carney & Sydeman, 1999).

These effects can alter the demographic characteristics of a population, such as abundance and age structure, especially if the impact is felt over more than one breeding season (Rodway et al., 1996).

Human disturbances affecting birds can be categorized into several types, each impacting their behavior, physiology, and population dynamics in different ways. Among them, the most common are noise and light pollution, habitat modification, human presence and recreational activities, chemical and plastic pollution, hunting and poaching, and introduced predators.

Noise pollution can affect birds, inducing stress responses like light or avoidance behaviours, and disrupt forage. Noise can also impair reproduction by affecting incubation, brooding, pair bonding, mate attraction, and parental responses to chicks (Francis et al., 2009; Blickley & Patricelli, 2010). Colonial birds are particularly vulnerable, as disturbances can trigger widespread reactions within colonies (Burger, 1998). Artificial light, disrupts interspecific interactions and birds can become disoriented and collide with each other or with structures, resulting in direct mortality, or affect foraging behaviour and communication, increase predation risk and reduce reproductive success (Longcore & Rich, 2004). Introduced predators, that humans have intentionally or accidentally brought to new environments, can be a significant threat to birds, particularly for island species and ground-nesting birds. Direct predation of eggs and chicks, disruption of breeding success by nest abandonment and lower reproductive output, changes in nesting sites and foraging behaviour are some of the most widespread impacts.

In addition, there are a number of factors that alter the habitat of coastal birds. Industrial development causes direct habitat loss, and the increase of tourism puts additional pressure on the extent and quality of nesting and feeding habitats for beach-dependent species (Defeo et al., 2009).

Excessive use of the waterway by boats, and water sports not only causes disturbance from noise and fast movement, but also sediment resuspension, water pollution, disturbance to fish and wildlife, destruction of aquatic vegetation and shoreline erosion from excessive wave action. This can lead to destruction of banks-side and emergent vegetation and alter the habitat, affecting the availability of food or nesting cover (Asplund, 2000). Beach raking, sand scraping (used for seawalls), and off-road vehicles degrade beach and dune habitat and damages nesting ground of beach-breeding birds (Defeo et al., 2009; McLachlan et al., 2013).

In some species habituation can reduce the impact of disturbance (Villanueva et al., 2014; Nisbet, 2000; Walker et al., 2006), but some species never habituate, or appear to habituate behaviourally but suffer long-term physiological effects that are difficult to measure (Cyr & Romero, 2009; Walker et al., 2006). Colonial breeding species may be more likely to tolerate higher levels of disturbance than solitary breeders, with incubating birds less likely to abandon their clutch than laying birds (Hockin et al., 1992).

Protective measures to reduce human disturbance during the nesting season increase the suitability of a site and can promote reproductive success. Striking a balance between human access and protecting bird populations is a challenge for conservation managers.

1.2 Human activities that cause disturbance

The effects of human disturbance on bird colonies is highly dependent on the magnitude, frequency, timing and duration of it (Burger et al., 1995).

Recreational activities: hiking, hunting, walking dogs, fishing, water sports, flying drones. Close contact with humans at breeding sites can lead to direct destruction of nests and eggs and behaviour change leading to stress, nest abandonment, or reduced reproductive success.

Transportation: cars, bicycles, all-terrain vehicles, boats, airplanes. In addition to direct destruction of nests and eggs, noise pollution and close contact through boats and aircraft can lead to flushing, nest abandonment and increased predation of eggs and young, which prevent certain bird species from breeding (Carney & Sydeman, 1999). Gulls and terns react particular sensitive to close and high speed motorboats and personal watercraft activity (Burger et al., 1995).

Tourism: boat traffic, large crowds, intensive recreational activities, habitat loss due to holiday resort tourism can affect both habitat availability and productivity of beach-breeding birds by increasing beach erosion rates and intensifying human disturbance (Yasué & Dearden, 2006).

Construction and development: Increased human development in coastal areas can lead to habitat loss and increased disturbance by driving birds away from their traditional nesting habitat (Carney & Sydeman, 1999). Industrial plants and structures cause increased lighting and affect feeding patterns, which can be detrimental through disorientation, which can lead to exhaustion or direct mortality. The development of new residential areas also brings with it the introduction of invasive species and predators (cats, rats, dogs, foxes), which reduces breeding success (Taylor, 2000).

Research: entering colonies, handling eggs and chicks and capturing adults. Scientific investigators need to closely monitor demographic parameters of colonial waterbirds and present therefore most intense kinds of disturbance, which can reduce breeding success (Carney & Sydeman, 1999; Blackmer et al., 2004). The disturbance can cause parents to permanently desert their eggs, resulting in certain failure, or it could cause parents to temporarily neglect their eggs, which can reduce hatching success (Blackmer et al., 2004).

1.3 Types of disturbance mitigation measures

1.3.1 Human access management

Managing human access to protect wetland birds from disturbance can include: Reducing or preventing access to areas within a site, path management, limiting visitor numbers or strictly controlling certain activities (Batey, 2013).

Creating Buffer zones: Human access is restricted at a certain distance from habitats used by birds. This is a very common management option to reduce the impact of disturbance (Batey, 2013). The intensity of the disturbance, the time of year and the sensitivity of the species (flight initiation or set-back distances) should all be considered when determining the buffer distance for a particular situation (Valente & Fischer, 2011).

Exclosure: Preventing human access to areas through landscape barriers or fencing provides a refuge for birds and reduces the impact of human disturbance especially on ground-nesting seabirds (Batey, 2013).

Zoning: Zoning allocates areas for specific activities. It provides an opportunity to reduce the impact of disturbance by controlling the most disturbing activities in or near areas of importance to birds (Batey, 2013). Restricting watercraft in and around important coastal areas throughout the year can slow the rate of succession through natural coastal processes, thereby preserving habitat for a longer time period (Maslo et al., 2019).

Regulating or restricting visitor numbers: Reduces disturbance pressure on habitats used by birds, but is ultimately difficult to control (Liley et al., 2011; Batey, 2013). Should take into account that visitor restrictions lead to reduced public education and awareness (Batey, 2013).

Path design and management: Is a useful tool for controlling visitor distribution and can therefore be modified to manipulate the level of wildlife disturbance in sensitive sites (Batey, 2013). Compared to access restrictions or exclosures, it is a more publicly acceptable option for wildlife conservation (Finney et al., 2005).

Screening of paths and providing hides: Reducing human visibility by screening paths and providing hides for wildlife observers is likely to minimise disturbance (Batey, 2013).

Careful behaviour of researchers: Visiting colonies early in the day to avoid thermal stress, avoiding unnecessary handling of chicks, limiting the number of intrusions and their duration, minimizing physical contact with birds and moving slowly when inside colonies (Brown & Morris, 1994; Brown & Morris, 1995). In addition, scientific activities should be limited to small segments of a colony and careful precautions should be taken that are known to reduce or mitigate the negative effects of intrusion (Brown & Morris, 1995)

Restrict dog access: Inform dog owners of good practices such as keeping dogs on the leash, aimed at reducing the effects of disturbing dogs (off-leash dogs, barking) (Liley et al., 2011; Batey, 2013).

1.3.2 Habitat management

Increase habitat: Improve the habitat with increased food availability and improving nesting areas through vegetation management. For aquatic birds, providing islands, spits and headlands can increase nesting areas (Hockin et al., 1992).

Restoration: Land restoration programmes, such as beach restoration of low-lying beaches or surrounding wetlands.

Removal of invasive species: Predator removal or control can increase reproductive success and survival, which can have a positive effect on the population or lead to recolonisation (Williams et al., 2020). Where eradication is not feasible, local control of invasive species on islands can have positive outcomes for native birds (Vanderwerf et al., 2014).

Urban regulations: Permissions for construction in coastal areas, that could have a significant impact on bird populations through disturbance must be carefully considered before being approved (Hockin et al., 1992). Shielding artificial street lights and lights from constructions along the coast, at least those near breeding areas (Hockin et al., 1992).

1.3.3 Education

Education reduces the negative impacts of disturbance by changing visitors' knowledge and behaviour (Marion & Reid, 2007). The content, delivery and style of communication influence the effectiveness of education in changing visitor behaviour (Marion & Reid, 2007).

Signs: They inform site users of restrictions and provide information on conservation issues, including disturbance (Batey, 2013). Signs are an effective way of enhancing the visitor experience and promoting sustainable interactions with wildlife, outlining methods of changing behaviour by changing beliefs about wildlife through interpretation (VanderWalde, 2007; Zeppel & Muloin, 2008; Ham & Krumpe, 1996).

Wardens in protected areas: They can intervene to prevent disruptive activity, enforce restrictions, provide information to site users and encourage positive behaviour through persuasion

(Batey, 2013). But they are unlikely to reach a large audience and their usefulness is reliant on their power to enforce current byelaws (Littlefair, 2003; Liley et al. 2011).

1.3.4 Efficient practices

Overall, there is very little evidence of the effectiveness of most management options in reducing disturbance to wetland and coastal birds (Batey, 2013). A combination of measures to reduce the impact of disturbance, is more successful than a single method approach (Bennett et al., 2011), but making it extremely difficult to assess the impact of individual options (Batey, 2013).

Monitoring the effectiveness of employed measures should be an essential part of management strategies. This involve quantifying the effects of human disturbance on breeding success and visitor disturbance, and then testing the effects of measures on visitor behaviour and birds. Monitoring can be done by direct observation due to scientists, remote sensing (satellites, drones or aerial photography) and by installing surveillance cameras (Allbrook & Quinn, 2020).

Effective combinations of management options:

- Use of signage with wardens (Medeiros et al., 2007)
- Exclosure with visitor number restriction (Ikuta & Blumstein, 2003)
- Zoning with education and enforcement (Burger, 2003)

Effective singular management options:

- Buffer zones: The most commonly recommended method of minimising disturbance to waterbirds is to create buffer zones between human activities and habitats used by birds (Valente & Fischer, 2011).
- Education: A major problem in wildlife-human conflict is a lack of understanding and awareness (Taylor & Knight, 2003), so providing clear interpretation, either written or verbal, can encourage behaviours that minimise disturbance and can go a long way to alleviating the problem (Ballantyne & Hughes, 2006; Marion & Reid, 2007; Marschall et al., 2017).

1.4 Disturbance on Barreta Island

Human disturbance on Barreta Island is due to short-term presence of tourists in the grey dune. The Algarve region has seen a rise in tourism in general and the expansion of ecotourism and birdwatching in Ria Formosa Natural Park can challenge nature conservation (Istomina et al., 2016; Yeboua, 2022).

Barreta Island is home to the biggest Audouin's gulls (*Larus audouinii*) breeding colony, representing 31% of the global population (Oliveira et al., 2024). During the 1960s-1970s, the species experienced a high demographic reduction which may be due among other disturbances to a negative response of Audouin's gull to human presence (Bradley, 1988; Oro et al., 2001). Although Audouin's gulls went into a rapid population reduction and is assessed as Vulnerable under the IUCN red list, the Portuguese Audouin's gull population steeply increased during the last decade (BirdLife-International, 2024; Oliveira et al., 2024). Audouin's gulls' reproductive season takes place from April to August (Pereira et al., 2022) and is correlated to the tourism intensification period. Other breeding seabirds potentialy afected by disturbance are Little tern *Sternula albifrons*, Yellow-legged gull and Lesser black-backed gull *Larus fuscus*.

Under the LIFE Ilhas Barreira project an awareness campaign to avoid anthropogenic disturbance due to human intrusion was put in place. The aim of this study was to assess a change in visitors' behaviour after the implementation of the campaign on Barreta Island.

2 | Methods

2.1 Study Area

The Ria Formosa Natural Park is a 60 km long complex coastal lagoon system in Faro, located in Algarve, South Portugal. Ria Formosa is classified as a Special Protection Area (SPA) and a Site of Community Importance, as part of the NATURA 2000 EU network, as well as considered as a Natural Park under national legislation. The sorrounding Barrier Islands create unique and essential habitats such as "grey dunes" favouring breeding seabirds' colonies, including Little terns *Sternula albifrons*, Yellow-legged gulls *Larus michahellis*, Lesser-black gulls *Larus fuscus* and Audouin's gulls.

The Barreta island is one of the five islands of Ria Formosa, with a length of 8.6 km and an area of approximately 3.2 km2, being 150 m apart from the Ancão peninsula (to the west), and 700 m from Culatra Island (to the east). The island is also close to the city of Faro, with a minimum distance of 4 km, but there are several islets and salt marsh areas in between.

Barreta Island is inhabited by just one fisherman and the existing infrastructures are limited to three shelters and a restaurant (which can operate all year round), all located in the eastern part of the island, and a boardwalk with around 1.7 km from the pier to Cape Santa Maria. Access beyond the established trail to the dunes is restricted, though visitors often disregard the rule. The island is accessible for visitors year-round, with a notable increase in tourist activity during the summer months.

Figure 1 | Audouin's gull in the breeding colony on Barreta Island

2.2 Disturbance mitigation measures

To minimize human disturbance in breeding areas and discourage walking on the dunes, several awareness and informational signs were installed along the boardwalk of Barreta Island in April 2023 (Fig. 2). Simultaneously, a section of this boardwalk was modified to address the ongoing erosion in the original area (Fig. 3).

Additionally, a series of environmental education and awareness activities were conducted throughout the project period, targeting local schools, residents, and maritime tour companies. These activities focused on promoting the natural values of Barreta Island and encouraging best practices.

Figure 2 | One of the awareness panels installed on Barreta island.

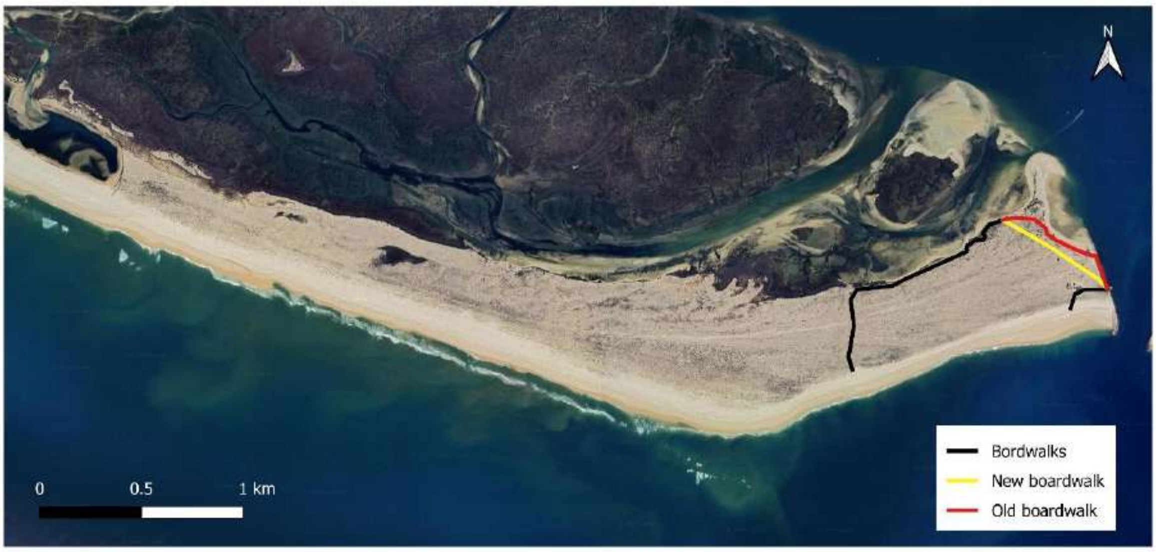

Figure 3 | Barreta Island and location of the boardwalk, with the old and new section altered in April 2023.

2.3 Camera monitoring

To evaluate differences in behaviour of tourists walking in the dunes before, and after the deployment of awareness signs, a grid of 22 camera-traps (PRIMOS Mug Shot Trial Camera Model 65064, 12MP and Bushnell CORETM NO GLOW TRAIL CAMERA, 24MP) spaced 500x500m was set on two thirds of Barreta Island in January 2020 (Fig. 5). Compreending the area with highest pressure from humans. Camera-traps were set to take three photos one second apart, triggered by a motion sensor and were activated from January 2020 to June 2024, with memory cards and batteries replaced, roughly, once a month.

All images were processed using Timelapse software (Greenberg et al 2019). A collaboration with Microsoft – AI for Earth was set to use MegaDetector on image pre-processing, to remove the enormous amount of images with no humans or other animals. In a secod step, images were classified by trainned observers throught visual observation. Species, number of individuals and habitat type (grey dune, sand beach or boardwalk) were assigned for each image. Human category did not include project related people (i.e. technicians, researchers or volunteers). Images with humans were filtered to remove those taken within 3 seconds of the previous image. Additionally, images captured within short time intervals were manually reviewed to exclude duplicate records of the same individuals.

Figure 4 | Camera-traps on Barreta Island in operation (right), and open for configuration (left)

Figure 5| Location of the 22 camera-traps on Barreta Island, on a grid spaced 500*500 m.

2.3 Data Analysis

Human disturbance has been quantified for each camera, with a monthly Relative Abundance Index (RAI; Linhart & Knowlton, 1975) as the number of human photos per 100 camera-days (i. e: with camera-days meaning 1 day of active camera), to include the camera activation effort.

The equation used to calculate the RAI, based on Linhart & Knowlton (1975), was:

$$RAI = \left(\frac{Number\ of\ Detections}{Effort}\right) \times 100$$

Data were grouped according to the touristic season:

- Low: months with low tourist activity (January, February, November, December)
- Mid: months with moderate tourist activity (March, April, May, October)
- High: months with high tourist activity (June, July, August, September)

The analysis was conducted for two periods, before and after the implementation of intervention measures:

- Pre: months prior to the introduction of intervention measures (January 2020 to April 2023)
- Pos: months following the implementation of intervention measures (May 2023 to June 2024).

To assess differences in the number of human photos per 100 camera-days (RAI) between the defined seasons and periods, non-parametric statistical tests were applied, given that the data did not follow a normal distribution, assessed with the Shapiro-Wilk test. The Wilcoxon rank-sum test (also known as the Mann-Whitney U test) was used to compare RAI values between the pre and pos periods for each season. The results were considered significant if the p-value was less than 0.05. All statistical analyses were conducted with RStudio (R version 4.4.0).

3 | Results & Discussion

The results of human photos per monitoring month can be gound on Figure 6, with detailed information on Annex A. A higher amount of photos of human walking on the dunes in Deserta island were registered between July and October 2023, with the highest record in August.

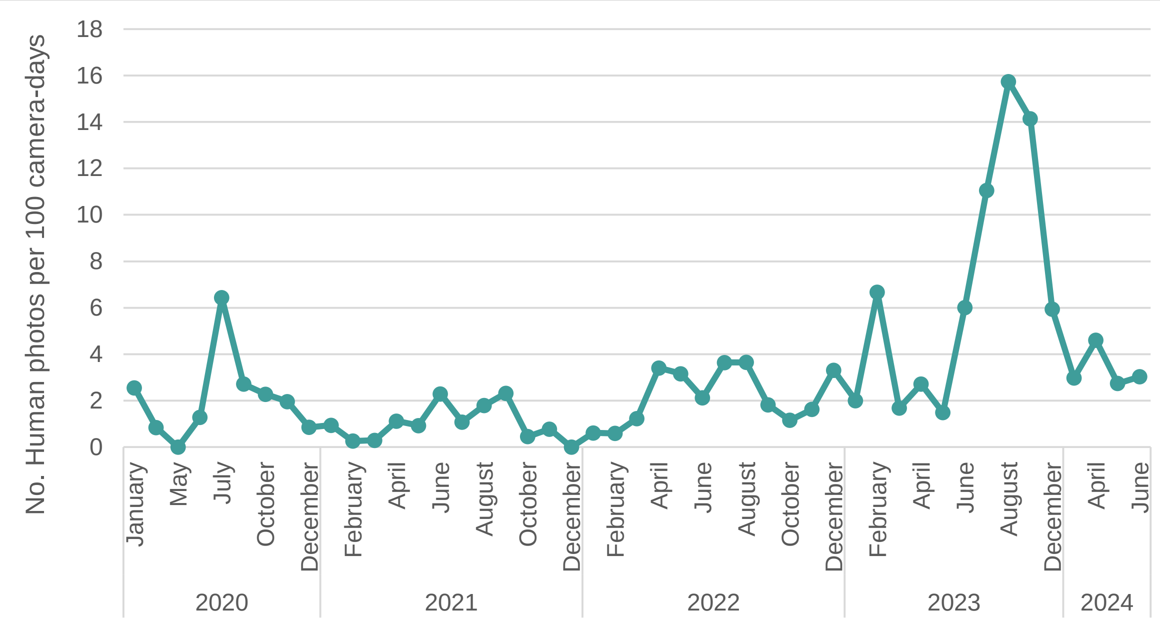

Figure 6| Number of human photos per 100 camera-days, per month and year, recorded in the camera-traps installed in Barreta island.

When analyzing seasonal patterns, a higher number of humans were recorded during the high tourist season (June to September, Fig. 7). However, no significant statistical differences were observed across seasons (Kruskal-Wallis: $\chi^2 = 0.51$, df = 2, $p = 0.78$).

In contrast, the Relative Abundance Index (RAI) was significantly higher during pre- (mean ± standard deviation = 4.74 ± 12.83) then post-intervention (1.91 ± 2.47) period (Wilcoxon test: W = 1620, $p < 0.05$). However, the pre-intervention period had a higher median RAI (pre = 0.84, post = 0.00), reflecting more consistent human activity across locations before the measures were implemented.

Focusing on seasonal differences within each period, the highest mean RAI was observed in the post-intervention period during the high tourist season (mean = 6.87 ± 18.52), followed by the low season (mean = 3.78 ± 8.24). Conversely, when considering medians, the highest values were recorded in the pre-intervention period, with the high season showing the highest median (1.45), followed by the mid (0.58) and low seasons (0.31, Fig. 8).

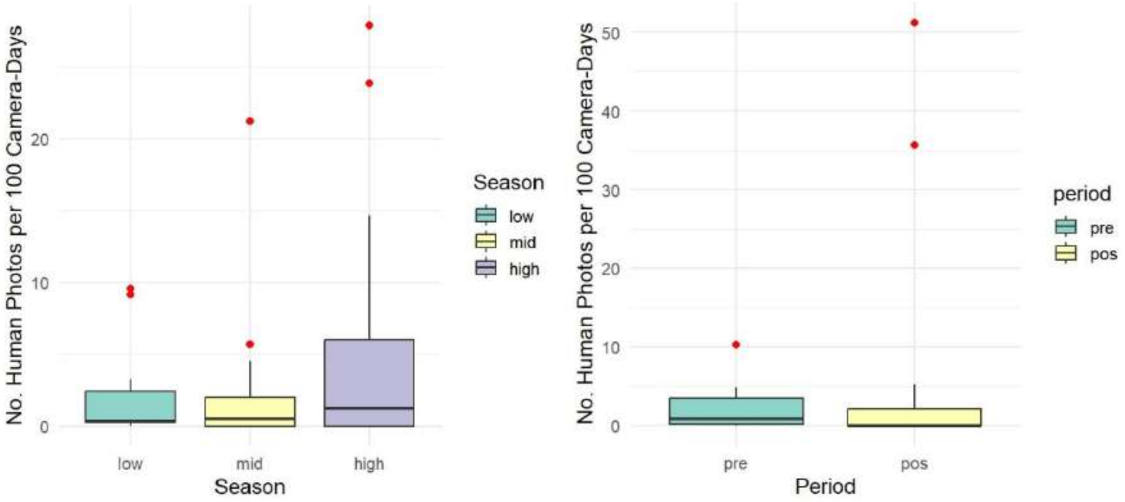

Figure 7| Number of human photos per 100 camera-days, between touristic seasons (left) and before and after the implementation of measures (right) on Barreta island.

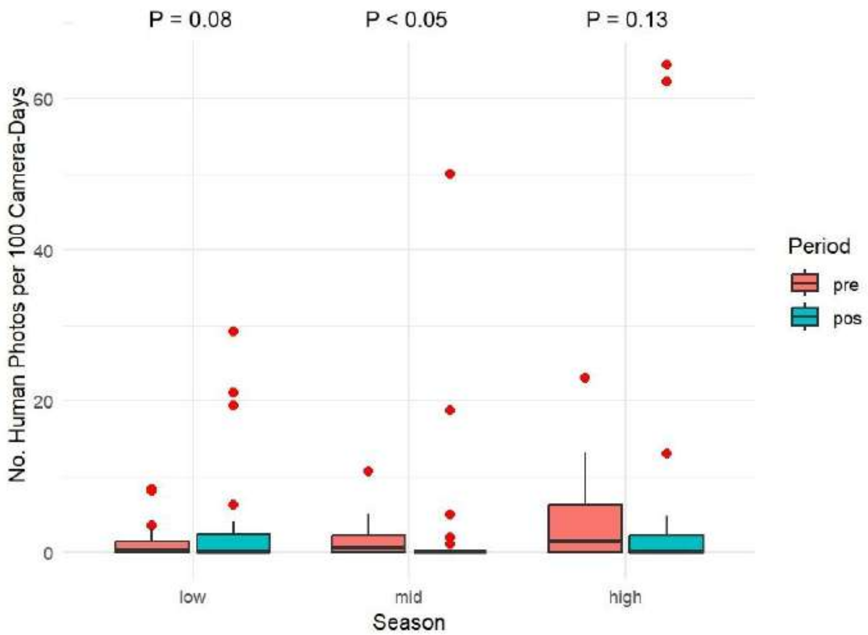

Figure 8| Number of human photos per 100 camera-days, before and after the implementation of measures according to touristic seasons, and p-values from the Wilcoxon tests assessing the difference between pre-implementation and post-implementation for each of the seasons.

These results suggest that during the post-intervention period, there was greater variability in the number of photos captured, with some extreme high values driving up the average. In contrast, the higher median in the pre-intervention period indicates more consistent and centralized values across most points before the measures were implemented. It is important to note, however, that the monitoring during the pre-intervention period spanned three years, whereas the post-intervention period covered only one year.

The higher mean RAI in the post-intervention period, coupled with substantial variability, suggests that the implemented measures did not have a uniform impact across all locations.

When analysing human activity in areas on te boardwalk compared to areas off the boardwalk, te areas on the boardwalk have higher RAI than those off te boardwalk (Fig. 9). On Boardwalk areas no significant difference in RAI between pre- and post-intervention periods ($W = 15.5$, $p = 0.60$), suggesting that while extreme values increased, overall trends in human presence remained variable.

When comparing human activity between boardwalk and non-boardwalk areas, RAI was consistently higher on the boardwalk than in areas off the boardwalk (Fig. 9). In boardwalk areas, there was no significant difference in RAI between pre- and post-intervention periods ($W = 15.5$, $p = 0.60$), suggesting that while extreme values increased, overall trends in human presence remained variable.

In contrast, human activity in non-boardwalk areas significantly decreased post-intervention ($W = 90$, $p < 0.05$), indicating that management measures may have been effective in reducing disturbance in these locations. Moreover, the difference between boardwalk and non-boardwalk areas became statistically significant post-intervention ($W = 18$, $p < 0.05$), confirming that human presence became highly localized, potentially increasing trampling and habitat disturbance near the boardwalk.

Spatial mapping of RAI further illustrates these changes. Post-intervention, human activity on the dunes was concentrated in two specific areas (Fig. 10), whereas pre-intervention, human presence was more evenly distributed across Barreta Island. This shift suggests that the intervention influenced movement patterns, leading to a more localized impact, particularly in the northern section near the boardwalk, which exhibited the highest levels of human activity (Fig. 10).

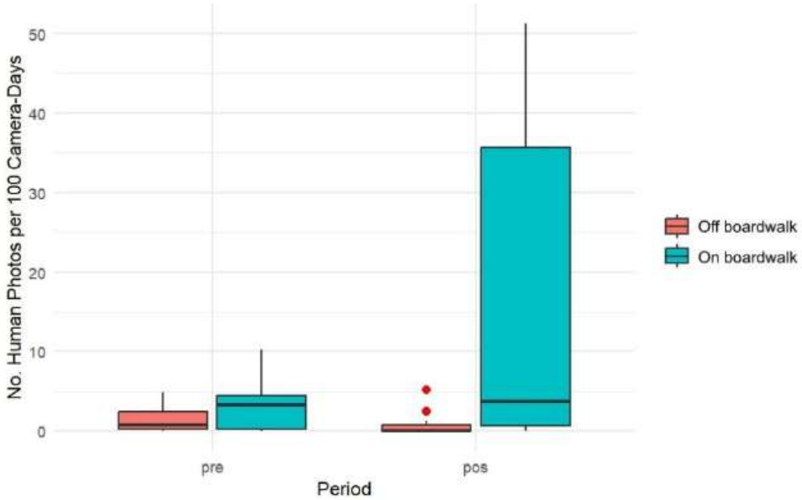

Figure 9| Number of human photos per 100 camera-days, before and after the implementation of measures according to location areas on the boardwalk and off the boardwalk.

The modification of a section of the boardwalk may have contributed to the observed increase in human activity in the area. Many people access the island through the northeast bay, yet the current boardwalk does not extend to that area and is inadequate for those arriving via the bay. This often results in individuals crossing the dunes to connect with the boardwalk or taking shortcuts to reach the bay or directly to sensitive habitats. Additionally, some visitors prefer walking along the shoreline rather than using the designated boardwalk, further increasing the disturbance to the dunes and nearby ecosystems.

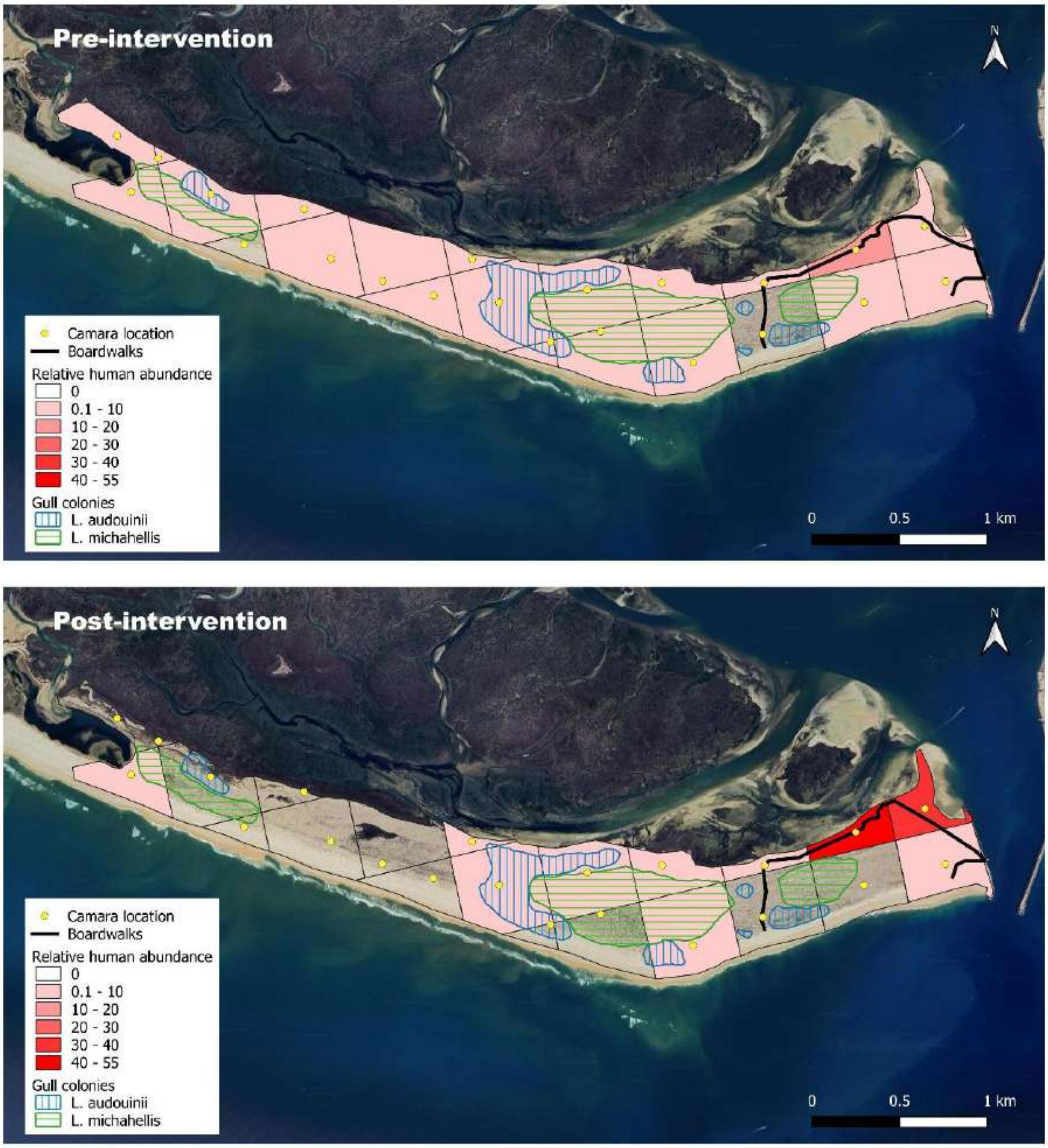

Figure 10| Relative human abundance (RAI) given by the number of human photos per 100 camera-days, before and after the implementation of measures in the monitoring grid, and the location of the severall gull colonies on Barreta island.

When analyzed by season, the spatial distribution of human disturbance followed similar patterns, with activity clustering near the boardwalk. However, during the low season, activity also concentrated in the western part of the island near the lagoon, while in the high season, it was primarily concentrated near the beach (Fig. 11).

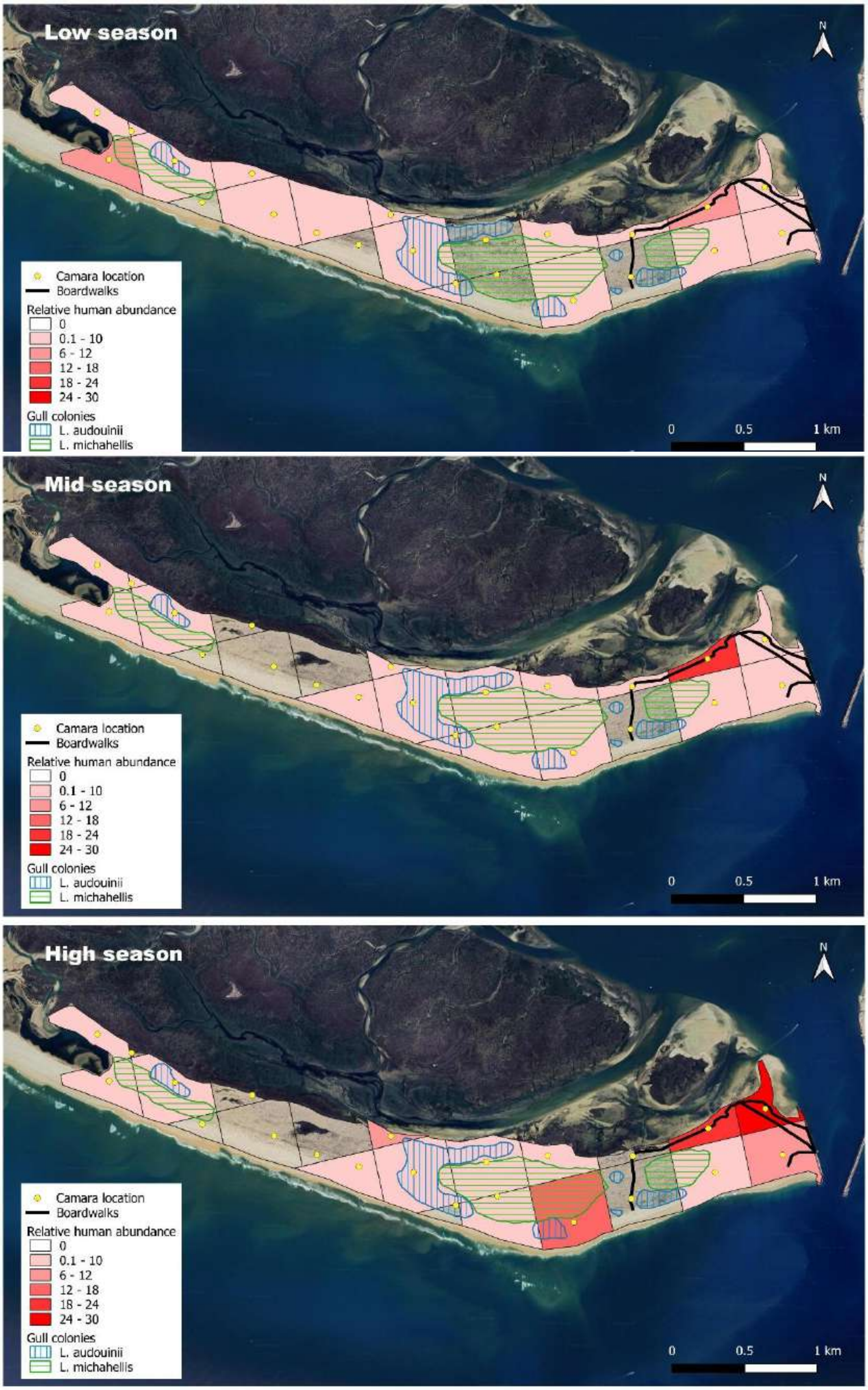

Figure 11| Relative human abundance (RAI) given by the number of human photos per 100 camera-days, in the three touristic seasons considered, and the location of the severall gull colonies on Barreta island.

The widespread human presence across the entire island and throughout all seasons point to the disturbance may not solely be attributed to tourists but also to local residents or other user groups. The areas from the middle to the western parts of the island are located far from the pier, with some being over 5 kilometers away. Here, most of the photos recorded fishermen, shelfish harvesters, or visitors with private boats. Beach tourists were only observed travelling such distancesalong the sandy beach, rarely walking through the grey dune. Although against regulations, small boats can be observed crossing the narrow canal in the north of the island. Additionally, a significant number of boats are frequently anchored in the northeastern bay during the summer months. This highlights the potential role of boat access in facilitating human activity in areas that are otherwise difficult to reach, contributing to disturbance in these sensitive habitats.

The camera trap images also reveal the presence of other users crossing the island's dunes, such as illegal campers (Annex B). Furthermore, there are indications of more illicit activities occurring on the island. This is supported by repeated instances of deliberate interference with the equipment, such as cameras being intentionally covered, damaged, or going missing. These actions suggest an effort to avoid detection and highlight the potential for illegal activity beyond simple non-compliance with island regulations.

All gull colonies on the island have experienced some level of human disturbance, even those located in the western areas, far from the pier and boardwalks (Fig. 11). After the interventions, these disturbances appear to diminish and become more localized (Fig. 10), although the shorter post-intervention monitoring period may limit the robustness of this observation. The relatively low levels of human disturbance, particularly during critical periods of gull reproduction, likely result in minimal impacts on the colonies under current conditions. Additionally, the continued presence of gulls near the boardwalk indicates a certain level of tolerance by gulls to human activity. However, if disturbance levels were to increase, especially during the mid-season, which coincides with the critical egg-laying and incubation periods, there is a heightened risk of nest abandonment (Carney & Sydeman, 1999). Such disturbances could significantly affect reproductive success and compromise the long-term stability of the colonies.

During the project period, breeding Little Terns on Barreta Island has been sporadic, with shifting nesting areas (Fig. 12). As these birds nest on the primary dunes along the beach and frequently shift nesting locations, the positioning of our monitoring cameras was not suitable for assessing the impact of disturbance on this species. However, nesting attempts near populated beach areas have shown lower chances of reproductive success, primarily due to increased predation by cats (Pereira et al., 2022). Awareness signs and protective fencing installed on neighboring islands have proven effective in reducing clutch predation, contributing to improved breeding success at Praia de Faro, Culatra, and Armona Islands (Pereira et al., 2022).

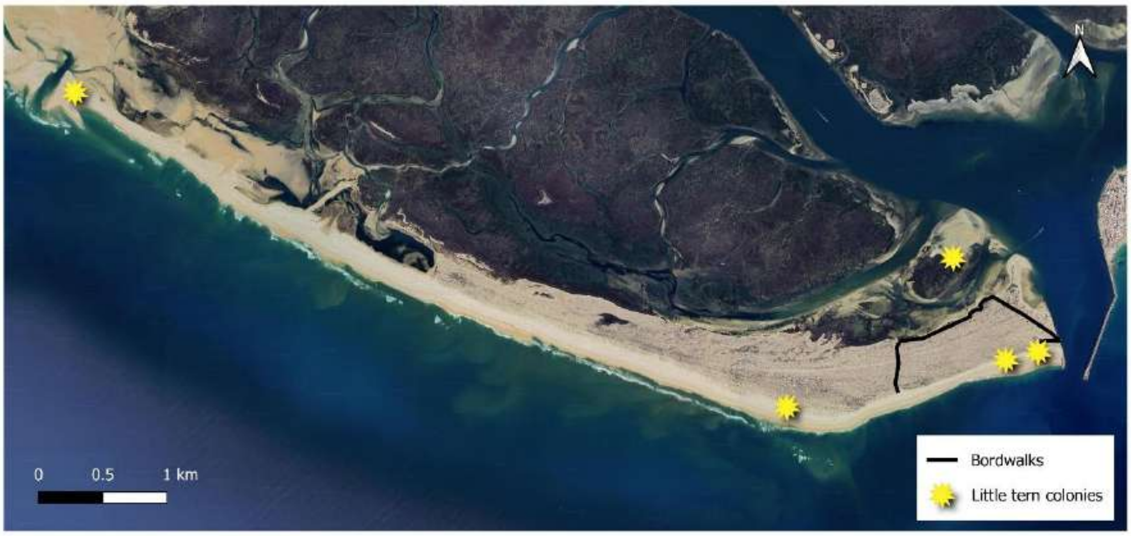

Figure 12| Locations of Little terns breeding areas in Barreta island in the last years.

Even if human disturbance to gull colonies is currently not severe, there is considerable pressure on the priority habitat of grey dunes, which is protected under the EU Habitats Directive. The trampling caused by people crossing dunes, leads to habitat degradation, soil erosion, and the destruction of specialized flora adapted to these fragile environments (Santoro et al. 2012). Many of these plant species are highly specialized and play a crucial role in stabilizing the dunes and maintaining biodiversity. Without adequate protection and enforcement, ongoing disturbance could jeopardize the ecological integrity of this priority habitat, undermining conservation efforts for both flora and fauna dependent on it.

4 | Conclusions

Localized human activity post-intervention:

Overall Relative Abundance Index (RAI) of human presence decreased post-intervention, the variability in human activity increased, with localized hotspots of intense disturbance. A key outcome of the intervention was the concentration of human activity near the boardwalk, with a significant decrease in non-boardwalk areas. This suggests that while the intervention influenced movement patterns, it did not uniformly reduce human presence across the island.

Seasonal Variability:

Although human activity was highest during the peak tourist season (June–September), seasonal differences were not statistically significant. However, seasonal patterns varied: during the low season, activity was more concentrated around the western lagoon linked to the use by local fishermen and shelfish harvesters. Whereas in the high season, it was primarily focused near the beach and boardwalk, and most related with tourists.

Access and infrastructure challenges:

The modification of the boardwalk appears to have contributed to increased human activity in certain areas. The lack of proper boardwalk access to the northeast bay, combined with visitor disregard for awareness signs, can leed to the higher use of informal paths further disturbing sensitive habitats. Expanding or adjusting the boardwalk to provide direct access to the northeast bay could help mitigate this issue by reducing the need for visitors to cross fragile dune ecosystems.

Non-touristic disturbance:

Human presence across the island, across seasons and in remote western areas, shows that disturbance is not solely driven by tourists. Local residents, fishermen, and small boat users also contribute to habitat disruption. Strengthening patrolling and surveillance, particularly in remote areas, could help deter unauthorized access and encourage compliance. Furthermore, targeted educational campaigns for local residents could raise awareness about the ecological significance of dune habitats and promote responsible behavior to minimize human impact.

Impact on gull colonies:

All gull colonies on the island experienced some level of disturbance, including those in remote areas far from the pier. post-intervention observations suggest a diminished but more localized impact. Given the gulls' apparent tolerance to human presence, current disturbance levels may not yet be critically affecting their reproductive success. However, any increase in human activity, particularly during egg-laying and incubation, could lead to nest abandonment and long-term colony instability.

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Annex

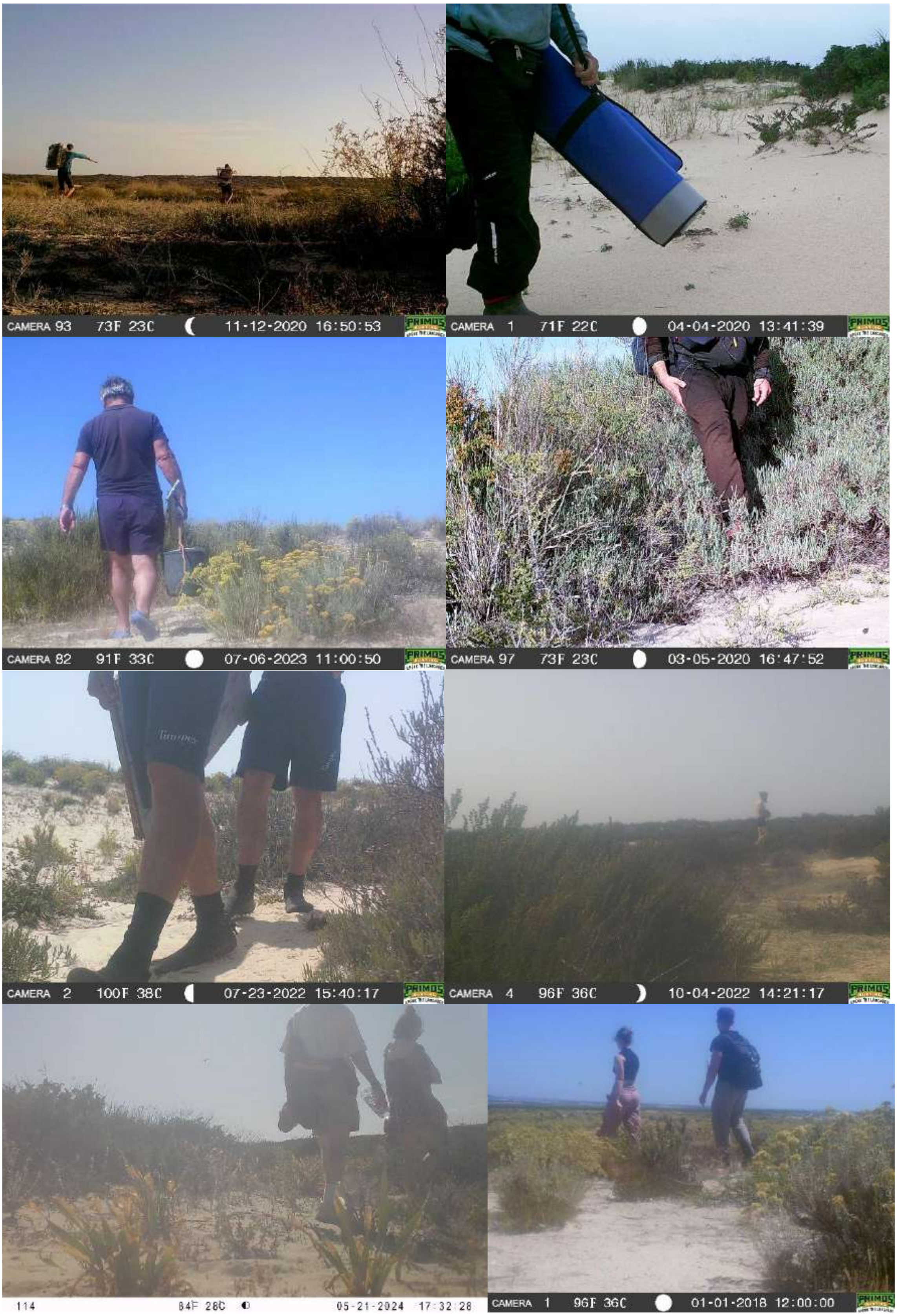
Annex A

Tabela I - Relative Abundance Index (RAI) of humans, represented by the number of human photos per 100 camera-days, categorized by month within each tourist season (low, mid, high) and the period of implementation of measures (Pre: pre-implementation; pos: Post-implementation), using camera traps on Barreta Island.

Year	Month	Period	Season	RAI
2020	January	*Pre*	Low	2.55
2020	February	*Pre*	Low	0.84
2020	May	*Pre*	Mid	0.00
2020	June	*Pre*	High	1.28
2020	July	*Pre*	High	6.43
2020	September	*Pre*	High	2.71
2020	October	*Pre*	Mid	2.28
2020	November	*Pre*	Low	1.96
2020	December	*Pre*	Low	0.85
2021	January	*Pre*	Low	0.94
2021	February	*Pre*	Low	0.26
2021	March	*Pre*	Mid	0.30
2021	April	*Pre*	Mid	1.12
2021	May	*Pre*	Mid	0.93
2021	June	*Pre*	High	2.30
2021	July	*Pre*	High	1.08
2021	August	*Pre*	High	1.79
2021	September	*Pre*	Mid	2.32
2021	October	*Pre*	Mid	0.45
2021	November	*Pre*	Low	0.78
2021	December	*Pre*	Low	0.00
2022	January	*Pre*	Low	0.61
2022	February	*Pre*	Low	0.59
2022	March	*Pre*	Mid	1.23
2022	April	*Pre*	Mid	3.41
2022	May	*Pre*	Mid	3.16
2022	June	*Pre*	High	2.12
2022	July	*Pre*	High	3.64
2022	August	*Pre*	High	3.65
2022	September	*Pre*	High	1.82
2022	October	*Pre*	Mid	1.15
2022	November	*Pre*	Low	1.63
2022	December	*Pre*	Low	3.31
2023	January	*Pre*	Low	2.00

	February			6.67
	March		Mid	1.68
	April	*Pos*		2.71
	May			1.49
	June		High	6.02
	July			11.05
	August			15.74
	October		Mid	14.14
	December		Low	5.95
2024	February			2.97
	April		Mid	4.60
	May			2.74
	June		High	3.03

Annex B – Examples of pictures of humans, taken by camera traps on Barreta island.


CAMERA 93 73F 23C 11-12-2020 16:50:53
PRIMOS
CAMERA 1 71F 22C 04-04-2020 13:41:39
PRIMOS
CAMERA 82 91F 33C 07-06-2023 11:00:50
PRIMOS
CAMERA 97 73F 23C 03-05-2020 16:47:52
PRIMOS
CAMERA 2 100F 38C 07-23-2022 15:40:17
PRIMOS
CAMERA 4 96F 36C 10-04-2022 14:21:17
PRIMOS
114 84F 28C 05-21-2024 17:32:28
CAMERA 1 96F 36C 01-01-2018 12:00:00
PRIMOS