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A photographic approach to monitor spatial dynamics and population trends of Arctic Tern colonies in two touristic bird watching spots in the Westfjords, Iceland.

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Abstract

This study examines the population dynamics and spatial distribution of Arctic Terns in two tourist sites in Iceland's Westfjords: Vigur Island and Súðavík. In 2023, counts revealed 458 terns in Súðavík and 991 in Vigur. We propose a monitoring approach using photography to estimate the population, including non-breeders. Additionally, an interspecies interaction was observed in Vigur, where terns appear to be relocating towards the puffin colony. This behaviour is hypothesised to serve as a defence mechanism against predators, utilising the puffins' frequent, low-altitude flights, as a protective ceiling.

Keywords: Arctic Tern, *Sterna paradisaea*, Iceland, population, ornithology, Atlantic puffin, *Fratercula arctica*

INTRODUCTION

Located just South of the Arctic circle, Vigur Island (geographical coordinates, WGS 84, -22.828 °E 66.055 °N) is a famous Icelandic touristic place in the Westfjords, known for being home to several iconic bird species, such as the Atlantic Puffin

Fratercula arctica, the Black Guillemot *Cepphus grylle*, or the Common Eider *Somateria mollissima*. Amid economic shifts and a declining population, the Westfjords region of Iceland has experienced a downturn in its fishing industry. To counter this, local authorities have promoted tourism and encouraged local entrepreneurship (Vannini 2023). Iceland's blooming tourist industry brings a surge of visitors to regions such as the Westfjords, renowned for their natural beauty and opportunities for wildlife observation, including bird watching. This increase in human presence, while beneficial for the economy, poses significant risks to the delicate balance of local ecosystems (Maher et al. 2022). The impact of tourism is not isolated; it is part of a complex web of global environmental challenges. Human activities, along with global challenges like climate change (Daunt & Mitchell 2013, Paleczny et al. 2015, Bannan et al. 2022) have significantly impacted seabird populations (Croxall et al. 2012). The repercussions of unchecked human activities are many, leading to the degradation of vital habitats and disrupting the breeding cycles of various species, as evidenced by reduced incubation periods (Croxall et al. 2012, Dias et al. 2019). Specifically, the Arctic Tern *Sterna paradisaea* has been adversely affected. Factors such as reduced prey availability significantly impact the breeding success of colonies in a single season (Vigfúsdóttir et al. 2013, Häkkinen et al. 2023). Every year from May to early September, Iceland welcomes 20 to 30% of the world's breeding population of Arctic Tern (Asbirk et al. 1997), and a notable decline in the Westfjords has already been documented (Petersen et al. 2020). While Arctic Terns are not globally threatened, earning a 'Least Concern' status on the IUCN Red List (BirdLife International 2018), their situation in Iceland is more precarious, classified as 'Vulnerable' on a national level (Náttúrufræðistofnun Íslands 2018, Skarphéðinsson 2018). Consequently, any additional stress, such as tourism, would worsen their population's condition. Human presence is frequently perceived by birds as a predatory threat (Beale & Monaghan 2004a). In Iceland, the collection of eggs is for example permitted until the 15th June (Act No. 64/1994 on the protection, conservation, and hunting of birds and wild mammals).

Although Iceland hosts a substantial population of Arctic Terns and is a critical breeding ground for the species, research focused on understanding these birds in the country remains limited. Arctic Tern populations decline underscores the urgent need for comprehensive studies that can inform effective management, leading to robust conservation strategies. By deepening our understanding of their ecology and the specific challenges they face, research can equip both scientists and local communities with the insights necessary to make informed and effective decisions for the preservation of this species. A first step would be to implement reliable and accurate monitoring methods tailored to the Icelandic context, enabling long-term assessments of the trends in

the targeted populations. This is particularly important in areas where tourism is actively promoted and encouraged.

In the Westfjords, Arctic Terns exhibit flexibility in their nesting choices, often selecting urban areas. Notably, they nest near a supermarket and gas station in Ísafjörður, and close to the town's industrial zone. Similarly, in the village of Suðureyri, part of the same municipality, a smaller colony is found near a playground. These nesting sites are subject to disturbances from non-touristic activities. Conversely, two renowned bird watching spots in the Westfjords, Vigur Island and the Langeyri peninsula in Súðavík (geographical coordinates, WGS 84, -22.991 °E 66.027 °N), are specifically promoted for their bird populations. They provide different levels of protection and various attractions, some related to birds and others not.

Consistent monitoring of these tern colonies is consequently crucial for assessing and improving the effectiveness of their conservation measures. This approach aligns with the Icelandic Tourist Board (Ferðamálastofa) 2030 policy framework, advocating research-based decision-making in tourism management, including wildlife observation (Ferðamálastofa 2020). Hence, this study details and discusses recent monitoring of the Arctic Tern populations in Vigur Island and Súðavík and emphasises a counting method using photography and GPS data collection for future monitoring of the same populations, with the aim to characterise the spatial and quantitative evolution of Arctic Tern populations.

MATERIALS & METHODS

Study area

This study was carried out in the Westfjord region of Iceland, in two sites, Vigur Island and the Langeyri peninsula in Súðavík (Fig. 1).

The first site, Vigur Island, is a privately owned location renowned as an eiderdown farm and a premier bird watching destination. Every year, the island also welcomes, among others, breeding Atlantic

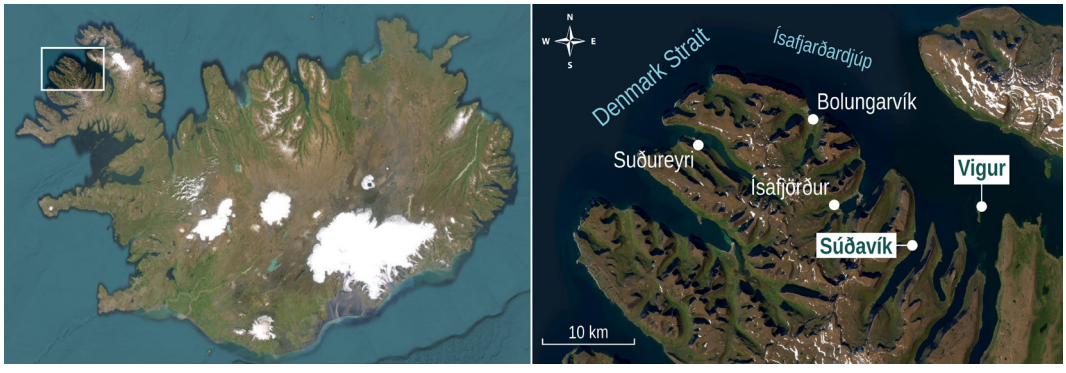

Figure 1. Location of the two investigated sites in Vigur Island and Súðavík, Westfjords, Iceland.

Puffins, Black Guillemots and Arctic Terns. Although primarily tailored for cruise ship tourism, the access to the island is carefully controlled. However, it is important to mention that guided tours in Vigur include visits through the Arctic Tern nesting areas. These tours, which also educate visitors on eiderdown farming and the island's history, invariably traverse the tern colony, following various routes of differing lengths across the nesting grounds (Milesi-Gaches & Lhériau 2022).

The second site, Langeyri, is a peninsula in Súðavík which mostly remains natural. Alongside a few amenities like storage, and the local rescue team facilities, it's the birds that truly define Langeyri. Encircling a central pond, the area supports breeding colonies of Black-headed Gulls *Chroicocephalus ridibundus*, Common Eiders, and Arctic Terns, together with waders, passerines, and waterbirds such as Mallards *Anas platyrhynchos*, Greylag Goose *Anser anser*, or Red-breasted Mergansers *Mergus serrator* (Milesi-Gaches 2024). While tourism here is not as prominent as in Vigur and access isn't as tightly controlled, the peninsula is private property with open access. Notably, to protect the birdlife, the owner closes off a section from April 10th to July 7th annually, by putting up a sign, close to a dirt road which crosses the nesting ground. Another activity in the peninsula includes gathering of blueberries and crowberries towards the end of summer.

Vigur Island enjoys heightened visibility through its dedicated website, active presence on major social media platforms, and frequent features in tourism-related press and cruise ship company programs. In contrast, Langeyri in Súðavík, while not hidden, is primarily promoted through local channels, including leaflets and maps. Nonetheless, both sites are recognised as bird watching hotspots on ebird.org (eBird 2023).

Counting by photography

The counts of tern colonies were carried out using photography. Particularly, one observer took photographs from a distance of the flying birds, while another person was walking through the colony, thus fostering birds to take off. In 2023, terns in Súðavík and Vigur Island were counted on the 20th and 22nd of June, respectively, during the incubation period. Before the counts, 10 minutes of casual observations were conducted up to three days prior to the actual counting, in order to gather preliminary insights into the distribution of terns, finalise the walking route, and identify suitable locations for photographing the birds. On Vigur Island, it became evident that the colony was divided into four distinct sections, shaped by both natural and anthropogenic features (e.g., paths, hills), as noted by the owners and observed during our visit to the island. Before counting terns in each perceived section, we waited for the birds to return to their nests to avoid counting birds from another section. When disturbed by a person, most birds, both breeders and non-breeders, take flight. We therefore opted for a photographic method,

as it captures the entire range of colony members, including non-breeders, unlike a nest count, which reflects only the number of breeding pairs. Despite the possibility of some birds being absent from the photographs or not identifiable, photography remains the most suitable methodology for studying rapidly moving flocks, such as those observed in Arctic Terns (Sutherland et al. 2004).

Photographs were obtained with a Canon EOS 60D camera equipped with a MC Granit-11 4.5/80-200 zoom lens. The series of photos was aggregated with the software Inkscape 1.3 (Inkscape Project 2023) to reconstitute the person's path through the colony (Fig. 2). Developed as a graphic design software, Inkscapes provides several features, including counting all shapes in the current document, through the key combination CTRL+A. Available in many languages and working on all major operating systems, Inkscape is a free, reliable and open-source desktop application, usable for long-term monitoring of bird populations. In an empty document, the aggregated photograph was imported, and the layer in which it was located was then locked, to later allow Inkscape to only count shapes drawn on terns, and not the background image (Fig. 2). Before proceeding with data analysis, adjustments were made to the photographs to enhance bird detectability, including modifying luminosity, contrast, and sharpness. Additionally, the person walking through the colony as part of the counting process was removed from the images to ensure privacy. No further alterations were made to the photographs.

We anticipated challenges such as poorly identifiable objects in the photographs and the presence of other bird species or individuals that were difficult to distinguish. Similarly, we expected reduced visibility of birds due to lighting conditions or landscape features in some photographs. To ensure accuracy, only terns that could be confidently identified, either by their distinctive appearance or characteristic shape, were included in the count. The discussion section further explores the full range of how terns appeared in our photographic data.

Due to the distribution of terns on Vigur Island, the colony was sectioned into four distinct areas, primarily based on topography. Several attempts were made to define the boundaries of each section, where bird identification from photographs proved challenging. Before initiating data collection for the counts, we ensured there were no overlaps between sections and that movement through one section would not disturb terns in adjacent areas. Details of the four delineated sections are provided in the results section. The same counting methodology was consistently applied across all sections. Upon completion of the analysis, the bird counts were conducted using the software, facilitated by the key combination CTRL+A.

Evolution of tern populations

Available counts were compiled from existing literature and unpublished data

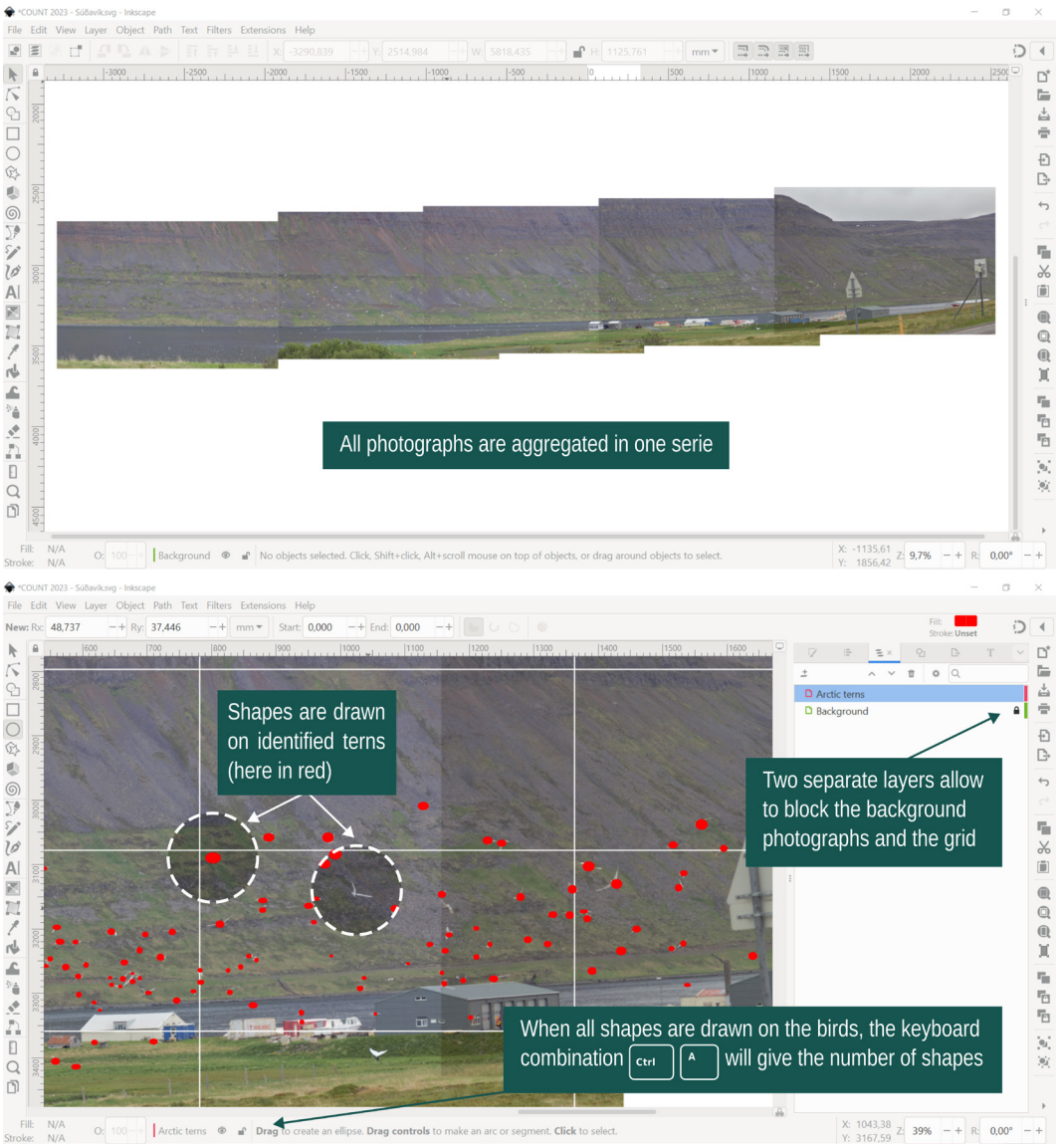

Figure 2. Screenshots of the counting method, for Langeyri in Súðavík, with Inkscape 1.3 (Inkscape Project 2023). Terns are indicated by red dots.

(courtesy of Pr Ævar Petersen). Due to the use of diverse counting methods, which varied from direct nest counts to flock estimations, the population trends of terns in Vigur and Súðavík were characterised in various ways in the results section.

Monitoring of Arctic Tern colony areas

From 2021 to 2023, the shape of the colony area has been monitored during the incubation period in June. We collected GPS coordinates of the nests located at the edge of the Vigur's colony. The shape of the tern colony in Súðavík is only known for 2023 (June). To determine the boundaries of the colony, one author identified the approximate limits based on observations. Then, they systematically walked around the colony, scanning the area to identify the outermost nests. By traversing slightly beyond what appeared to be the colony's edge, they ensured that no nests were overlooked. GPS coordinates of each nest located at the periphery were recorded using the mobile application GPS Point (Grečnár 2023). Recording was halted once a precision of 5m was achieved, or after 20 seconds, to prevent extended disturbances. GPS points were plotted and connected with Inkscape. The area of the Arctic Tern colony was estimated using the online tool SketchAndCalc® (SketchAndCalc 2023).

RESULTS

Data were collected through a series of photographs representing one section in Súðavík and four sections in Vigur, as illustrated in Fig. 3. Wherever possible, the person navigating the colony adhered to

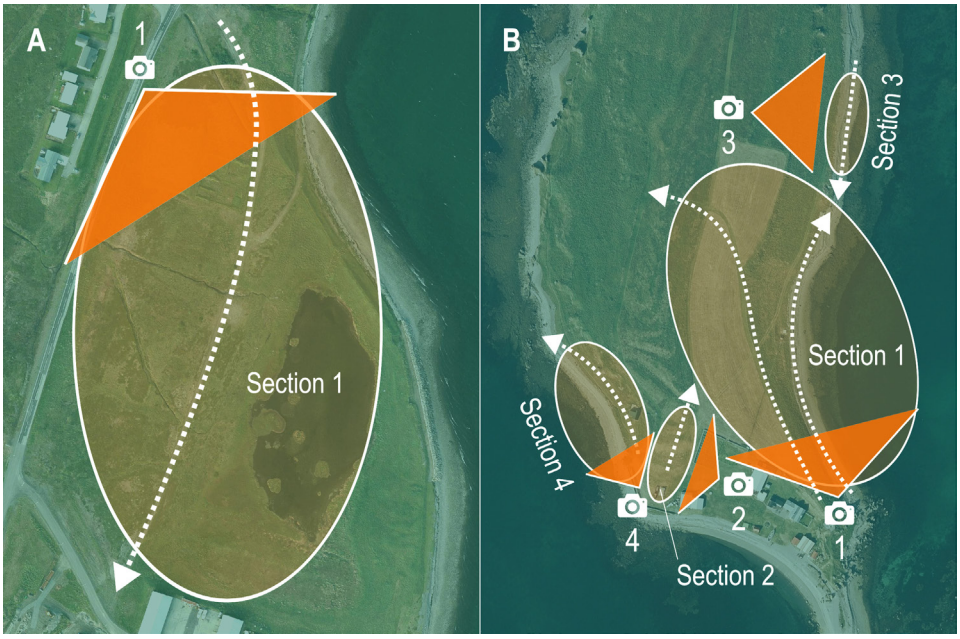

Figure 3. Schematic representation of the Arctic Tern colony photographed sections, with the trajectory taken by the person triggering birds to take off. (A) in Langeyri, Súðavík; (B) in Vigur Island (basemap: Loftmyndir ehf).

existing paths. In Vigur, two people walked through section 1, with one person walking alongside the coastline. To minimise disturbances, photographs were consistently taken from outside the colony boundaries.

Total population counts

In 2023, a total of 458 Arctic Terns were counted in Súðavík. While a relatively important number of non-breeding terns were present on the nearby beach that is part of the colony area (Fig. 3), they all took off during the census. Vigur hosted 991 terns. The counts, based on photographs of the entire flocks of birds taking off during the census, include both breeding and non-breeding individuals. Details of the aggregated photographs used to count birds with the software Inkscape are provided in Fig. 4. In each photographic capture, certain avian species were discernible, yet definitive identification as either terns or another species remained inconclusive. Additionally, several unidentified objects within these images presented the potential to be Arctic Terns. The documentation and analysis of these data are crucial in delineating the boundaries and limitations inherent in our counting methodologies (Tab. 1).

When incorporating the unidentifiable birds and objects as Arctic Terns into the population estimates, the counts for Vigur Island and Súðavík are revised to 1044 and 461 terns, respectively. This adjustment reflects an increase of 5% for Vigur Island and 1% for Súðavík in the estimated tern populations (Tab. 1).

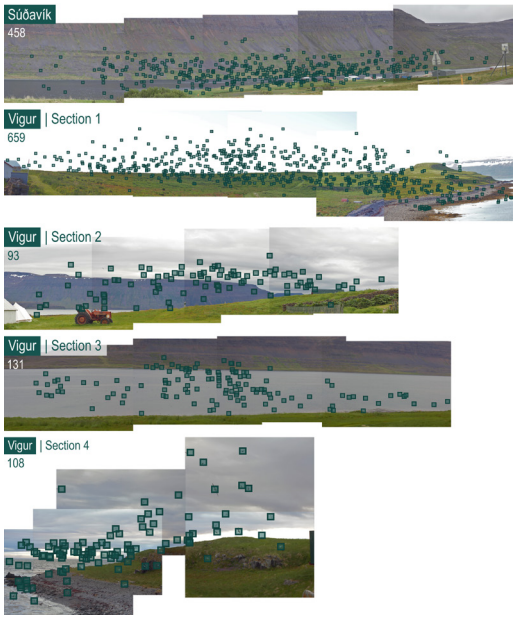

Figure 4. Aggregated photographs and associated counts for Súðavík and Vigur Island in 2023.

In the literature, only counts from the regional research institute, Náttúrustofa Vestfjarða, were found for Súðavík (Gallo et al. 2021, Gallo & Sigurðardóttir 2022). Other counts come from unpublished work made available by courtesy by Pr Ævar Petersen (Tab. 2). The total of 6 counts includes one nest count, four estimations and one count by photography. The censuses cover a 36 year period with an uneven distribution. Examining the development of the colony in Súðavík is evident: the tern population has been increasing (Spearman rank-correlation test, $\rho = 0.9$, $P = 0.03$), as shown in Fig. 5 (A) despite the use of different counting methods, including estimations, nest counts, and photography.

Table 1. Estimation of the theoretical maximum number of Arctic Terns in Vigur Island and Súðavík, by adding not identified birds and objects

Location		Unidentified Birds (UB)	Unidentified Objects (UO)	UB+UO / Total (%)	Total (theoretical maximum)
Vigur	Section 1	12	21	5%	659(692)
	Section 2	2	2	4%	93(97)
	Section 3	11	0	8%	131(142)
	Section 4	5	0	5%	108(113)
Vigur	**TOTAL**	**30**	**23**	**5%**	**991(1044)**
Súðavík	**TOTAL**	**3**	**0**	**1%**	**458(461)**

Table 2. Arctic Tern population census (number of individuals) in Súðavík and Vigur Island, including the 2023 counts

Year	Count	Method	Details	Reference
Súðavík				
1987	28	Nest count	14 pairs	Brynjúlfur Brynjólfsson (unpublished)
1991	150	Estimation	Total bird number	Kristinn H. Skarphéðinsson (unpublished)
2003	100	Estimation	Total bird number	Böðvar Þórisson (unpublished)
2020	270	Estimation	135 pairs	Gallo and Sigurðardóttir (2022)
2021	400	Estimation	Total bird number	Gallo et al. (2021)
2023	458	Photography	Total bird number	This study
Vigur Island				
2021	880	Transect line, nest count	440 nests. 60% of the colony covered	Milesi-Gaches and Lhériau, 2022
2021	1499 ±39	Transect line, nest count, estimation	440 nests. 60% of the colony covered + estimation for the last 40%	Milesi-Gaches and Lhériau, 2022
2023	991	Photography	100% of the colony covered	Fieldwork
2023	883	Photography	60% of the colony equivalent to 2021	Calculation based on 2023 fieldwork

Prior to 2023, data on tern numbers in Vigur were limited. The 2021 count recorded 440 nests, equating to 880 adult birds, but this only covered 60% of the colony. The whole breeding population was estimated in 1499 ± 39 breeding pairs (min: 1460, max: 1538; Milesi-Gaches & Lhériau 2022). However, this number may be imprecise due to the uneven distribution of the colonies, particularly as the densest areas were included in the 60% surveyed in 2021. Furthermore, the count only included breeding adults (Milesi-Gaches & Lhériau 2022). To analyse population changes between 2021 and 2023, we compared 60% of the 2023 count, excluding section 4 (Fig. 3), to the 2021 count. The most detailed count available is the incomplete 2021 nest census, which covered only 60% of the colony due to adverse weather conditions and hatching eggs (Milesi-Gaches & Lhériau 2022). However, the 2023 count enables a correction to make it more comparable with the 2021 census. The section 4 of the area covered in the 2023 count corresponds approximately to the missing part of the 2021 census. Therefore, the most accurate method to assess population changes is through a relative comparison between the 2021 and 2023 data for equivalent colony portions. Excluding section 4, the 2023 count recorded a total of 883 birds (Tab. 2). This suggests that the Arctic Tern population has remained stable over the 2021–2023 period. However, when considering the

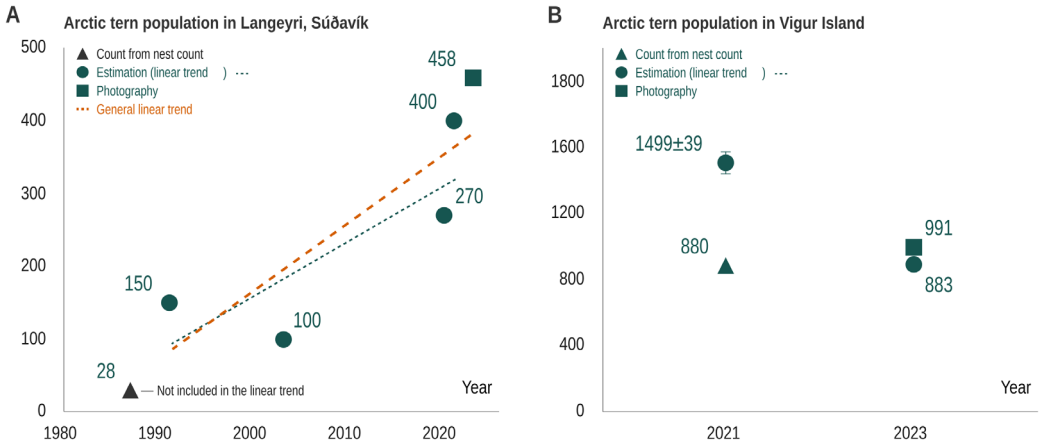

Figure 5. (A) Evolution of the Arctic Tern colony in Langeyri, Súðavík. The nest count performed in 1987 is excluded from the linear trend as it only accounted for breeding terns, while estimates and photo-based counts included all present birds. (B) Evolution of the Arctic Tern colony in Vigur Island. In 2021, the points represent both the count for 60% of the colony and the extrapolated estimate for the entire colony. In 2023, the points represent the total photographic count and an estimation based on 60% of the colony to allow comparison with 2021.

statistical estimation—despite inherent biases in the calculations—a noticeable decline in the Arctic Tern population on Vigur Island is indicated.

Nests distribution

In Súðavík, the colony occupied a surface of 34 727 m² which represents around 31% of the peninsula's natural surface. Arctic Terns were mainly sharing this space with Black-headed Gulls, Common Redshanks *Tringa totanus* and Common Snipes *Gallinago gallinago*. The tern colony is distributed between the main road and the pond, on its western side, and in the southern part of the peninsula, similarly between the pond and the buildings. Common Eiders are mostly nesting on the eastern side of the pond with few overlap with terns. However, Arctic Terns are using a wider area, including all the shoreline, notably those who are not breeding.

Although few counts were available for Vigur Island, more extensive data exists on the spatial distribution of terns. As an alternative or complement to invasive nest censuses, monitoring colony shape by recording the GPS coordinates of nests at the colony's edge has been proposed (Milesi-Gaches & Lhériau 2022). From 2021 to 2023, terns used in Vigur the same areas for both pre and post nesting times. The colony remains located close to buildings, in the southern part of the island (Fig. 6). In 2023, more nests were found at the edge of the perceived colony territory, leading to a more chopped shape. A pair of terns were also observed establishing its territory remotely in the

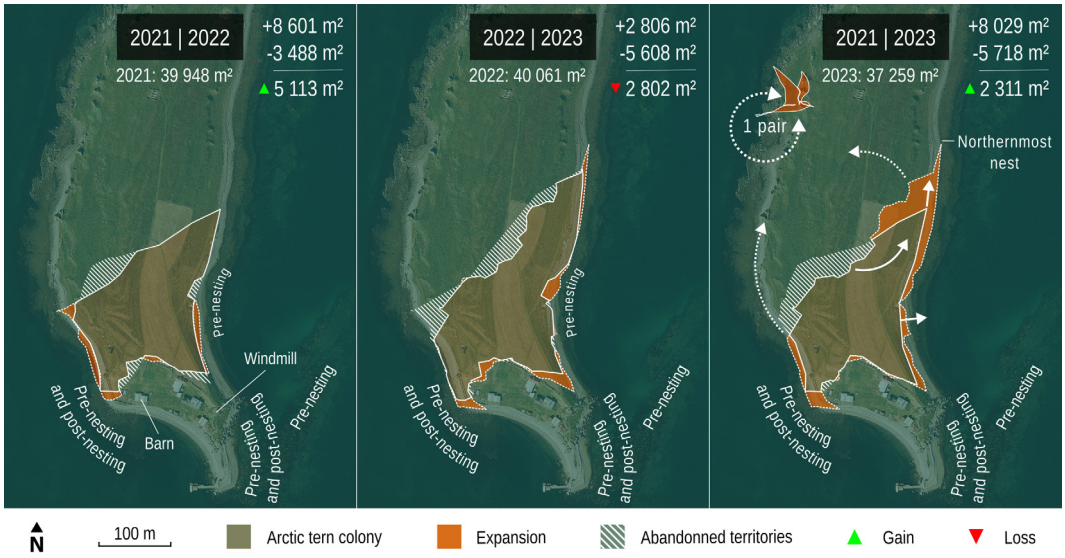

Figure 6. Evolution of the Arctic Tern colony in Vigur Island from 2021 to 2023 (basemap: Loftmyndir ehf).

western side of the island, close to an area dominated by Atlantic Puffins and Black Guillemots. No nest was located but terns displayed a defensive behaviour towards humans and were seen harassing black guillemots to steal their prey.

When comparing the territory between consecutive breeding seasons or over the 2021–2023 period, we can observe that terns abandoned the field area located in the middle of the island. The evolution of the territory shows clearly four trends. Terns are moving northwards and southwards alongside the eastern coast. As well, terns are solidifying their settlement on this coastline, with a more consistent distribution. Terns are also coming closer to buildings in the South west of the island, nesting around storage facilities (Fig. 6). Since 2021, the colony area shows a net gain of 2 311 m^2 (Fig. 6), with successive gains of 5 113 m^2 between 2021–2022 followed by a loss of 2 802 m^2 in 2022–2023. The northernmost Arctic Tern nest, observed for approximately 4 hours as part of a separate study, offers insights into the colony's northward shift since 2021. Adjacent to this nest is a puffin-inhabited territory with small cliffs where puffins also nest. The constant flow of puffins flying at low altitudes, often up to 10 metres (Fig. 7), acts as a protective barrier, shielding the area below from potential threats and hindering predators' access to eggs. Notably, in 2023, while seagull predation was high in Vigur, no predators were seen attempting to breach this, puffin highway' despite flying over the area, displaying no sign of interest.

DISCUSSION

Arctic Terns often display aggressive behaviour and do not hesitate to harass humans walking nearby their territory (Syrová et al. 2020). Thus making them likely to be the most interactive species of the bird spots where they are present. In the Westfjords, Vigur Island and the Langeyri peninsula in Súðavík constitute, to varying degrees, the most important bird watching sites in the north of the region (eBird 2023). With the recent surge in tourism in Iceland, particularly in the Westfjords, it is imperative to monitor bird populations and assess any human-induced impacts. The selection of effective monitoring tools is crucial for stakeholders and policy-makers to make informed decisions. Monitoring techniques of Arctic Tern populations in Vigur Island and Súðavík exhibit distinct characteristics. While few counts exist for Vigur, the area used by terns is well known and documented since 2021. In Súðavík, the situation is the exact opposite. While the tern colony area was only measured in 2023, more counts are available and were done with techniques which encourage comparative analysis. For colonial seabirds that breed in pairs, maintaining consistent monitoring methods is essential. Tern colonies, often unevenly distributed with several high-density areas, pose challenges for proportional estimates, as sampling a section of the colony can lead to misleading results (Heinänen et al. 2008). Comparing the 2021 Vigur census with 60% of the photographic count from 2023 provides insights into population trends but highlights

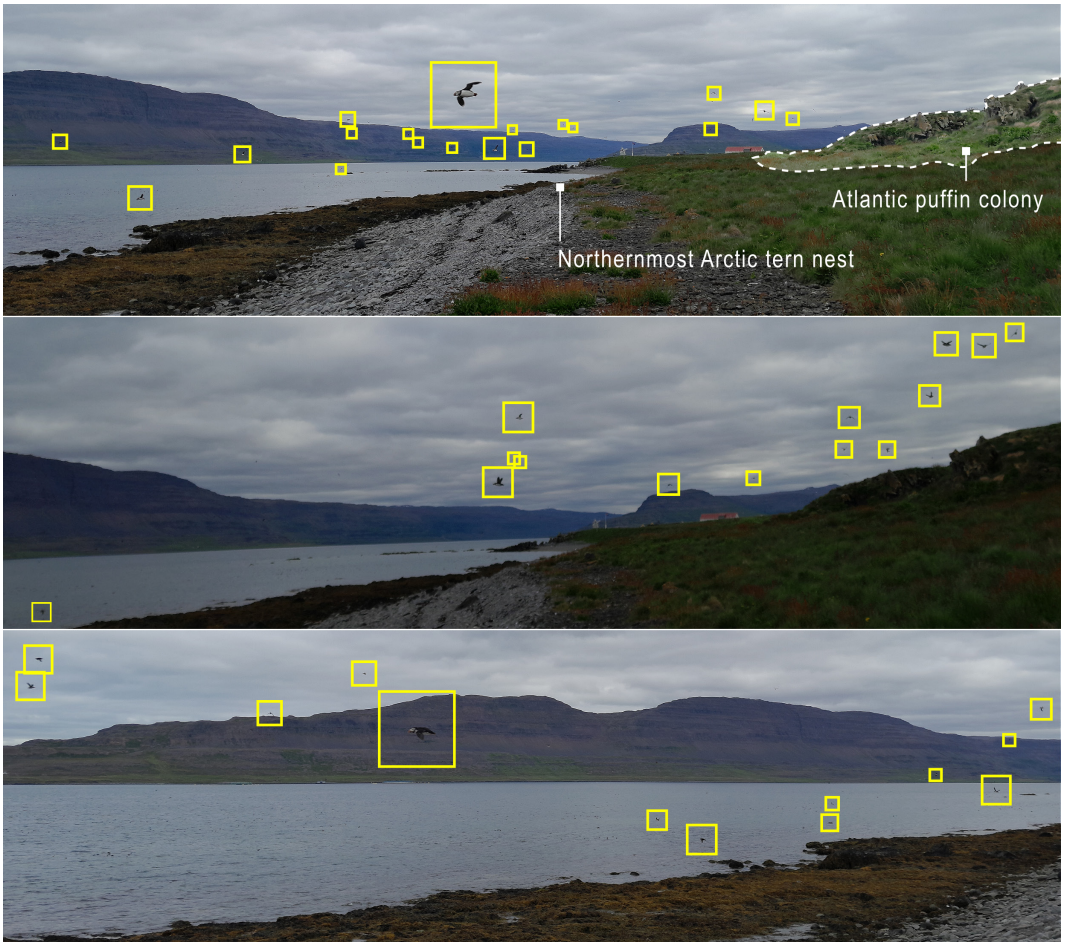

Figure 7. Series of photographs showing Atlantic Puffins flying over the northernmost Arctic Tern nests, in Vigur Island. The three photographs were shot on the 6th of July 2023, at 6:04pm.

the differences in the segments of the population these methods monitor. Nest counting, while invasive and time-consuming, provides limited reliability as it focuses exclusively on nesting pairs, capturing only breeding adults and neglecting non-breeding individuals and other demographic groups (e.g. non-breeders, inter-colony movers, etc.). In contrast, photographic surveys mitigate some of these issues by reducing operator fatigue, enabling recounting if needed, and accounting for a broader range of individuals (Milesi-Gaches & Lhériau 2022). However, challenges persist with this method, particularly in accurately identifying birds in photographs. Factors such as poor visibility or similarity in appearance to other species can hinder identification. This underscores the need for more comprehensive, less intrusive

monitoring techniques to accurately assess the entire bird population.

In the case of Vigur and Langeyri, other species were easy to identify, with the exception of distant birds in Súðavík, with Black-headed Gulls sometimes impossible to distinguish from Arctic Terns (Fig. 8). Occasionally, determining the presence of a bird in the photographs can be challenging, as the subject captured may potentially be a plant or debris, rather than a bird (Fig. 8, D). Even with adjustments made for unidentified birds and objects, these corrections are unlikely to markedly alter the estimated population size of the Arctic Terns. Notably, Section 1 in Vigur exhibited the highest number of unidentified objects (33), a detail that may be attributed to the varying weather conditions, specifically bright and cloudy skies, documented during the fieldwork. Additionally, the geographical nature of Vigur as an island provides expansive landscapes with distant horizons, which is evident in Fig. 4, potentially influencing the visibility and identification of subjects in the photographs.

Hence, we strongly endorse the enhancement of the existing photographic methodology by integrating direct observational techniques. This approach becomes particularly pertinent in areas like Súðavík, where the cohabitation of Arctic Terns and Black-headed Gulls can complicate species differentiation. In Langeyri, for instance, Black-headed Gulls are observed perching on an islet within the pond, a location not contested by Arctic Terns. Within our photographic dataset, the birds in these images are not easily distinguishable (as depicted in Fig. 8, B). However, through direct field observations, these birds were definitively identified as Black-headed Gulls. This identification was crucial in preventing inaccurate counting of these birds as part of the Arctic Tern population during the photograph analysis. Nonetheless, the photographic approach remains highly recommended due to its versatility, rapid execution, and straightforward implementation. In the majority of scenarios, Arctic Terns are readily identifiable in photographs, typically exhibiting a limited range of appearances (Fig. 8).

The identification of birds becomes most challenging when they are in the process of taking off or landing, as well as when they are sitting or incubating, due to the concealment of key characteristics such as wings in flight position (as demonstrated in Fig. 8, A). Despite these difficulties, it is still feasible and straightforward to record the number of unidentified birds, thereby enabling an estimation of the margin of error and quantifying one limitation of the counting process.

Observations play a key role in accurately determining the number of non-breeders, who often remain outside the nesting area in locations like Vigur Island and Súðavík, effectively forming a detached segment of the colony. Therefore, it's vital to structure observations to account for non-breeders, ensuring they are also included in the count. This requires careful consideration, as non-breeders may not take flight when an observer enters the tern territory, if the area used

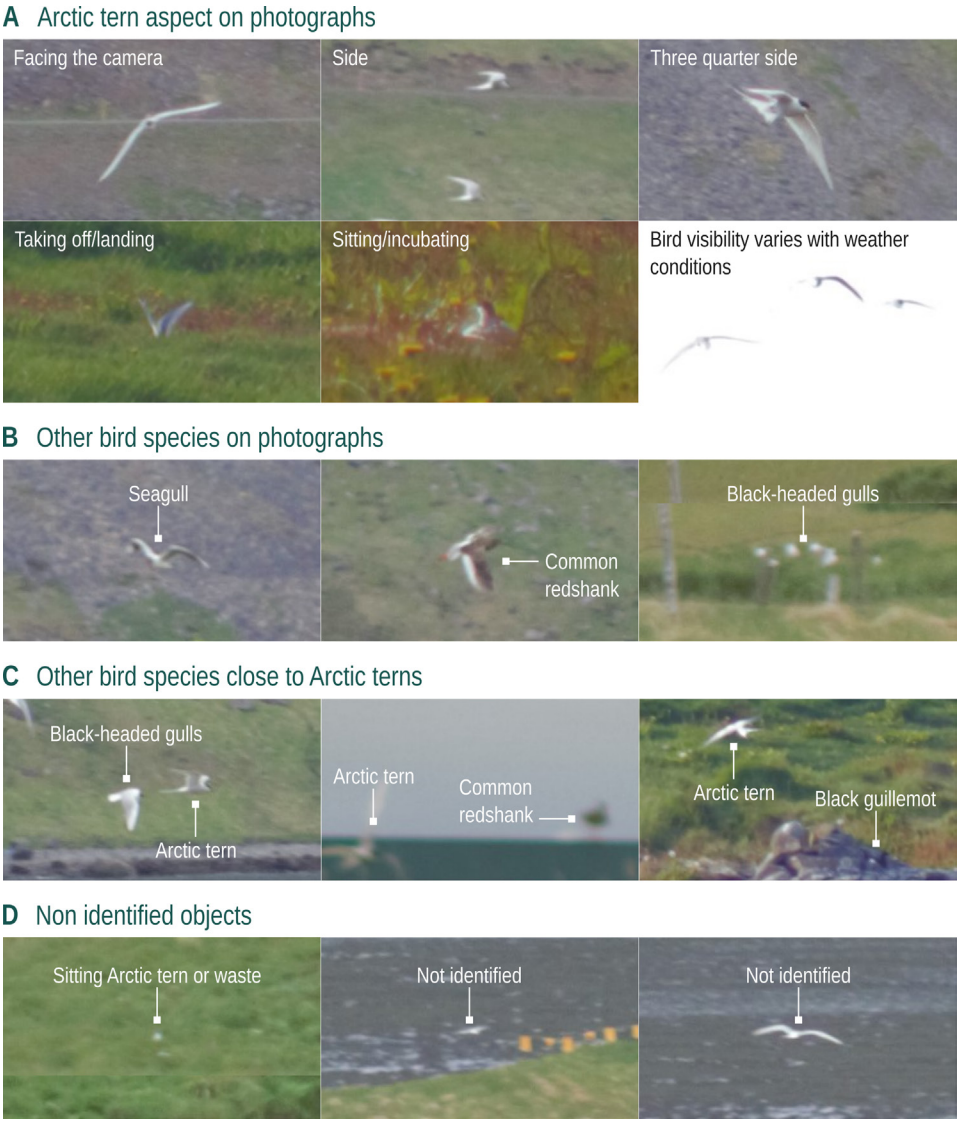

Figure 8. (A) Other species can be easily identified either by colour or wing and body shape. (B) Certain species are easily identified by colour or body and wing shape, while others require closer observation. (C) In proximity to an Arctic Tern, other species become easier to distinguish. (D) Distant and sitting birds are harder to identify due to fewer distinctive features, such as wing shape, and sometimes their position prevents definitive species identification.

by non-breeders is too far from the nesting ground. To capture an accurate census, one strategy could be to count non-breeders separately, based on their

specific locations and activity levels. Conducting a separate count for non-breeders, which is customised to their distinct behaviours and locations, will enhance the overall understanding of the colony's structure and size. However, it's crucial to synchronise this count with the main colony census. Performing these counts on the same day is vital, especially at the onset of the nesting period, when some non-breeders may simply be late in laying their eggs. Delaying even by a few days between counting non-breeders and the main colony can result in double-counting individuals, thereby skewing the data. Accurate synchronisation ensures a more reliable and accurate representation of the entire colony's population. In 2023, the Westfjords witnessed challenging weather conditions that impacted the Arctic Terns post-migration. A significant number of these birds, particularly in Vigur (estimated between 100 to 200, and around 60 in Súðavík), opted out of the nesting season. Given these circumstances, the photographic census method will account for those birds, allowing also to record, if necessary, detailed numbers about breeders and non-breeders. This technique is not only easier to implement but also less intrusive compared to nest counting (Cutler & Swann 1999). Although the photographic method necessitates human presence within the colony, the duration of disturbance is notably shorter compared to a nest count and fits with the commonly accepted presence limit of 20 minutes (Walsh et al. 1995). This brief intrusion is a reasonable trade-off for the more accurate data obtained. The method's ability to capture a broader scope of the population, including non-breeders and inter-colony movers, makes it a more comprehensive approach for monitoring tern populations under the challenging environmental and weather conditions experienced in the Westfjords.

Long-term monitoring is indeed vital for accurately understanding the dynamics of Arctic Tern colonies, such as those in Vigur. If assessments were based solely on data from 2021 and 2022, it might erroneously suggest an expansion of the colony beyond its actual extent. Time is a crucial factor in distinguishing between temporary fluctuations and genuine trends. For instance, the poor weather conditions of 2023 influenced a considerable number of terns to forgo nesting, thereby affecting population observations. The apparent slight increase in the Vigur colony's area in 2023, compared to 2021, must be interpreted with caution. Around 200 non-breeding terns were observed on the pebble beach, out of the nesting ground, indicating a shift rather than a true expansion. Furthermore, the observed activity of non-breeders, including at least one pair exploring new territory on the west coast, suggests that these birds may play a role in either expanding the colony or in movements between colonies. Currently, we can only hypothesise about the factors influencing the tern population's changes. In Vigur, the central higher elevation of the island, more exposed to wind, could be leading to the abandonment of nesting sites there. Additionally, the daily influx of tourists might also impact the

terns. In contrast, the tern population in Súðavík, an area theoretically accessible to all and thus potentially subject to frequent human disturbances, seems to be more significantly impacted by the proximity of a diverse array of other bird species nesting nearby. Other crucial factors likely influencing the population include prey availability, the impact of bird flu during migration, and overall survival rates (Petersen et al. 2020). These elements need to be considered in future studies to gain a comprehensive understanding of the health and dynamics of Arctic Tern populations in these areas.

The tern population in Súðavík appears to be on an upward trend, a hypothesis that needs verification through future population counts and detailed analyses of the colony's area. In Vigur, discerning a clear trend is more challenging due to various influencing factors. From a conservation perspective, it is prudent to treat the Vigur tern population as potentially declining, especially considering the atypical conditions brought about by the Covid-19 pandemic. This cautious approach will support more effective conservation strategies under uncertain environmental and biological influences. Before the pandemic, Vigur Island attracted approximately 10,000 tourists annually from mid-June to the end of September. The pandemic years saw a stark decline in these numbers, with only around 300 visitors in 2020, and then a gradual increase to 5,500 in 2021 and 8,000 in 2022 (Aston & Jónsson 2022). As a result, the tern population experienced reduced human disturbances during 2020–2022. This suggests that the context of our current study may not fully reflect the post-pandemic situation of terns in Vigur, nor in Súðavík, which also experienced reduced tourist activity due to pandemic-related travel restrictions. However, the nature and frequency of tourism-related disturbances are critical factors to consider. In Vigur, intense tourist activity concentrated within a limited timeframe could potentially be more disruptive than the sporadic and unpredictable disturbances at a site like Súðavík, which is accessible around the clock. This difference in the patterns of human presence could have varying implications for the tern populations in these two locations.

Another limit of this study is the lack of historical records about the presence and behaviour of Arctic Terns in the two locations. On the middle of Vigur Island, a small portion of the eastern coast is named Kríuhöll, which could be translated as 'Arctic Tern hill' (National Land Survey of Iceland 2023), suggesting historical nesting or usage by Arctic Terns. To address this gap, it is crucial to initiate and maintain detailed observations.

Finally, observations from 2023 in Vigur hint that Arctic Terns may be nesting near puffins, potentially as a strategy to mitigate predation risks. This behaviour, however, might be specific to areas with low human disturbance. In places with frequent human activity, terns might be frequently disturbed and compelled to cross puffin territories more often, inadvertently heightening their exposure to predators. During our data collection, when approaching their nests, terns, including those from

adjacent nests, were observed to fly away. This action underscores the challenges they face in returning to their nests through areas occupied by flying puffins, often requiring multiple attempts before successfully landing. Such observations underscore the complexity of interactions between different species and the impact of human presence on these dynamics. The colony's shift towards the north of the island or below the windmill, as shown in Fig. 6 and 7, seems to support the idea of terns moving closer to puffins. Moreover, interactions with Black Guillemots, who share part of their diet with terns and are often pursued by terns for food, may be another factor influencing this movement.

We concur with the recommendation to employ straightforward, long-term monitoring techniques for an accurate assessment of Arctic Tern populations in locations like Vigur Island and Súðavík. The utilisation of photographic methods offers a simple yet efficient way to estimate population sizes, capturing both breeding and non-breeding individuals. Complementing this with GPS tracking of the colony locations provides valuable spatial data, fostering the development of explanatory hypotheses and assisting in setting priorities for future research. Furthermore, behavioural observations are a critical component in evaluating the health of tern populations. Traditionally, birds showing minimal reaction to human presence were often interpreted as being unaffected. However, as Beale and Monaghan (2004b) noted, this assumption can lead to erroneous assessments of a population's vulnerability or health. In reality, a heightened responsiveness to humans can be indicative of a population in good health. This nuanced understanding of bird behaviour is crucial for accurate evaluations and effective conservation efforts.

This study emphasizes the need for a broader and more holistic perspective in future research. It is essential to consider not only direct observations but also to evaluate anthropogenic impacts, interspecies interactions, and habitat conditions. While the use of photographic methods and direct observations can be valuable tools for monitoring, it is crucial to ensure that such approaches minimise disturbance to the species studied. Some species, particularly those classified as endangered or vulnerable, like Atlantic puffins and black guillemots, may be highly sensitive to human intrusion, especially during critical periods such as incubation. Careful consideration of species-specific sensitivity and habitat conditions is necessary to avoid harmful impacts, such as nest abandonment. For example, colonies of Audouin's Gull *Ichthyaetus audouinii* in the Mediterranean Basin were reportedly abandoned following human disturbance (Yaylalı et al. 2003). Implementing such precautions will allow for effective data collection while safeguarding the welfare of the species and their habitats, thereby contributing to the development of sound conservation strategies.

Data availability statement

The datasets generated during and/or analyzed during the current study are

available from the corresponding author on a reasonable request.

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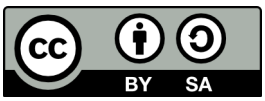

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