NÁTTÚRUSTOFA VESTFJARÐA

Aðalstræti 12
415 Bolungarvík
nave@nave.is

ARCTIC TERN (STERNA PARADISAEA)

Distribution, breeding success, and survey methods of Arctic terns in the Westfjords, 2022-2023.

Cristian Gallo

Ingrid Bobeková

Sigurður Halldór Árnason

December, 2023

NV nr. 32-23

NÁTTÚRUSTOFA VESTFJARÐA

Month-Year/ Mán-ár:
December-2023

Report/Skýrsla nr:
nr: NV nr. 32-23

Work number/ Verknúmer:
413

Pages/Blaðsiður:
61

Stage/Verkstig:
Final report / Lokaskýrsla

Distribution/Dreifing:
☒ Open/Opin
☐ Closed until/Lokuð til:
☐ Háð leyfi verkkaupa

Report name/Heiti skýrsla:
Distribution, breeding success, and survey methods of Arctic terns in the Westfjords, 2022-2023

Worked for/Unnið fyrir:
Icelandic Ministry of Environment, Energy and Climate (URN)/ Umhverfis-, orku- og loftslagsráðuneytið

Authors/Höfundur:
Cristian Gallo, Ingrid Bobeková & Sigurður Halldór Árnason

Project manager/Verkefnastjóri:
Cristian Gallo

ABSTRACT/ÚTDRÁTTUR

Arctic tern (*Sterna paradisaea*) colonies were monitored during the breeding season in the Westfjords of Iceland from 2020-2023. Colonies were mapped and 115 breeding sites were identified. Changes in the number of breeding pairs and clutch sizes were observed between the years. A focused breeding success study of colonies near Bolungarvík, Holt in Önundarfjörður, and Ísafjörður (in Skutulsfjörður) indicated site-specific influences on hatching and fledging success, likely related to prey availability and predation pressures. Drone trials conducted in 2022-2023 showed potential for mapping colonies and assessing the number of breeding pairs at optimal altitudes, with varying success across colonies, suggesting the promising use of drones for future Arctic tern survey.

Kríu (*Sterna paradisaea*) vörp á Vestfjörðum voru talin og vöktuð á árunum 2020-2023. Fjöldi varpa á Vestfjörðum var 115. Sveiflur voru í fjölda varppara og fjölda eggja í hreiðrum (clutch size) á milli ára. Varpárangur var metinn sérstaklega í vörpum í Bolungarvík, Holti í Önundarfirði og á Ísafirði en þær rannsóknir benda til svæðisbundinna áhrifa á klak-og varpárangur sem mögulega er hægt tengja við fæðuframboð og/eða afrán. Athuganir á notkun dróna til að kortleggja og meta fjölda varppara sýndu að mögulegt er að nota slíkar aðferðir við rétta lofthæð, en niðurstöður voru þó breytilegar á milli varpa, tíma dags, árs og svæða. Þessar niðurstöður benda til þess að notkun dróna til kortlagninga og talninga er fýsileg við rétt skilyrði.

Signature of project manager/Undirskrift verkefnastjóra:

NÁTTÚRUSTOFA VESTFJARÐA

Reviewed by/Yfirfarið af:
Sigurður Halldór Árnason

TABLE OF CONTENTS

OVERALL INTRODUCTION

These studies are part of the project, "Bird Monitoring in the Westfjords" ("Fuglavöktun á Vestfjörðum"), which is funded by the Icelandic Ministry of Environment, Energy and Climate (URN). In 2019 Náttúrustofa Vestfjarða (NAVE) secured funding directly through URN specifically allocated towards the monitoring of birds in the Westfjords by NAVE. The Bird Monitoring project, commencing in 2020, includes monitoring of the Glaucous gull (*Larus hyperboreus*), Guillemots (*Uria aalge* and *Uria lomvia*), Razorbill (*Alca torda*), Kittiwake (*Rita tridactyla*), Fulmar (*Fulmarus glacialis*) on two bird cliffs, the Arctic tern (*Sterna paradisaea*), the black Guillemot (*Cepphus grylle*), and birds in winter (Vetrafuglatlningar). In this report we focus specifically on the monitoring and research of the Arctic tern in the Westfjords. This monitoring included 3 different aspects (Chapters 1-3) of Arctic tern distribution and biology.

The Arctic tern, a colonial nesting seabird, breeds in the north Atlantic and winters in the south Atlantic. It has a circumpolar distribution during the breeding season across Arctic and subarctic zones (Birdlife International, 2023; Egevang et al., 2010). Iceland accounts for 20-30% of the world's breeding Arctic terns (Umhverfisráðuneytið, 1992; Asbirk et al., 1997; Mitchell et al., 2000), however the population has been suffering declines and poor breeding and recruitment success over the past decades. The species is now listed as Vulnerable on the Iceland Red List 2018, updated from Least Concern in 2000 (Skarphéðinsson, 2018). Given their global migratory pattern (Egevang et al., 2010), Iceland plays a crucial role in the annual life cycle of Arctic terns. Despite this importance, consistent data is lacking from the region, with some being anecdotal or unpublished.

The use of Icelandic waters and habitats by large seabird populations of the North Atlantic underscores the need for protection and sustainable management (Garðarsson, 1995). Accurate information on seabird breeding numbers, population changes and breeding success informs conservation management and conservation policy. Without this data it is impossible to understand what is happening in a colony and whether conservation management strategies have been successful or not. Standardising the methods used collecting in the data enables meaningful comparisons to be made between years and between colonies.

CHAPTER 1. DISTRIBUTION AND RE-DISTRIBUTION OF ARCTIC TERN COLONIES IN THE WESTFJORDS

BACKGROUND & AIMS

In the 1990's, estimates indicate that Iceland hosted a substantial Arctic tern population, as many as 250,000 to 500,000 pairs, accounting for 20-30% of the world's breeding Arctic terns (Umhverfisráðuneytið, 1992; Asbirk et al., 1997; Mitchell et al., 2000). This number was later adjusted to 150,000-25,000 breeding pairs on the account of it likely being an overestimation (Skarphéðinsson, 2018; Skarphéðinsson et al, 2016).

Colonies can range in size from a few tens to hundreds of pairs, to colonies with few thousands of pairs (Skarphéðinsson et al., 2016). Some estimations were carried out on the largest colonies, of which there were 41, with 8 of these colonies located in the Westfjords area (Skarphéðinsson et al., 2016) (Figure 1.1). More detailed counting efforts were conducted in specific regions, including the Snæfellsnes peninsula (Vigfúsdóttir et al., 2013), Hrísey (Þorsteinsson & Thorstensen, 2014), and Seltjarnarness (Hilmarsson, 2017) or for important bird areas in Iceland (Skarphéðinsson et al., 2016). However, there is a lack of comprehensive information regarding Arctic tern colonies in the Westfjords, including both distribution and the number of breeding pairs. In 2020, Náttúrustofa Vestfjarða initiated a monitoring scheme to address and fill this knowledge gap.

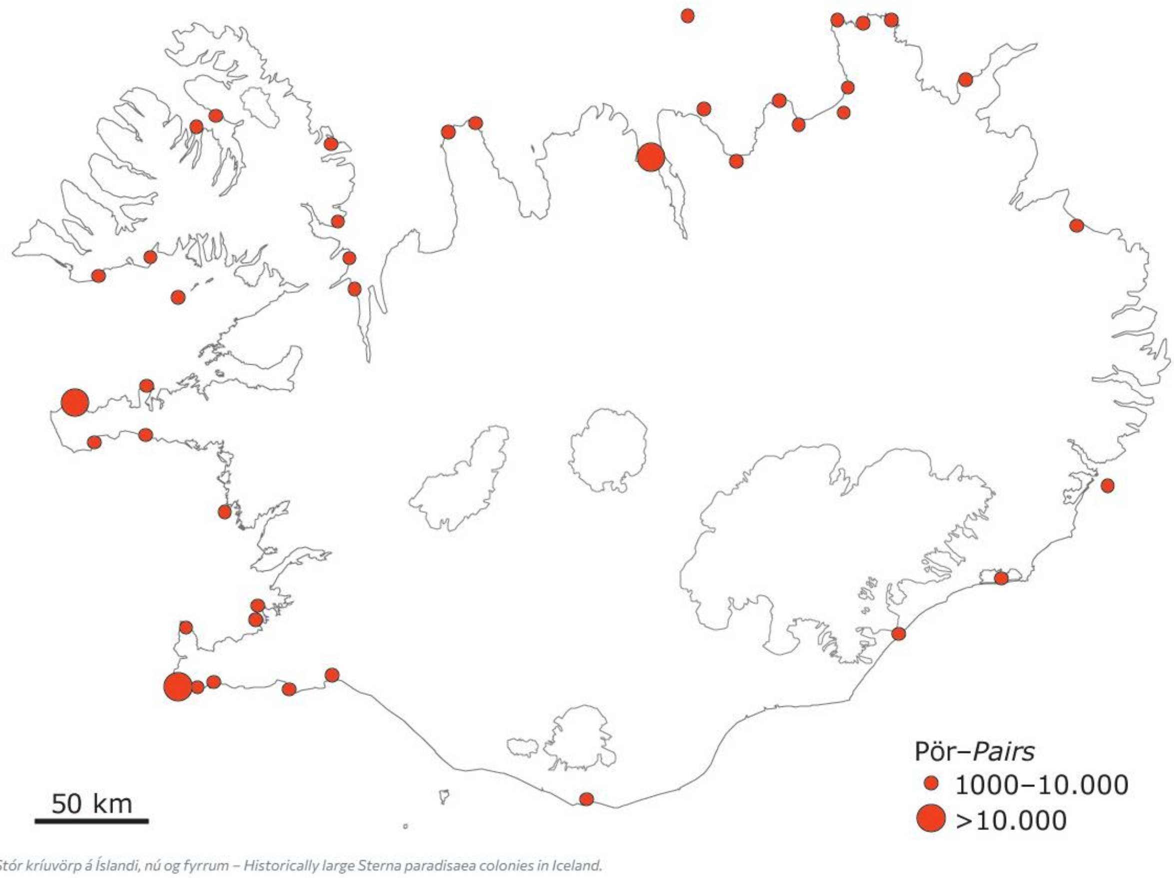

Figure 1.1. *Historical map of large Arctic tern colonies in Iceland. Map Fjölrit nr. 55 (Skarphéðinsson et al., 2016).*

METHODOLOGY

In the years 2020-2021, much of the Westfjords which was accessible by car was covered to document the locations of Arctic tern colonies and to estimate the number of breeding pairs in each colony (Figure 1.2). For the estimation of breeding pairs, three different counting methods were used: 1) if the colony was small with low vegetation and possible to observe from good vantage point, then direct counting of nesting birds was preferred; 2) if direct counting was not possible due to higher vegetation or poor visibility, then the birds were flushed from their nests and counted as they settled back down. This was typically done in sectors, depending on the colony size, and 3) for large colonies, where counting of nesting birds was impractical, the birds were flushed from their nests and estimated in the air (Walsh et al., 1995), with the number of breeding pairs derived using a 0,7-conversion index (Bullock & Gomersall, 1981).

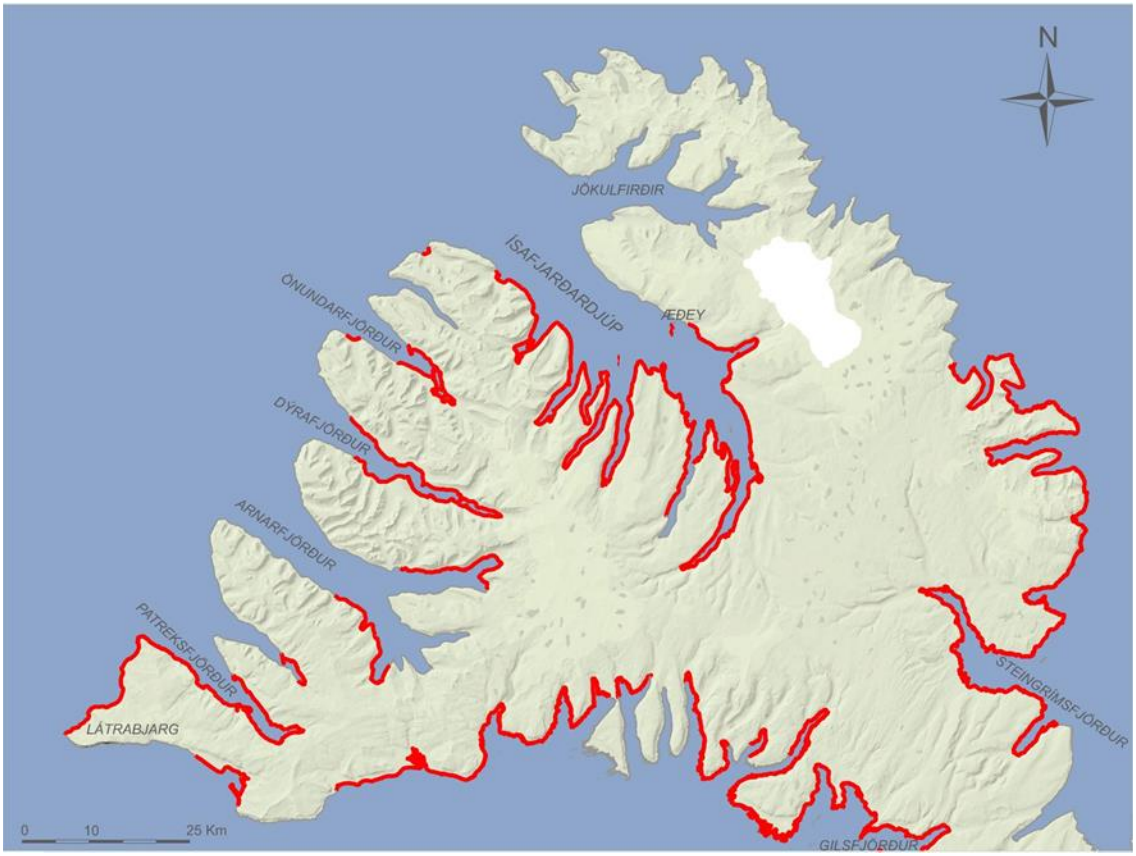

Figure 1.2. *Areas of the Westfjords checked for the presence of arctic tern colonies.*

Furthermore, thorough colony counts of nests/breeding pairs were conducted in select colonies. These include the colony on the island of Æðey in Ísafjarðardjúp (June 19 - 21, 2020), a section of Ásgarður in Látravík (June 23, 2021, and June 22, 2023), and a colony at Auðkula in Arnarfjörður (June 27-28, 2023; fig. 1.3). Counts of nests with eggs were conducted during the late incubation period, as this period generally coincides with the peak number of occupied nests in the colony. The methods used for each of these locations are detailed below.

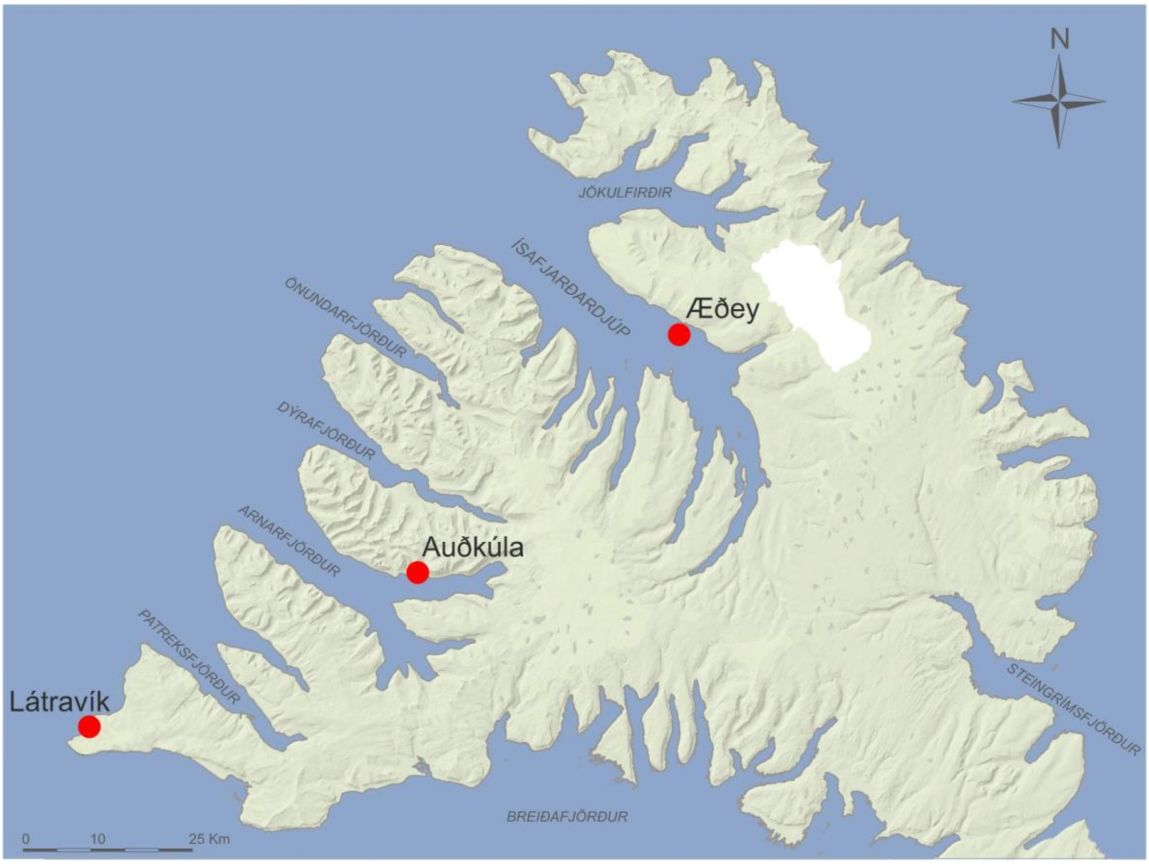

Figure 1.3. *Locations of 3 Arctic tern colonies where nests count was performed during this study period.*

Æðey 2020

Two distinct counting methods were employed. Part of the colony was assessed using a transect counting method (Figure 1.4) between 9:00 and 14:00 the 20th and 21st of June. Two lines (ropes) delineated a transect of the colony, and nest counts were performed between them. Two counters, starting from the ends of the transects, moved towards the middle, counting nests, and noting how many eggs each had. The observers then returned to the ends, moved one of the lines over (flip-flop line), and repeated the procedure until the entire colony area was covered (Sutherland, 1996). Transects were typically 1-3 meters in width, depending on the vegetation (e.g., dense vegetation inhibiting visibility). Another part of the same colony was mapped using a Trimble Yuma and GIS program Global Mapper version 22. The island was divided into 5x5 m quadrants, visible over the aerial photo, with each square surveyed and completed before moving to the next (between 16:00 and 20:00 the 20th of June). The location of each nest was marked, and it was noted whether the nest had 1 egg or 2 eggs.

Figure 1.4. *Transect counts with flip-flop line. 19 June 2020. Æðey island.*

Ásgarður (Látravík) 2020, 2021 & 2023

The first breeding pair estimation was carried out in 2020 by using the flush method (estimating the number of terns in the air). Flip-flop line transect counting was used in the subsequent year (2021) on the western part of the colony (where it was the densest), while sector-by-sector flush counts were conducted on the east part of the colony (above the farmhouse) (Figure 1.5). The same method was employed in 2023.

Figure 1.5. *Arctic tern colony in Ásgarður (Hvallátur in Látravík). The orange led line represents the area in which the colony was counted in 2021 and 2023. The white-dotted line represents the fence of the property.*

Auðkúla 2023

The colony in Auðkúla was divided into 17 areas based on fences, terrain features, and tern density acquired from a previous visit (Figure 1.6). The transect flip-flop line counting method was employed in parts of the colony (A2, A8, A15) where the terrain was suitable, and the colony was denser. In less dense areas or over difficult terrain, the survey was conducted with four counters walking abreast through the nesting area, as it proved to be more time-efficient than placing rope transects.

Figure 1.6. *Fields surveyed in Auðkúla (outlined in yellow). Numbers indicate different sections of delimited while counting.*

RESULTS

Ongoing survey of Arctic tern colonies

The data collected during these surveys is stored in a database and will be updated on a periodic basis. The simplified version of this database for 2020-2021 is provided in the Appendix (Table 1). Across the surveyed areas around the Westfjords, 115 breeding sites were identified, and the number of breeding pairs in each was estimated. Larger colonies were located at Lambavatn, Hvallátur, and Hænuvík in West-Barðasysla, each estimated to have around 700 pairs. Foss and Auðkúla in Arnarfjörður were estimated at 630 and 700 pairs, respectively. Bakkagerði/Bær in Selströnd had between 500-600 pairs, and Smáhamrar í Steingrímsfjörður ranged from 700-900 pairs. The Vigur Island estimate fell between 600-700 pairs (Milesi-Gaches & Lhériau, 2022). Other smaller colonies and single pairs were also documented (Gallo and Sigurlaug Sigurðardóttir, 2022). The presence of Arctic terns was noted in an additional 22 locations; however, breeding was not confirmed.

Our findings reveal that nearly 50% of Arctic tern colonies surveyed in the Westfjords in 2020-2021 had between 1-20 pairs, around 29% counted between 21-100 pairs, with 11% of colonies comprising between 101-300, and 11% with >301 pairs (Figure 1.7).

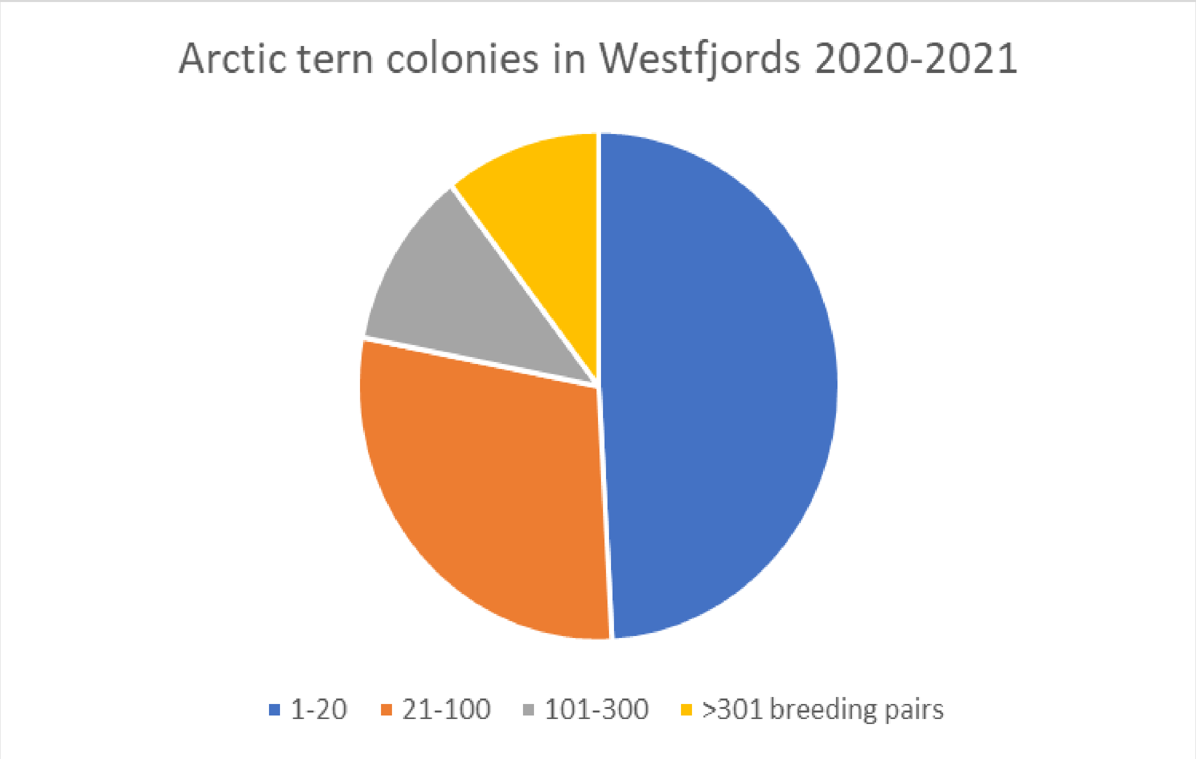

Figure 1.7. *Proportion of colonies of different sizes in the Westfjords, 2020-2021.*

Detailed counts of Arctic tern colonies

On the island of Æðey, 402 breeding pairs of Arctic terns were counted in 2020 (Figure 1.8 and 1.9). For the portion of the colony mapped using a Trimble Yuma device (131 nests), the numbers of eggs were also noted; 45 nests had 1 egg and 86 nests had 2 eggs. The remaining 271 nests which were counted did not note the clutch size (Table 1.1).

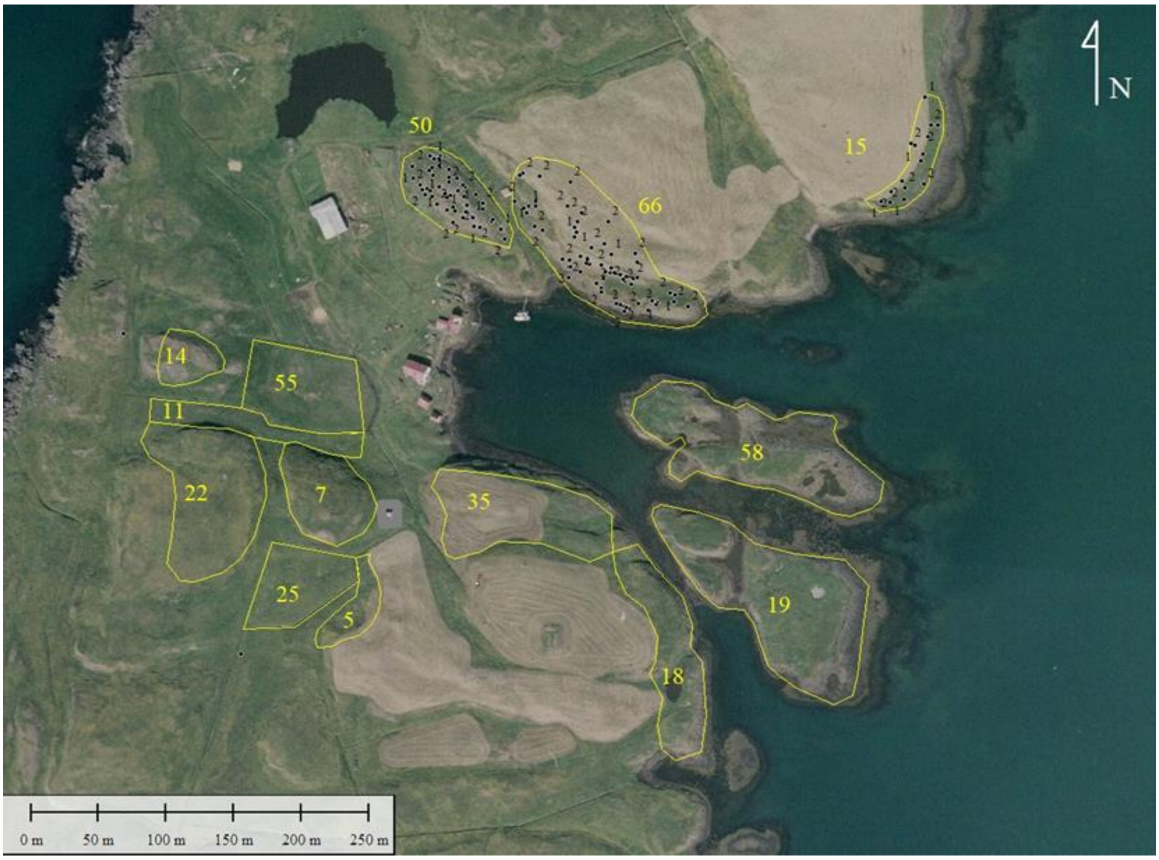

Figure 1.8. *Æðey 2020, total count of the Arctic tern nests. Yellow numbers indicate the number of nests in each area. Black dots represent individually marked nest with 1 or 2 eggs. See next figure (1.9) for detailed image. Aerial photo owned by Loftmynda ehf. Used with license from the Municipality of Ísafjörður.*

Figure 1.9. *Zoomed detail from Figure 1.8. Black dots represent individual marked nests with 1 or 2 eggs. Aerial photo owned by Loftmynda ehf. Used with licence from the Municipality of Ísafjörður.*

Table 1.1*. Arctic tern nests counted in Æðey. June 20-21, 2020.*

Year	1 egg	2 eggs	Counted	Total
2020	45	86	271	402

In Ásgarður at Hvallátur, the 2020 estimation of 1,000 terns brought the number of breeding pairs to 700, once the conversion index was applied. In 2021, a count was initiated with the aim to cover the entire colony, but unfortunately, it could not be completed due to unfavourable conditions. On the western part of the colony, a total of 243 nests were counted (68 nests with 1 egg, 171 with 2 eggs, and 4 with 3 eggs). The estimation on the east part of the colony (above the farmhouse) was between 300-350 pairs, bringing the total number of breeding pairs to 550-593 pairs. In 2023, a re-count on the western part of the colony saw a total of 159 nests (105 nests with 1 egg and 54 with 2 eggs). Above the house, another 150 nests were estimated, bringing the total number of breeding pairs to 309 nests (Table 1.2).

Table 1.2*. Arctic tern nests counted in Ásgarður (western part of the colony) and estimates for the east part of the colony. June 23, 2021, and June 22, 2023.*

Year	1 egg	2 eggs	3 eggs	Est.	Total
2021	68	171	4	300-350	550-593
2023	105	54	0	150	309

In Auðkula, the colony was divided into 17 areas according to fences, terrain features, and pre-observed nest density. The total count revealed 588 nests, with 182 nests having 1 egg, 405 with 2 eggs, and 1 nest with 3 eggs (Table. 1.3).

Table 1.3*. Arctic tern nests counted in Auðkula on June 27-28, 2023.*

Area	1 egg	2 eggs	3 eggs	Total
A1	1	0	0	1
A2	89	187	1	277
A3	2	6	0	8
A4	3	2	0	5
A5	4	16	0	20
A6	0	0	0	0
A7	5	6	0	11
A8	19	37	0	56
A9	27	74	0	101
A10	1	3	0	4
A11	4	2	0	6
A12	0	0	0	0
A13	9	17	0	26
A14	1	1	0	2
A15	17	54	0	71
A16	0	0	0	0
A17	0	0	0	0
	182	**405**	**1**	**588**

Clutch size

Two distinct years of data on clutch size from Ásgarður can be compared (Figure 1.10). In 2022, a higher proportion of nests had a clutch size of 2 eggs, however this relationship was reversed during the following count in 2023 when a higher proportion had 1 egg.

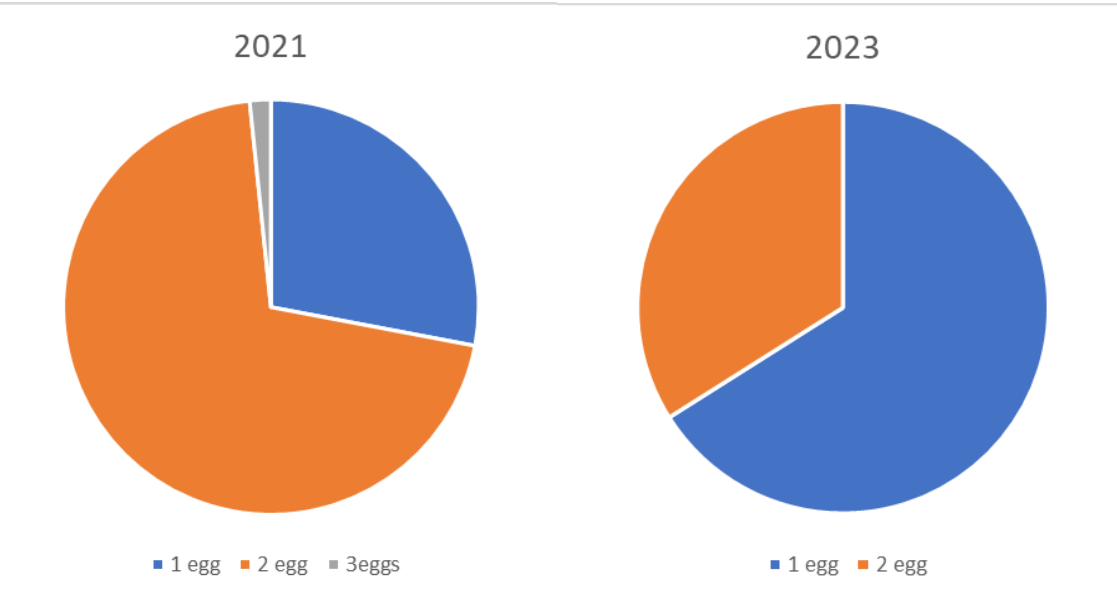

Figure 1.10. *Proportion of 1-egg, 2-egg, and 3-egg clutches on Ásgarður, in 2021 and 2023.*

DISCUSSION

The Arctic tern is often described as a species with fluctuating colony attendance, large variations in breeding numbers, and occasional years of skipped breeding. Breeding site fidelity at a regional level is high among Arctic terns, but frequent dispersal to neighbouring breeding colonies occurs (Devlin et al., 2008; Brindley et al., 1999; Egevang, 2010). The mapping of Arctic tern colonies in the Westfjords began in 2020 with the aim of better understanding this phenomenon, which is still poorly studied (Ævar Petersen, personal communication, 2020). Arctic tern colonies were predominantly found near inhabited villages, farms, or Eider duck protected areas. Information gathered from locals during this work suggested a decline in Arctic tern numbers over the last few decades, although some areas seem to report a sudden concentration of terns (for example Ásgarður).

Counts and estimates from 2020-2021 cannot be directly compared to previous studies, but some considerations can be made for seven colonies in the Westfjords based on the map presented in Fjölrit nr. 55 (Skarphéðinsson et al., 2016). These colonies were surveyed in 2020-2021 by Náttúrustofa Vestfjarða. For most of them, the terns were estimated in the air and subsequent adjustment factor for the number of breeding pairs was used. Æðey island was counted to the nest, Vigur island was partially counted, however the estimation is considered realistic.

Historically, these colonies supported over a thousand breeding pairs, but comparisons with our counts indicate a decrease in all of them. While colonies located in Æðey, Vigur, Árnes, Bakkagerði, and Broddanes still maintain populations larger than 300 pairs, the other two colonies which were presumably located at Brjánslækur/Seftjörn and Haukabergsvaðall show a drastic decrease or complete loss of the population. In all likelihood, such a drastic decrease can be linked to reallocation of the terns rather than complete loss of all individuals in the colony. The colony at Brjáslækur had 180-230 pairs in 2020 but was nearly empty in 2023, the colony at Haukabergsvaðall was almost empty in 2020. These placenames referred to here are areas visited in the 2020-2021 count and may not have a direct reference with historical names and counts (e.g. as seen in Figure 1.1).

In Ásgarður (Látravík), the Arctic tern colony decreased by half between 2021 and 2023. It is essential to note that Hvallátur comprises a few summerhouses and a farm that has been permanently used in recent years. Unfortunately, Kristin Guðmundsson, who lived on this farm, passed away in the winter of 2021. When the colony was first visited in 2020 and subsequently in 2021, it was clear that his human presence in Ásgarður had a significant impact on the tern nesting ground selection, as all terns were found nesting inside the fenced property, even though there was knowledge of Arctic tern nesting all over the nearby sandy area before.

Upon revisiting the colony in Ásgarður in 2023, we observed that Arctic terns were more dispersed, outside the property fence of Ásgarður and throughout the sandy area in Hvallátur, yet in lower density than inside the farm fences. It is also crucial to note that 2023 marked a late starting year for Arctic tern nesting in many colonies in the Westfjords which could have led to a lower number of nests. Results not only show a decrease in breeding pairs inside the colony itself but from detailed nest clutch size, clearly show an inversion in the number of nests with 2 eggs compared with 1 egg (Figure 1.10).

On the island of Æðey, the landowner remembers times when Arctic terns were in thousands, more distributed over the island all the way on Djúphólmi and Kúhólmi. Presently the colony has smaller and more concentrated around the houses. The reliability of two different methods used could not be compared except that flip-flop line counting necessitates 2 people while mapping using a Trimble Yuma and GIS necessitates only one person. Using the latter method, it is possible to get an idea of how nests with different clutch sizes are distributed throughout the colony.

In Auðkúla, even though the number of breeding pairs could have been low due to the unfavourable conditions of spring 2023, the colony is relatively easy to access and will be monitored in the future, hopefully in combination with 2-3 other colonies in Arnarfjörður.

Though poorly documented, Egevang C., (2010) concludes that the redistribution of Arctic terns between colonies may be caused by locally occurring phenomena, such as predation and disturbance. In our experience, predation in the Westfjords is often linked to farm abandonment, while disturbance seems to play a smaller role.

CHAPTER 2: BREEDING SUCCESS, A CASE STUDY IN 2 COLONIES

BACKGROUND & AIMS

Recent decades have seen significant declines in the Arctic tern (*Sterna paradisaea*) populations nesting in Iceland, marked by poor breeding success and recruitment (Petersen et al., 2020; Skarphéðinsson, 2018), particularly in the southwest of Iceland (Vigfúsdóttir et al., 2013). Patterns in the population dynamics of seabirds can serve as an indicator of broader ecosystem wide changes (Parsons et al., 2008). This is evident in the well documented relationship between forage fish availability and breeding success of many seabirds (Cury et al., 2011; Fayet et al., 2021; Garðarsson, 2006; Lilliendahl et al., 2013; Monaghan et al., 1989; Vigfusdottir et al. 2013). Reduced breeding success and population declines in Iceland are not limited to Arctic terns; Atlantic puffins (*Fratercula arctica*), guillemots (*Uria aalge*, *Uria lomvia*), razorbills (*Alca torda*), Northern fulmar (*Fulmarus glacialis*) and others have declined significantly (Asbirk et al. 1997; Garðarsson, 1995; Garðarsson, 2006; Garðarsson et al., 2011; Petersen, 2006). Assessing breeding success in Icelandic fjord systems is likely to provide a good indication as to food availability in the nearby marine ecosystem, reflected in nesting patterns and reproductive success (Hamer et al., 2002; Newton, 1998). Data from long-term monitoring projects become crucial for understanding and predicting these broader ecosystem-wide patterns.

The objective of this research is to investigate the breeding success of two distinct Arctic tern colonies located in the Westfjords of Iceland.

This inquiry will be pursued through the examination of the following metrics:

1. Clutch Size: The average number of eggs per nest.

2. Hatching Success: The proportion of eggs that successfully hatch into chicks.

3. Fledging Success: The achievement of fledging, which signifies when a chick can sustain flight—a crucial milestone in its early life.

To comprehensively explore fledging success, three definitions were considered, each shedding light on different aspects during the breeding season:

3a. ***Fledged Chicks per Egg Laid***: Provides insight into the overall breeding effort's success by revealing the number of eggs that successfully develop into flying chicks.

3b. ***Fledged Chicks per Hatched Chicks***: Excluding failed or predated eggs, this metric focuses on pre-fledging chick survival.

3c. ***Fledging Success per Nest***: Average number of flying chicks produced by each nest attempt of a parent pair, irrespective of the initial number of eggs or successfully hatched chicks.

METHODOLOGY

Study site

Tern colonies were selected based on their proximity to the NAVE office in Bolungarvík. Initially, the focus was solely on monitoring nesting success in tern colonies at Bolungarvík and Holt (Önundarfjörður). Ísafjörður was included as an extra site due to its high nest density and thus practicality for erecting large fences, as discussed later. In 2022, these three sites were chosen, but in 2023, only the colonies in Bolungarvík and Holt were selected again (Figure 2.1).

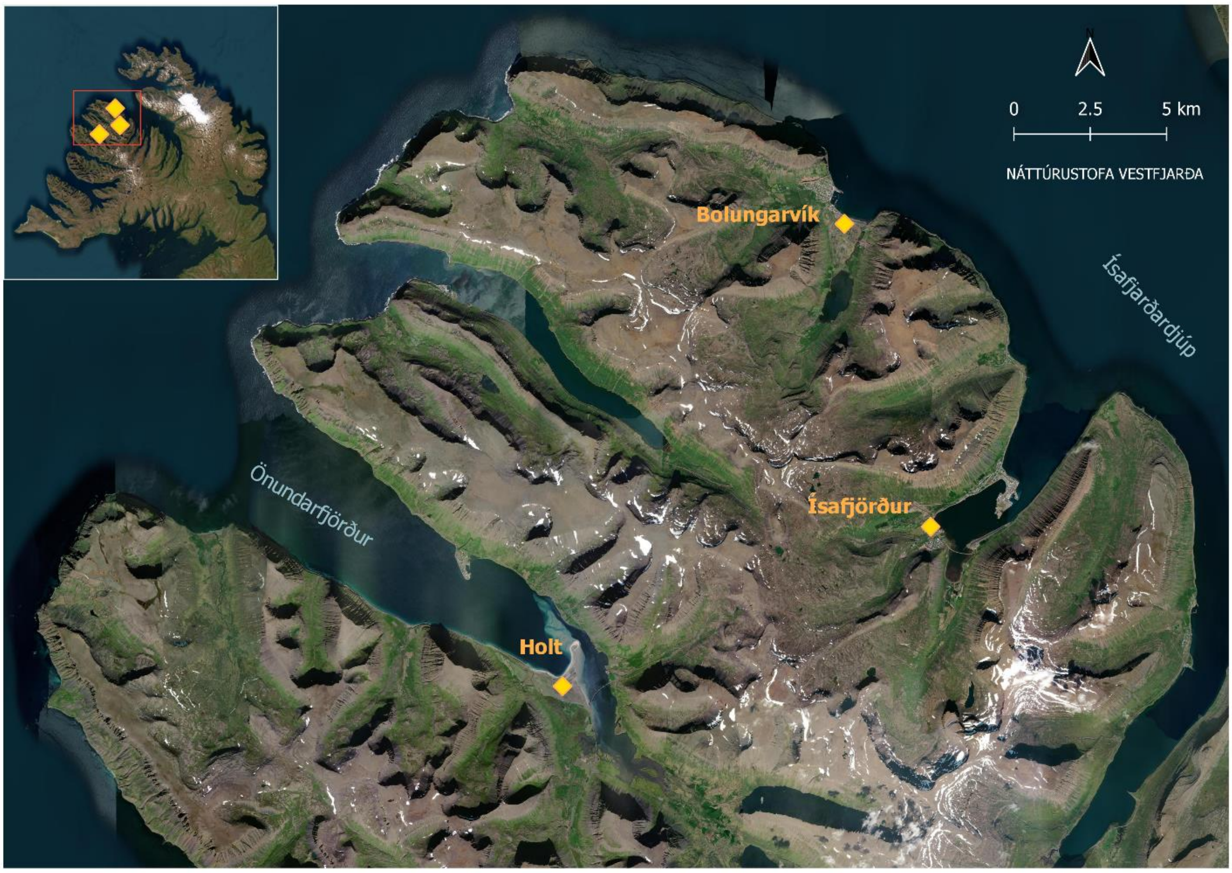

Figure 2.1. *Location of the three study sites in the Westfjords, Iceland.*

The Bolungarvík study site is situated on the outskirts of the town in a grassy field (Figure 2.2-2.3). The vegetation varies, ranging from dense growth of approximately 30 cm in height in some areas to sparser coverage in others. The ground remains vegetated throughout, with small wet patches. This location, formerly the Bolungarvík airstrip, is in proximity to an industrial area of town, and a sand/gravel mine and sorting area. The portion of land closer to the sea is also used as a common eider farm. The largest direct distance from the seaside to the farthest nests in the sample is approximately 375 meters. The 2023 estimate suggests a colony size of approximately 250-300 pairs.

Figure 2.2. *Aerial view of the study site (outlined in yellow) in Bolungarvík. 2022.*

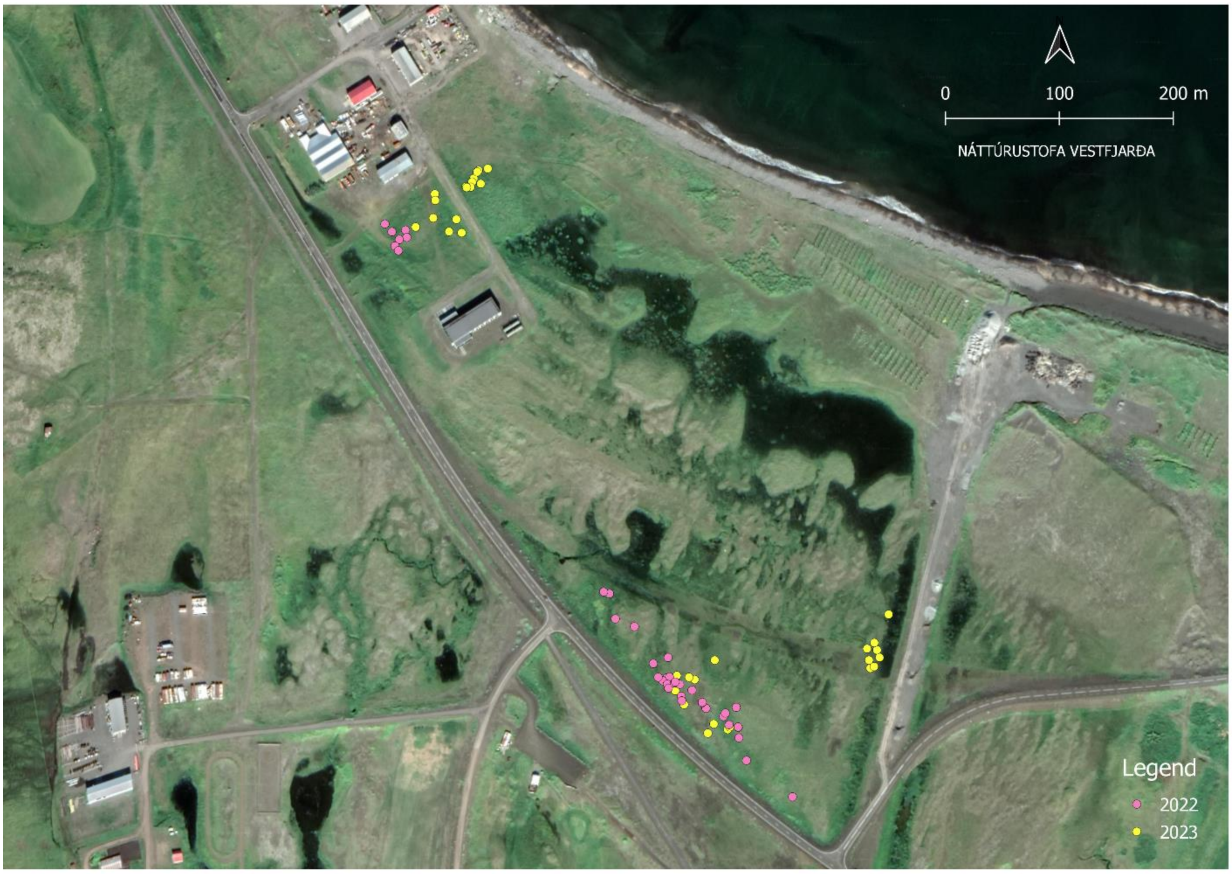

Figure 2.3. *Distribution of sample nests in Bolungarvík in 2022 and 2023.*

The Holt (Önundarfjörður) colony is situated in an area characterized by a mix of coastal duneland and poor heath with sparse vegetation, including moss, lichens, short grasses, and flowering plants, along with sandy or gravel patches (Figure 2.4-2.5). Functioning primarily as a common eider farm, the site is not open to the public and is also rich in various breeding birds, such as waders, gulls, and waterfowl. The farthest nest in the sample is located approximately 625 meters from the seaside, the location lies between a low-traffic road and road access to a recreational beach near a disused airstrip. The 2023 estimate indicates a colony size of around 220 pairs.

Figure 2.4. *Aerial view of the study site (outlined in yellow) in Holt. 2022.*

Figure 2.5. *Distribution of the sample nests in Holt in 2022 and 2023.*

The Ísafjörður study site is situated between the parking lot of Bónus/Órkan petrol station, roads leading to a residential community, homes, and an empty field (Figure 2.6-2.7). The vegetation is a mix of grass, invasive lupine (*Lupinus nootkatensis*) which rises in excess of 50 cm during its peak growth, and patches of poorly vegetated surface. The area surrounding this colony is highly trafficked by people, and there are often incidents of human-tern conflicts, especially in 2023 when members of Ísafjarðarbær actively attempted to discourage the colony from settling in the area through various controversial means, including acoustic deterrents, manure spreading, and collecting or crushing eggs. This ongoing human interference in this colony contributed to the decision not to address this site in the second year.

***Figure 2.6**. Aerial view of the study site (outlined in yellow) in Ísafjörður. 2022.*

Figure 2.7. *Distribution of sample nests in Ísafjörður in 2022.*

Field methodology

The methodology for assessing nesting success drew from the *Tern Conservation Best Practice Monitoring Methods* (Babcock & Booth, 2020), the *Seabird Monitoring Handbook for Britain and Ireland* (Walsh et al., 1995), and prior research conducted in Iceland (Vigfúsdóttir 2012; Vigfúsdóttir et al., 2013; Æ. Petersen, personal communication, 2022). The approach involved selecting a sample of nests within a colony and erecting low, open-top fences made of wire mesh around them. These fence enclosures were securely pinned to the ground, and the bottom edges were covered with surrounding natural materials (e.g., grass, sand, gravel) to prevent chicks from passing underneath. This widely used technique in tern productivity monitoring allows for tracking individual families throughout the breeding season by inhibiting the chicks from dispersing and becoming indistinguishable from other colony members (Arnold et al., 2022; Vigfusdottir et al., 2013; Monaghan et al., 1989; Nisbet & Drury, 1972; Pearson, 1968; Robinson et al, 2001).

The colonies were initially visited in mid-June for fence installation. Samples of nests were grouped in clusters, focusing on 2-3 areas of each colony where the tern nests were concentrated. This was to ensure a distribution of nests from different sections of the colony, and to avoid prolonged disturbance in one area of the colony during setup and monitoring; however, the selection method was not random. Some discrimination was also applied to nest selection based on the terrain. Nests situated on uneven ground, for instance, were not considered, as there was a greater chance for the young to escape from under the fence. While the intent was to collect a random sample of nests in terms of clutch sizes, the selection process could have imparted bias on this metric. This limitation will be discussed further.

At the time of setup, eggs underwent a float test (Hays & LeCroy, 1971; Liebezeit et al., 2007) to estimate the start of nesting and predict the time of hatching (Figure 2.8), to help plan key monitoring visits (Figure 2.9). GPS locations of the enclosed nests were recorded, and stakes with unique numbers were placed at each enclosure for revisiting purposes.

Figure 2.8. *Using a plastic cup to measure the float stage of an arctic tern egg. 2022.*

Over the first two years, there was some trial and error with the enclosure style to find what was most practical for these specific study sites. In past studies and literature, various enclosure sizes have been used (e.g., Vigfusdottir et al., 2012; Æ Petersen, personal communication, 2022). In 2022, most nests in Holt and Bolungarvík were enclosed in 2.5-5.0 meters circumference, equivalent to approximately 0.5m²-2m² in area (Figure 2.9). Initially it was proposed to fence half of the nests individually in small fences and half together in large fences, however it proved difficult to find an area in Holt and Bolungarvík where nests were dense enough to feasibly fence several nests together.

Only in one area near Bolungarvík was it possible to fence five nests together (15 m circumference, approximately 18m² area). Due to the density of the extra colony in Ísafjörður (in 2022), it was possible to enclose all the nests there within two fences (30 m in circumference or 72 m²) (Figure 2.9). In 2023, only 5 m circumference enclosures were used in Holt and Bolungarvík, with all nests individually enclosed (Figure 2.10-2.11). That same year shelters made from cut PVC pipes were added within the enclosures (Figure 2.12), as areas of low vegetation had little cover and could have been a source of stress to the enclosed young (Arnold et al., 2022; McGowan et al. 2018).

Figure 2.9. *Example of 30-metre enclosure set up in Ísafjörður, encompassing approximately 15 nests. 2022.*

Figure 2.10. *Setting up a 5-metre circumference enclosure around a tern nest in Bolungarvík. 2022.*

Figure 2.11. *5-metre circumference enclosure around a tern nest in Holt, with a PVC pipe provided as shelter in a low vegetation area.*

Figure 2.12. *PVC pipe being used as cover by a tern chick in Holt. 2023.*

Monitoring

Following setup, the enclosed nests were revisited approximately once a week, and the fate of each nest was determined. Each egg/young was classified with the following fates:

- **Alive/active**: A chick or a warm egg is present in the enclosure.
- **Dead/failed**: Body, or cold/damaged unhatched egg is found in or around the enclosure, or other certain evidence of mortality.
- **Disappeared (assumed dead)**: The chick or egg is not found, and the young did not meet fledging requirements before disappearing from the enclosure. While there is a small chance of it escaping through the fence, the likely scenario is predation.
- **Fledged**: The chick reached a minimum mass of 80 g and wing length of 100 mm and was subsequently not seen in its enclosure on the following visit. These metrics were derived from known growth curves and similar research done previously (Drent et al., 1987; Klaassen et al., 1989; Vigfusdottir,2012). If a chick was found dead after reaching the size criteria for a fledged chick, either outside or inside the enclosure, it was still recorded as fledged in the registration of nesting success but marked as dead after that. However, post-fledging survival was not examined beyond this in the context of the present study.

As nesting started at different times in the selected colonies, the sites were not always visited on the same days. Sites were visited until the chicks inside the sample nests had either fledged or had failed (missing or dead). Once the nests were empty, the enclosures were taken down.

Ringing and Biometric data

Chicks were marked with engraved metal rings on the tarsus around the age of one week for individual tracking and possible fate and movement data if they are recaptured or recovered in the future (Figure 2.13). Biometric data was obtained, measuring mass using a Pesola spring scale (Figure 2.14) and wing length using a stopped wing ruler. The wing length is measured from the shoulder to the longest feather once they are straightened out (Figure 2.15). This data was obtained both when chicks were ringed and additionally on revisits during nest checks to determine.

Figure 2. *A week-old tern chick fitted with a unique metal ring on its tarsus for tracking purposes. Holt, 2023.*

Figure 3. *Using a Pesola spring scale to measure the mass of a tern chick (inside bag). Sigurlaug Sigurðardóttir, 2022.*

Figure 2.15. *Extending the wing of a juvenile tern to measure its length from the shoulder to the longest feather-tip.*

Statistical analysis

A two-tailed z-test was used to examine statistical differences in the means for hatching success and the three metrics of fledging success between Bolungarvík and Holt for each year. Between-year comparisons were not made at this stage due to slight alterations in methodologies during the first two years (e.g., different enclosure sizes, presence of shelters, etc.)

RESULTS

Two years of data are presented in Tables 2.1-2.4. In 2022, clutch size of the samples was similar between the 3 sites, with clutch size ranging between 1.7 and 1.8 eggs per nest on average across the 3 sites (Figure 2.16). In 2023, clutch sizes were slightly smaller in Holt (1.43 eggs per nest compared to 1.67 in Bolungarvík). For the first two years of the study, clutch size results will be treated with caution, and as a representation of the selected sample rather than representative of the whole colony due to possible nest selection bias. The aim is to collect with more randomness in mind in subsequent years and collect a larger subset of information (including nests not enclosed) to get a more inclusive understanding of the mean clutch size of the colony.

In 2022, 74-80% of laid eggs successfully hatched into chicks (Figure 2.16), and there was no significant difference between the three sites ($z = -1.317$, $p = 0.18684$). Fledging success per egg, per hatched, and per nest was lower in Holt than in Bolungarvík and Ísafjörður (Figure 2.17). Nests in Bolungarvík and Ísafjörður, on average, produced more than 1 fledged chick per nest, while only every second nest in Holt produced one chick on average. In terms of fledging success out of hatched chicks, there was a significant difference between Bolungarvík (73%) and Holt (40%) ($z = -3.1147$, $p = 0.00188$; Figure 2.17). With regard to fledging success per egg, there was also a significant difference between Bolungarvík (61%) and Holt (30%) ($z = -3.3574$, $p = 0.00078$; Figure 2.17).

In 2023, the differences were more pronounced between Bolungarvík and Holt (Figures 2.16-2.17). Hatching success was again significantly lower in Holt (60% successfully hatching compared to 88% in Bolungarvík; $z = -3.0685$, $p = 0.00214$). Fledging success was again lower in Holt, with each nest producing only 0.37 chicks, while in Bolungarvík, pairs managed to produce 1.3 chicks per nest on average (Figure 2.17). In terms of chicks fledged per hatched, 89% fledged in Bolungarvík, with a significantly lower value of 42% in Holt ($z = -4.1458$, $p < 0.00001$; Figure 2.17). The same applies when looked at per egg laid, 78% fledged in Bolungarvík, and 26% in Holt ($z = -5.0551$, $p < 0.00001$; Figure 2.17).

Table 2.1. *Nest counts and fates in 2022 in Holt, Bolungarvík, and Ísafjörður.*

2022	Holt	Bolungarvík	Ísafjörður
Nest sample	30	32	27
Eggs	54	57	46
Hatched chicks	40	48	37
Fledged chicks	16	35	31

Table 2.2. *Metrics of breeding success in 2022 in Holt, Bolungarvík, and Ísafjörður.*

2022	Holt	Bolungarvík	Ísafjörður
Clutch size (per nest)	1.80	1.78	1.70
Hatching success (per egg laid)	0.74	0.84	0.80
Fledging success (per egg laid)	0.30	0.61	0.70
Fledging success (per chick hatched)	0.40	0.73	0.84
Fledging success (per nest)	0.53	1.09	1.15

Table 2.3. *Nest counts and fates in 2023 in Holt and Bolungarvík.*

2023	Holt	Bolungarvík
Nests	30	30
Eggs	43	50
Hatched chicks	26	44
Fledged chicks	11	39

Table 2.4. *Metrics of breeding success in 2023 in Holt and Bolungarvík.*

2023	Holt	Bolungarvík
Clutch size (per nest)	1.43	1.67
Hatching success (per egg laid)	0.60	0.88
Fledging success (per egg laid)	0.26	0.78
Fledging success (per chick hatched)	0.42	0.89
Fledging success (per nest)	0.37	1.30

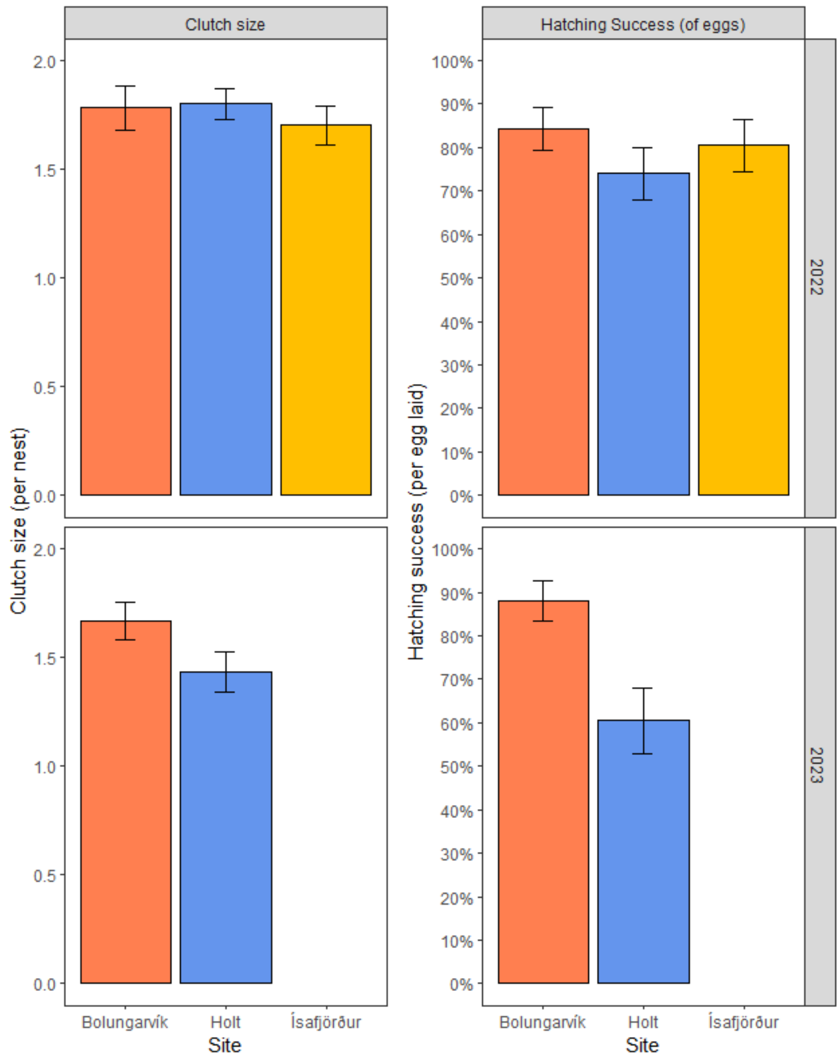

Figure 2.16. *A) Clutch size and B) Hatching success of the study sites over the two years. Error bars indicate standard error of the mean.*

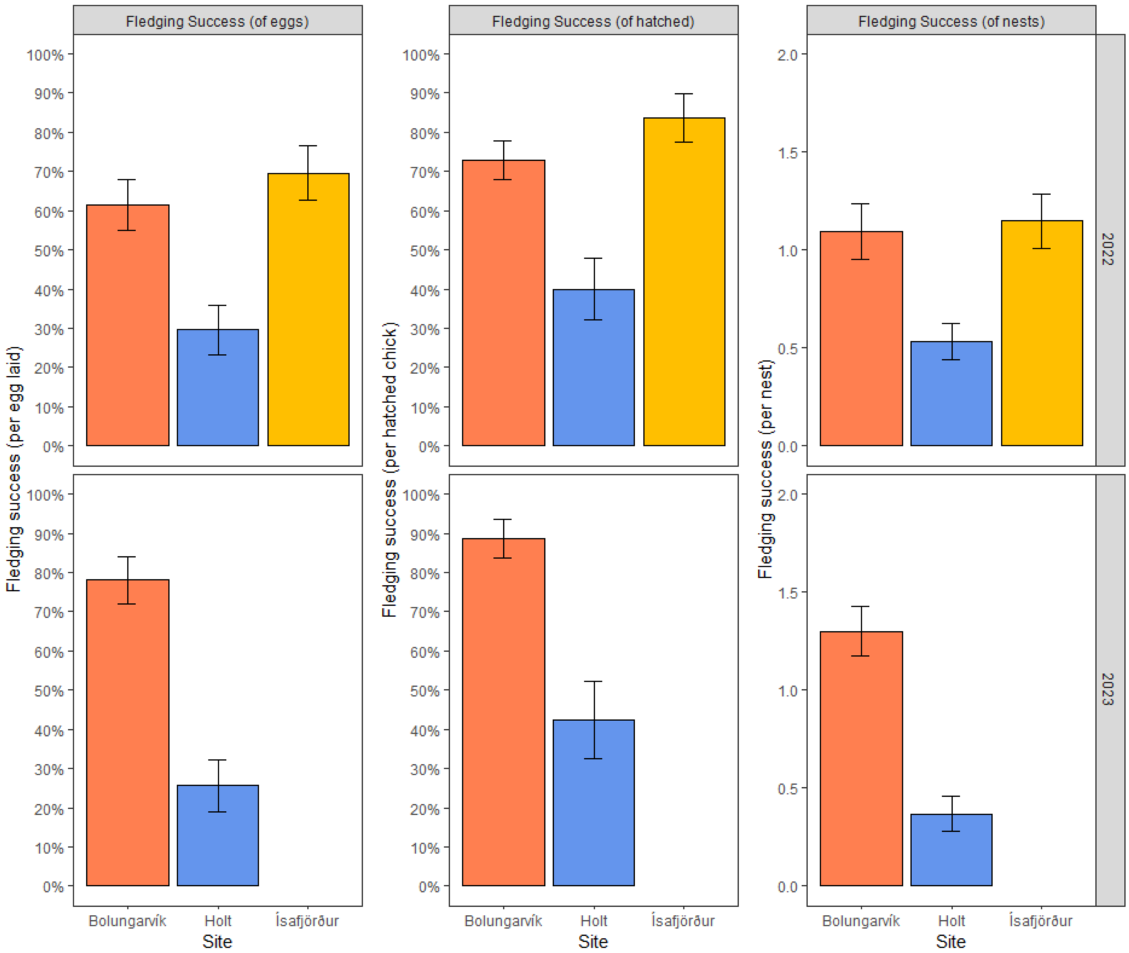

Figure 4. *Fledging success measured as A) per egg laid, B) per chick hatched, and C) per nest, across the different sites in two years. Error bars indicate standard error of the mean.*

Looking at the fates (per egg laid) (Figure 2.18), similar proportions of failures were associated with disappearances of chicks or eggs (assumed predation) and direct mortalities (chicks found dead or eggs failed to hatch). In 2023, the proportion of the latter category in Holt was much lower, with a greater number of disappearances accounting for failures.

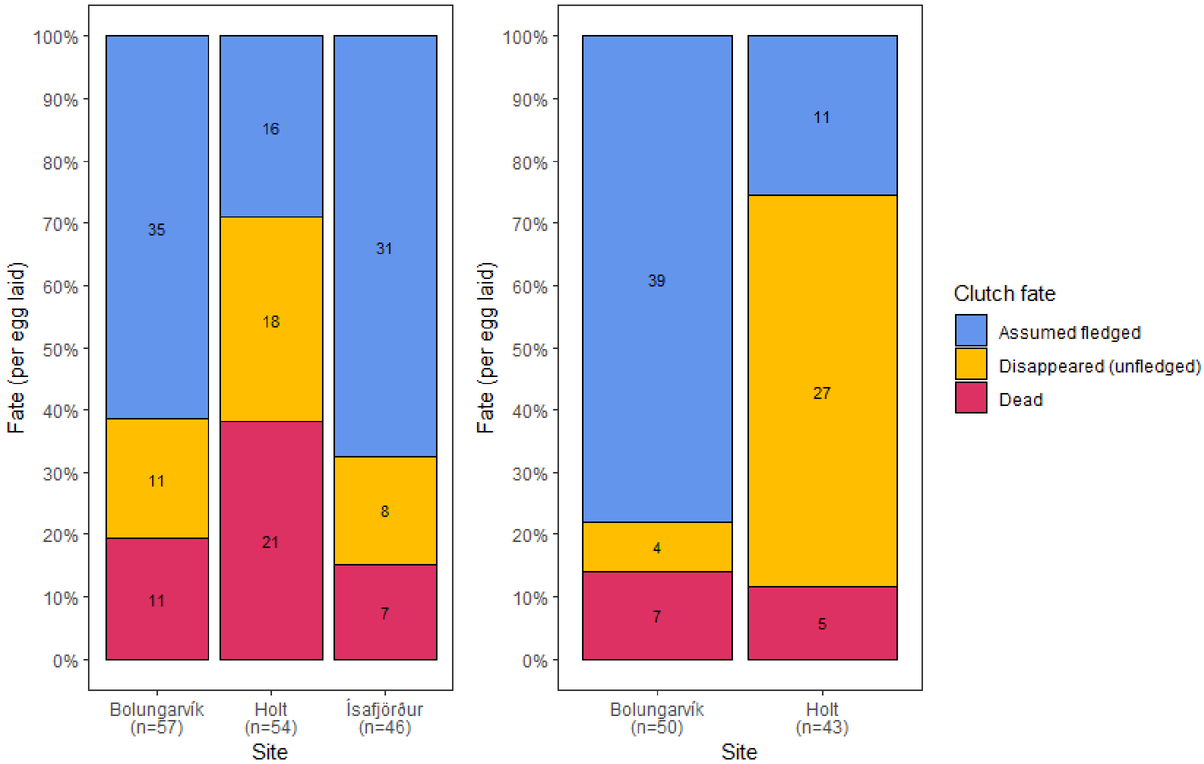

Figure 2.18. *Fates of clutches in each site over the two years; whether chicks died, disappeared, or fledged (per egg laid).*

Additional findings

An unexpected finding was the presence of uneaten flatfish (Figure 2.19) in the enclosures in the Holt study site. They ranged from 4.5-7.9 cm in length and included both European flounder (*Platichthys flesus*) and European plaice (*Pleuronectes platessa*). No such remains were found in Bolungarvík site. The collection of data on this was not consistent as it was not an expected variable but will be considered in the discussion and will be collected more attentively in following years.

Figure 2.19. *Examples of flatfish found within the enclosures in Holt. 2023.*

DISCUSSION

At this point, it is only possible to speculate, based on our observations and references to the literature, about the driving factors behind the variable breeding success among the studied sites. By documenting the fate of the young, we can infer which commonly understood factors influencing breeding success, such as food availability and predation, may be acting on the studied populations. Below we explore several factors.

Food availability

Studies of seabird diets indicate that in Iceland, the primary dietary preference is sandeel (*Ammodytes spp.*) in the southern and western parts of the country, and capelin (*Mallotus villosus*) as well as krill (*Euphausiacea*) in the waters of northern and eastern Iceland (Lilliendahl, 2009; Thompson et al., 1999). Capelin populations are heavily exploited in Iceland (MFRI, 2023; Valtýsson & Jónsson, 2018). While sandeel populations are not harvested in Iceland, the population is substantially reduced since a crash in 2004 (Skarphéðinsson et al., 2016). Poor nesting success of Arctic terns in the southwestern part of the country has been linked to a shortage of available dietary resources (Vigfusdottir et al., 2013). Such breeding failures because of food shortages been documented in other regions as well (Schreiber & Kissling, 2005). In Shetland waters, for instance, a notable decline in the sandeel population after the mid-1980s led to severe breeding failure among seabirds, including Arctic terns, in the region is well documented; abandonment of clutches and starvation of chicks occurred for six consecutive years (Furness, 2007; Monaghan, 1992; Monaghan et al., 1989; Walsh et al., 1990). Observations of other species in Iceland, such as Atlantic puffins (*Fratercula arctica*), indicate that food availability is still better in the northern part of the country (Vigfusdottir et al., 2013).

Arctic terns, under favourable conditions, typically lay around two eggs and may produce one to two fledged chicks (Monaghan et al, 1989). The Bolungarvík site in the first two years of the study aligns with this pattern, and thus it can be said that the colony there is likely experiencing ideal breeding conditions. Conversely, during unfavourable years, the occurrence of single-egg clutches increases, and pairs often encounter difficulties in successfully raising any chicks, as observed in studies by Monaghan et al. (1989), Robinson et al. (2001), and Suddaby & Ratcliffe (1997). Fledging success emerges as a likely limiting factor in Iceland in breeding success, rather than diminished clutch size or reduced hatching success (Petersen et al., 2020; Vigfúsdóttir et al., 2013). While hatching success was not as high in 2023, possibly due to predation of eggs, post-hatching failure was an important factor driving the low productivity in the Holt site in both years of the study thus far.

Our results can be compared with similar studies that took place in several nesting areas on Snæfellsnes (Western Iceland) in the years 2008-2011, where nesting success in most of the nesting areas ranged from 0.05 to 0.5 chicks per nest, and only one nesting area reached an average of one fledgling per nest in one summer (Vigfúsdóttir et al., 2013). The poor nesting success in this region was attributed to food shortages, a theme also evident in the presently studied site in Holt. The presence of uneaten flatfish in Holt's enclosures suggests a limitation in preferred prey, forcing the parents to bring alternative prey sources, which are either inedible or not attractive to the young. When non-preferred prey is used to feed chicks, breeding success is lower (Monaghan et al., 1989; Wanless et al., 2005).

Observations of terns eating non-preferred prey have occurred in other parts of Iceland as well (Vigfusdottir, 2012), although much of this information is anecdotal or unpublished. There were no such observations in the Bolungarvík site, which is performing remarkably well in contrast. Spatial or temporal fluctuations in prey distribution, as highlighted by Burthe et al. (2012), can exacerbate food shortages during young rearing. Surface-feeding habits restrict terns to a narrow prey depth range of 50 cm, making them susceptible to changes in prey depth. The remarkable pole-to-pole migration of Arctic terns also limits their time at breeding grounds for nesting attempts, heightening their sensitivity to the misalignment of prey availability and other environmental conditions.

Predation

Chicks which went missing from the enclosures before reaching the fledging requirements were assumed to have been predated, rather than having escaped from the enclosures (in all cases of missing chicks, the enclosure and its surroundings were thoroughly checked, and the fences were investigated for holes or weak points). As the proportion of dead to missing chicks was relatively similar across all sites in 2022, this could indicate similar levels of pressure from both predation and food limitations. Notably, however, fewer chicks were found dead in their enclosures relative to missing in 2023 in both sites, possibly indicating an increase in predation pressure. It cannot be discounted, however, that between the death of a chick (due, for instance, to starvation) and weekly nest visits, they haven't been scavenged by a predator.

The difference in predation between the sites, if present, could be attributed to various factors. The generally taller and denser vegetation cover in the Bolungarvík site might have offered more hiding and protection to chicks from predators and environmental elements. As none of the predation events were witnessed, it cannot be pinpointed what the predator or predators in this case are – whether avian or mammalian. Colonial nesting in birds is suggested to provide protection against avian predators, although this advantage might be offset by the drawbacks of intraspecific competition during the breeding process (Erwin, 1978). Some studies have found correlates between colony size and predation, but the direction of the correlation was dependent on the type of predators (Brunton, 1999) and should be treated very much as a case-by-case scenario, as the studied sites have different conditions and likely different assemblages and densities of predators.

Optimising enclosure methodology and its limitations

It was evident that being enclosed provided various degrees of stress to the chicks. In trying to escape, the chicks pressed their heads against the mesh frequently enough to cause abrasions of the skin above the bill. Almost all chicks showed signs of doing this at some point during their growth, in both sites, but some cases were more severe than others. It is uncertain whether this impacted the chicks' overall fitness and fledging success in this study. A previous study had indicated that there were no differences in the well-being of the young and age of fledging between enclosed and unenclosed nests (Pearson, 1968); however, this could be dependent on a case-by-case basis and would be pertinent to investigate further. There are obvious challenges to this, as the entire reason for enclosing the nests is to be able to follow the young long enough to determine their fate.

Regardless of the final goal, it is a priority to find a way to reduce stress and injury of the birds; some measures have been tried so far. Enclosing a large area with multiple nests was investigated as a potential solution. In large enclosures, the chicks have more freedom to roam and possibly more opportunity for hiding places in vegetation. This was tried in the first year and has proved challenging in the two main sites given the low density of nests. Certain information is also lost with the method, such as being able to connect the fate of the chicks to the individual nests and associated parameters such as laying date and clutch size.

The addition of shelters in 2023 was also aimed to reduce stress and has been utilized in other studies. Because fence enclosures prevent parents from moving their young to more sheltered areas, making shelters available is important when conducting studies in conservation-important populations (Arnold et al., 2022). We found that use of shelters by the young was inconsistent across the sample nests. Some were frequently used by the chicks, as evident through faeces inside or witnessing the chick itself, while some remained apparently unused even in low-vegetation areas. This could be attributed to individual variation in behaviour or other unknown factors, as all shelters were the same size and positioned in a similar manner within the enclosures.

The amount of vegetation, which differs between the sites, needs to be investigated in the future, for correlations between apparent stress and the amount of cover. McGowan et al. (2018) found that shelters were only used by chicks when inadequate natural cover was present, however in our study site, some nests contained minimal vegetation, and yet the shelters remained apparently unused. Further analysis into the correlation between vegetation type, use of shelter was not conducted, but should be considered in the future. It is possible that undertaking this type of study with enclosures in a poorly vegetated area is not ideal for Arctic terns.

Both types of fence netting (including the type which was recommended in the best practice guidelines) were found to cause abrasions. Further exploration of net options to suit these study sites is necessary, or simply adding a soft barrier at the bottom of the existing enclosures where the chicks are pressing their faces could alleviate the risk of injury. Further, nests should be enclosed only in areas where there is limited human disturbance to reduce additional stressors and attempts to escape.

CONCLUSION & FUTURE WORK

The past two years of the breeding success study have uncovered questions and variables that would be good to isolate to begin to understand what drives the different performance of the two Arctic tern colonies. It is aimed to continue to investigate their breeding success over the coming years. These first two years tried different iterations of the recommended methods to find what works best in these specific study sites, both to make the work practical and to reduce the potential impact on the birds. While there are still matters to improve, in the following years, additional questions can be more confidently answered due to a higher consistency of the method and data collection.

It would be insightful to address the correlation of various factors: For instance, how breeding success varies with the distance of nests to the sea, enclosure size, vegetation cover, shelter vs. no shelter, timing of breeding, clutch size, age of disappearance, age of fledgling, colony size, position within the colony etc., by collecting additional data and also using retrospective data that was collected over the first two years. A third colony could potentially be added for contrast with a third fjord system.

More focused studies could also be done in conjunction with the present one. It is particularly of interest to investigate breeding success as a function of prey availability through a provisioning study. This would involve collecting information about the prey delivered to chicks through observation (e.g., prey type, size, frequency of delivery, etc.), using methodologies such as those outlined in Babcock & Booth (2020). It would also be interesting to understand the predation patterns. This could be investigated using wildlife cameras.

CHAPTER 3: FEASIBILITY OF USING DRONES TO COUNT TERN COLONIES

BACKGROUND & AIMS

The aim of this work is to determine the feasibility of using a drone to map colonies, count nests, and survey breeding success by counting juvenile terns in their colonies. Arctic tern nest surveys have been conducted by physically entering the colony and counting while moving forward in the colony, thereby flushing the birds, and provoking undesirable stress. Even though few methods are available, counting nests in a colony can be time-consuming and usually requires at least 4 people. Surveying Arctic tern colonies with a drone from above could potentially reduce the need for physically entering the colony, but unfortunately, even the drone can cause disturbance and stress because terns could perceive it as a predator scouting for prey in the colonies and eventually attack it. Droning could require only one person (pilot) in the field, but this method presents challenges that this study aimed to explore.

METHODOLOGY

Guidelines for drone flights over tern/gull nests were adhered to, based on Best Practice Monitoring Methods (Babcock & Booth, 2020). According to these guidelines, the Arctic tern colony should be approached at a high altitude (>80 m), and then the flight should slowly descend over the nest to a height of a minimum of 15 m.

A DJI Mavic II Pro drone was used. In 2022, the colonies in Holt, Bolungarvík, and Ísafjörður were initially droned by Sigurlaug Sigurðardóttir. In 2023, further droning tests were carried out in the colonies in Bolungarvík, Broddanes and Langeyri (Suðavik) by Cristian Gallo. In the same year, droning of Arctic tern colonies in Hvallátur and Auðkúla was not performed due to technical issues. The intention was to drone these colonies simultaneously with detailed nest counting to test the accuracy compared to detailed line counting (refer to Chapter 1 of this report).

As recommended, the drone was initially flown over the colonies at a height of >80 m. Subsequently, the drone descended to different heights ranging from 50 to 20 meters to conduct test trials, capturing images of adult birds, nests and young in order to assess if they would have been visible and, therefore, countable.

To run some counting tests on the images, in order to compare between different factors, juvenile terns were divided into two classes based on their sizes. Chicks 2–3 weeks of age were bigger; these were classified as *A* juveniles. Chicks around 1 week of age are small and are difficult or impossible to spot from an altitude of around 40m, due to their size and because they have a tendency to hide under the grass; we refer to these as *B* juveniles.

RESULTS

2022 Drone Trials

Initial drone attempts in 2022 examined 3 colonies (the same which were used for the breeding success study in Chapter 2 of this report). The experiences and findings by Sigurlaug Sigurðardóttir are summarised for each below.

Holt:

This area hosts a variety of other breeding birds, including several wader, gull, and waterfowl species. Among these, whimbrels (*Numenius phaeopus*) proved aggressive towards the drone, flying up to a height of 80 m and attacking the device. After multiple attempts, it was decided to retreat due to the risk posed to the whimbrels. As a result, no usable images were produced from this trial.

Bolungarvík:

According to Sigurlaug's experience, terns were in non-stop flight while attempting to map the area with a drone, even at a height of >80 meters. Attempts were made to approach the nest from three different directions without success, and thus the attempt had not yielded images useful for counting or comparisons.

Ísafjörður:

The droning test at the colony by Bónus in Ísafjörður proved to be a successful test, and part of the colony could be photographed while the birds were settled on their nests. Pictures were taken of the nest at a height of about 30 m, and from them, it was possible to distinguish adult birds on the ground (Gallo & Sigurðardóttir, 2022).

2023 drone trials

Trials in 2023 were conducted with the intent of finetuning the methodology and further experimenting with parameters (e.g. drone altitude, vegetation cover) for optimal visibility of the terns and potential for counting from the images afterwards. The experiences and findings are detailed below:

Broddanes:

The Arctic tern colony in Broddanes is in the vicinity of Bæjarnes (Hostel). The section of the colony situated on the west side of the Hostel was used for the trial. The field is square-shaped (area 4,600 m^2), well delimited by a fence (Figure 3.1). The vegetation comprised mostly of high grass but with patches of lower grass. The trial droning was conducted on 2-3 August 2023. The number of breeding pairs were counted previously, to be approximately 142 pairs, from good vantage point using the flush method (Chapter 1).

Figure 3.1. *Arctic tern colony at Broddanes, west side. Picture taken at 100 m height.*

At an altitude of 40 m, six pictures were needed to cover the area where the colony extend, with each picture covering a space of 800 m2. At this height, terns did not seem bothered by the presence of the drone. Adults were easily spotted on the ground; however, juveniles were difficult to spot (Figure 3.2). Chicks 2–3 weeks of age (A) were large enough that it was possible to locate some in the images (Figure 3.3). Chicks around 1 week of age (B) were too small, were well camouflaged and their tendency to hide under the vegetation make them impossible to spot at a height of 40 m.

Figure 3.2. Zoom in on part of picture taken 40 m height with arrows indicating an adult tern and an A juvenile (2–3-week-old). Picture taken 40 m.

Figure 3.3. Zoom in on part of the picture taken 25 m height with the arrow indicating an adult with a B juvenile (1 week old) and an A juvenile (2-3 weeks old). Picture taken 25 m.

Quantitative analysis was carried out on the pictures taken at 40 m altitude covering the whole area. Drone photos, taken at a 40 m altitude, were analysed for signs of adult terns on the ground, presence of *A* and *B* juveniles, and spots where nests were presumably located but not occupied by adult terns or juveniles at the time of droning (Figure 3.4). From this analysis, we counted 25 adult terns, 124 probable nests, 37 *A* juveniles, and zero *B* juveniles. The total number of possible nests equals 186 which represents 30% more breeding pairs than the 142 pairs previously counted.

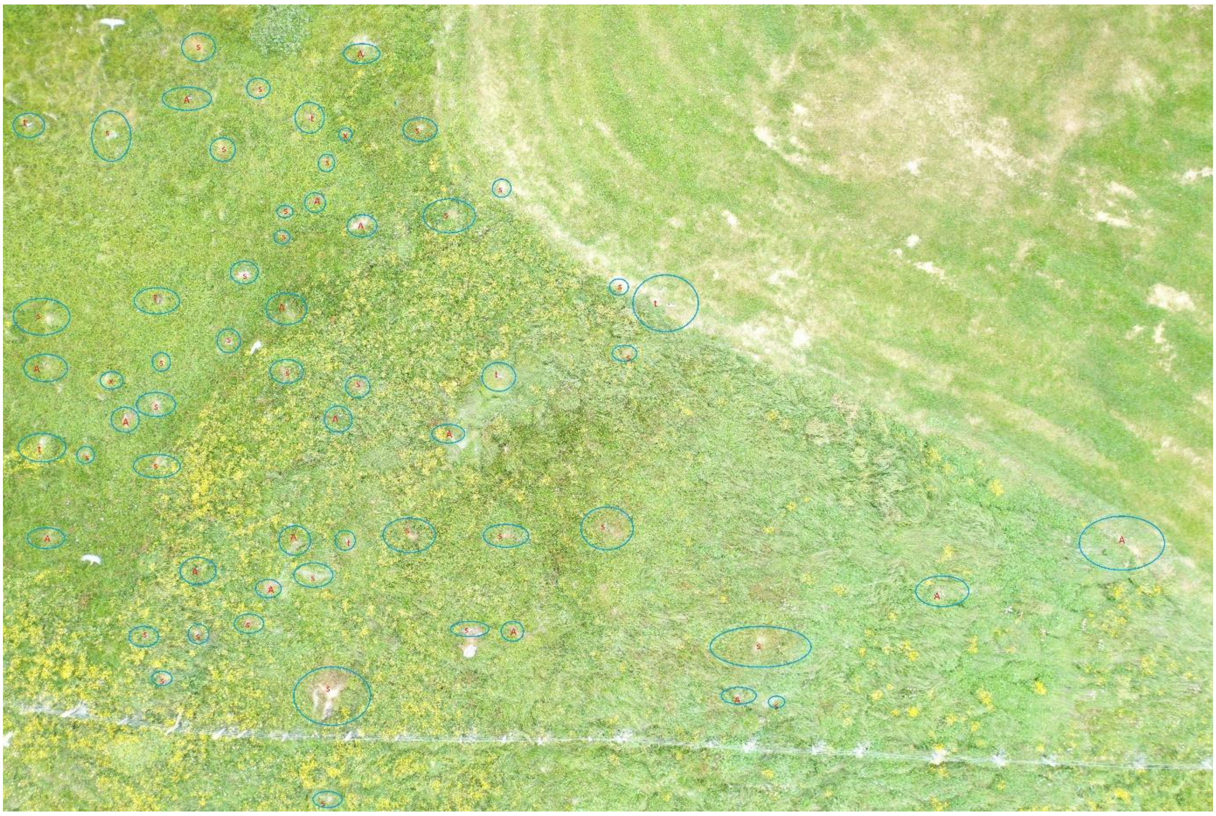

Figure 3.4. Example of picture analyse for adult terns, probable nests, *A* young and *B* young. Picture taken from 40m. Blue circles represent breeding terns and nest spots.

When the drone was moved to a 30 m height, the terns were more frustrated, but it still was not possible to spot the *B* juveniles. At 25 m height, the drone covered an area of 400 m^2; therefore, 14-16 pictures were needed to cover the entire survey area. At this height, adult terns were starting to fly around the drone, and a few of them even attacked it. It is likely that *A* juveniles were hiding and could have been more difficult to count (Figure3.5). Pictures were taken at several test spots where *B* juveniles were known to be present, but still, they could not always be spotted as they were hiding under the vegetation. At under 20 m, terns were consistently attacking the drone.

Figure 3.5. *Zoom in picture of B juvenile present at a spot but not visible. Blue circles represent breeding spots. The numbers indicate the number of young in the ground. Picture taken 25m.*

Bolungarvík:

In Bolungarvík, the Arctic tern colony is more dispersed with fewer nests grouped together. Two subsections of the colony were primarily observed. In the area closer to the town, a few trial tests were conducted on the 28th of July 2023. In this colony, many terns were still on the nest, although a few young were present. At 45 m altitude, pictures were taken of a test area where nests were previously counted a few days prior (Figure 3.6). The area presented low vegetation, and the detailed nest count found 43 nests. From the pictures taken with the drone at 45 m height, it was possible to distinguish the adult tern on the ground, but in some cases, it was not possible to determine if the terns were sitting on the nest or standing. From the count on the pictures, 62 adults were found. This test drone count overshoots the nest counts by 19 nests (almost 1/3). In a different section of the colony, where fence enclosures were erected around the nests as part of the breeding success study (Chapter 2), a zoomed-in example shows that at this site *A* juveniles could be spotted in the nest while *B* juveniles were still challenging to spot (Figure 3.7).

Figure 3.6. *Test count of adult Arctic terns nesting/standing on a nesting ground. Picture taken 45m height.*

Figure 3.7. *Example of zoom-in from a drone picture taken at 45 m height. Yellow circles indicate nesting terns, black arrows indicate young terns.*

At 25 m altitude *B* juveniles were still sometimes very hard to spot even on the ground with low vegetation cover (Figure 3.8). At 15 m altitude, drone pictures covered around 80 m^2 of ground, it became feasible to spot the *B* juveniles, but high vegetation still proofed an obstacle for definite count (Figure 3.9).

Figure 3.8. *Arctic tern B young with parent on low vegetation ground. Picture taken 25m.*

***Figure 3.9**. Picture taken 15 m altitude. Red circles indicate young terns.*

DISCUSSION

In 2022, the feasibility of using drones for nest surveys varied across colonies. Factors such as the presence of defensive whimbrel and stressors affecting adult tern behaviour during trials played a significant role in influencing practicality. Despite mixed results in the presently studied nesting areas, successful drone operations over tern nests have been reported elsewhere (Babcock & Booth, 2020). This may reflect the behaviour of the terns present near Bónus, Ísafjörður, who are in close proximity to humans, cars, and nest directly underneath the flight path of aircraft.

Building on the insights gained from the 2023 trials, it was determined that estimating nesting terns at heights between 40-50 meters using the DJI Mavic Pro II drone was feasible in select colonies. Total nest counts at 40-50 meters were typically realistic, irrespective of vegetation density. However, both trials resulted in numbers which typically had roughly 30% more breeding pairs than surveys conducted using the on-ground nest counts.

In one trial (Bolungarvík), this higher number may be attributed to both tern parents being on the ground. The higher count in a subsequent trial (Broddanes) is likely due to counting of the probable nesting spots rather than adult terns sitting on the nest. This inaccuracy may be attributed to the late-season tests, as juvenile presence means parents do not sit on the nest, and both could be foraging for food at the same time or be both present at the nest site. Still, it cannot be ruled out that that adult terns were present in the colony for protection due to the presence of the drone hovering over the colony.

Using a drone proved unfeasible for breeding success assessments, at least at 40 m altitude, as only part of the juveniles (2-3 weeks old) could be counted while the smaller chicks (1-week-old) could not. At 25-30 meters, drone resolution allowed for better distinction of the chicks, but the trial test proved ineffective in spotting the younger juveniles since they hide under vegetation cover. Babcock and Booth (2020) seem to suggest taking photos at a 15 m altitude, and indeed at this altitude, spotting juveniles is more feasible. However, we found this height caused too much stress to the adult terns and, and by covering a limited area at a time would prolong this stress and require more time spent in the colony, at least if the entire colony needs to be surveyed.

CONCLUSION

We found that flying at 30-40 meters was determined to be the optimal altitude for the safety of the terns and cost-effectiveness in terms of time spent. This altitude facilitated counting sitting adults, nesting spots, and some of the bigger juvenile terns. Smaller juveniles, 1st-week chicks, were challenging to spot even at a 20 m height, being difficult to discern from the background terrain. Accurate chick counting required consideration of varying age groups, with a higher error rate for smaller chicks. We further recommend exploring enhanced drone settings such as infrared imagery, improving image quality, and understanding the impact of variables such as drone colour (white versus black), season, and time of day on the reaction of the terns. Despite mixed results, success in certain colonies highlights the potential of drones for Arctic tern surveys.

OVERALL CONCLUSION

Birds such as terns are considered good indicators of the state of ecosystems, telling us the state of the habitat in which they live in and obtain resources from. Long-term monitoring can provide valuable information about changes and pressures on land, as well as in the marine system. Over time, the findings from the breeding success study (Chapter 2) can be analysed in conjunction with the colony counts (Chapter 1) to have a fuller picture of Arctic tern performance and trends in the Westfjords region, aided also by new methods of quantifying colonies such as with the use of drones (Chapter 3). Scientists and wildlife managers face the challenge of identifying which phase of the species' yearly cycle is most vulnerable or contributing to population declines. This knowledge is crucial for implementing conservation measures aimed at preserving or restoring these populations (Petersen et al., 2020). Given Iceland's significance in the tern's annual life history and the known struggles of Arctic terns and other seabirds alike in recent decades, it is important to continue to fill in knowledge gaps, including monitoring the numbers and shifts of colonies, and understanding the drivers of breeding success in the region.

REFERENCES

Arnold, J.M., Oswald, S.A., Wilson, S., and Szczys, P. (2022). Understanding widespread declines for Common Terns across inland North America: productivity estimates, causes of reproductive failure, and movement of Common Terns breeding in the large lakes of Manitoba. *Avian Conservation and Ecology*, *17*(1),14. https://doi.org/10.5751/ACE-02067-170114

Asbirk, S., Berg, L., Hardeng, G., Koskimies, P., Petersen, Æ. (1997). Population sizes and trends of birds in the Nordic countries: 1978–1994. *TemaNord, 614*, 88.

Babcock, M & Booth, V. (2020). *Tern Conservation Best Practice Monitoring Methods*. Roseate Tern Life Project.

BirdLife International. (2023). *Species factsheet: Sterna paradisaea.* http://datazone.birdlife.org/species/factsheet/arctic-tern-sterna-paradisaea

Brindley E., G., N. Mudge, C. Dymond, B. Lodge, D. Ribbands, P. Steele, E. Ellis, D. Meek and S. a. N. Ratcliffe. (1999). "The status of Arctic Terns Sterna paradisaea at Shetland and Orkney in 1994". Atlantic Seabirds 1: 135-143.

Brunton, D. (1999). "Optimal" Colony Size for Least Terns: An Inter-Colony Study of Opposing Selective Pressures by Predators. *The Condor, 101*(3), 607–615. https://doi.org/10.2307/1370190

Bullock, I.D. & Gomersall, C.H. (1981). The breeding populations of terns in Orkney and Shetland in 1980. Bird Study 28:187-200.

Burthe, S., Daunt, F., Butler, A., Elston, D., Frederiksen, M., Johns, D., Newell, M., Thackeray, S. & Wanless, S. (2012). Phenological trends and trophic mismatch across multiple levels of a North Sea pelagic food web. *Marine Ecology Progress Series, 454*, 119-133.

Cury, P.M., Boyd, I.L., Bonhommeau, S., Anker-Nilssen, T., Crawford, R.J.M., Furness, R.W., Mills, J.A., Murphey, E.J., Österblom, H., Paleczny, M., Piatt, J.F., Roux, J.P., Shannon, L., & Sydeman, W.J. (2011). Global Seabird Response to Forage Fish Depletion—One-Third for the Birds. *Science*, *334*, 1703-1706. doi: 10.1126/science.1212928

Devlin, C. M., A. W. Diamond, S. W. Kress, C. S. Hall and L. Welch (2008). Breeding Dispersal and Survival of Arctic Terns (Sterna paradisaea) Nesting in the Gulf of Maine. 125: 850-858.

Drent, R.H., Klaassen, M. & Zwaan, B. (1987). Predictive growth budgets in terns and gulls. *Ardea, 80*, 5-17.

Egevang, C. (2010). Migration and breeding biology of Arctic terns in Greenland. PhD thesis. Greenland Institute of Natural Resources, Dep. of Arctic Environment, NERI, Aarhus

University & Department of Biology, Centre for Macroecology, Evolution and Climate, University of Copenhagen. Greenland Institute of Natural Resources & National Environmental Research Institute, Aarhus University, Denmark. 104 pp.

Egevang, C., Stenhouse, I.J., Phillips, R., Petersen, Æ., Fox. J.W. & Silk, J.R.D. (2010). Tracking of Arctic terns Sterna paradisaea reveals longest animal migration. Proceedings of the *National Academy of Sciences*, *107*, 2078–2081.

Erwin, R.M. (1978). Coloniality in terns: the role of social feeding. *Condor*, *80*, 211-215.

Fayet, A.L., Clucas, G.V., Anker-Nilssen, T., Syposz, M., Hansen, E.S. (2021). Local prey shortages drive foraging costs and breeding success in a declining seabird, the Atlantic puffin. *Journal of Animal Ecology*, *90*(5), 1152-1164. https://doi.org/10.1111/1365-2656.13442

Furness, R.W. (2007) Responses of seabirds to depletion of food fish stocks. *Journal of Ornithology*, *148*, 247-252.

Gallo, C. & Sigurðardóttir, S. (2022). Framvinduskýrsla um fuglavöktun á Vestfjörðum árið 2022. NV nr. 21-22. Bolungarvík.

Garðarsson, Á. (1995). Numbers and distribution of common murre Uria aalge, thick-billed murre U. lomvia and razorbill Alca torda in Iceland. *Bliki*, *16*, 47-65.

Garðarsson, Á. (2006). Recent changes in numbers of cliff-breeding seabirds in Iceland. *Bliki*, *27*, 13–22.

Garðarsson, Á., Guðmundsson G.A., & Lilliendahl, K. (2011). Numbers of Northern Fulmars Fulmarus glacialis in Iceland: notes on early records, and changes between 1983–86 and 2005–09. *Bliki*, *31*, 1–10.

Hamer, K.C., Furness, R.W. & Caldow, R.W.G. (1991) The effects of changes in food availability on the breeding ecology of great skuas Catharacta skuain. Shetland. *Journal of Zoology*, *223*, 175-188

Hays, H. & LeCroy, M. (1971). Field Criteria for Determining Incubation Stage in Eggs of the Common Tern. *The Wilson Bulletin*, *83*(4), 425-429.

Hilmarsson, J.O. (2017). Varpfuglar á Seltjarnarnesi 2017. Unnið fyrir umhverfisnefnd Seltjarnarness.

Klaassen, M., Bech, C., Masman, D. & Slagsvold, G. (1989). Growth and energetics of Arctic Tern chicks (Sterna paradisaea). *Auk*, *106*, 240-248.

Liebezeit, J. R., Smith, P.A., Lanctot, R.B., Schekkerman, H., Tulp, I., Kendall, S.J., Tracy, D.M., Rodrigues, R.J., Meltofte, H., Robinson, J.A., Gratto-Trevor, C., McCaffery, B.J., Morse, J., & Zack, S.W. (2007). Assessing the development of shorebird eggs using the flotation method: species-specific and generalized regression models. *The Condor*, *109*, 32 – 47.

Lilliendahl, K. (2009). Winter diets of auks in Icelandic coastal waters. *Marine Biology Research*, *5*(2), 143-154. DOI: 10.1080/17451000802279636

Lilliendahl, K. & Solmundsson, J. (1998). The summer diets of six Icelandic seabird species. *Bliki*, *19*, 1-12.

Lilliendahl, K., Hansen, E.S., Bogason, V., Sigursteinsson, M., Magnúsdóttir, M.L., Jónsson, P.M., Helgason, H.H., Óskarsson, G.J., Óskarsson, P.F., Sigurðsson, Ó.J. (2013). Recruitment failure of Atlantic puffins Fratercula arctica and sandeels Ammodytes marinus in Vestmannaeyjar islands. *Náttúrufraedingurinn*, *83*, 65–79.

McGowan, P.C., Reinstma, K.M., Sullivan, J.D., Devoss, K.P., Wall, J.L., Zimnik, M.D., Callahan, C.R., Schultz, B., & Prosser, D.J. (2018). Use of Bank Swallow (*Riparia riparia*) burrows as shelter by Common Tern (*Sterna hirundo*) chicks. *Waterbirds*, *41*, 179-182. https://doi.org/10.1675/063.041.0210

MFRI. (2023)., Loðna/Capelin - Mallotus villosus. In: Ástand nytjastofna sjávar og ráðgjöf 2023 / State of marine resources and advice 2023. https://www.hafogvatn.is/static/extras/images/31-capelin-autumn1408221.pdf

Milesi-Gaches D., Lhériau A., 2022. Census of breeding seabirds in Vigur Island, Westfjords, Iceland in 2021. Bird Census News 2022, 35/1–2: 10–20.

Mitchell, P.I., Newton, S.F., Ratcliffe, N., Eds, T.E.D., Dunn, T.E., Poyser, A.D. & May, L. (2000). Seabird Populations of Britain and Ireland (eds PI Mitchell, SF Newton, N Ratcliffe, and TE Dunn). T and A.D. Poyser, London.

Monaghan, P. (1992). Seabirds and sandeels: the conflict between exploitation and conservation in the northern North Sea. Biodiversity & Conservation, 1, 98–111. https://doi.org/10.1007/BF00731037

Monaghan, P., Uttley, J. D., Burns, M. D., Thaine, C., Blackwood, J. (1989). The Relationship Between Food Supply, Reproductive Effort and Breeding Success in Arctic Terns Sterna paradisaea. *Journal of Animal Ecology*, *58*(1), 261-274. http://dx.doi.org/10.2307/4999

Newton, I. (1998). *Chapter 7 – Food Supply, in: Population Limitation in Birds*. Academic Press. https://doi.org/10.1016/B978-012517365-0/50007-7

Nisbet, I.C.T., Drury, W.H. (1972). Measuring breeding success in common and roseate terns. *Bird-Banding*, *43*(2), 97-107.

Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, M., Foster, S. & Reid, J.B. (2008). Seabirds as indicators of the marine environment. *ICES Journal of Marine Science*, *65*(8), 1520–1526. https://doi.org/10.1093/icesjms/fsn155

Pearson, T.H. (1968). The Feeding Biology of Sea-Bird Species Breeding on the Farne Islands, Northumberland. *Journal of Animal Ecology*, *37*(3), 521-552. https://doi.org/10.2307/3073

Petersen, Æ. (2006). Iceland, pp. 42–47. In: Bakken, V., Boertmann, D., Mosbech, A., Olsen, B., Petersen, Æ., Ström, H., Goodwin, H. (eds). Nordic Seabird Colony Databases: results of a Nordic project on seabird breeding colonies in Faroes, Greenland, Iceland, Jan Mayen and Svalbard. TemaNord 2006: 512, p 96.

Petersen, Æ. (2008). Iceland, pp 19–22. In: Petersen A, Irons D, Anker-Nilssen T, Artukhin Y, Barrett R, Boertmann D, Egevang C, Gavrilo MV, Hario M, Mallory M, Mosbech A, Olsen B, Osterblom H, Robertson G, Strøm, H (eds) CAFFs Circumpolar Biodiversity Monitoring Program: Framework for a Circumpolar Arctic Seabird Monitoring Network. CAFF CBMP Report no. 15. 67 pp.

Petersen, Æ., Robertson, G.J., Thorstensen, S., Mallory, M.L. (2020). Annual survival of Arctic terns in western Iceland. *Polar Biology*, *43*, 1843-1849. https://doi.org/10.1007/s00300-020-02749-5

Robinson, J.A., Hamer, K.C. & Chivers, L.S. (2001). Contrasting Brood Sizes in Common and Arctic Terns: The Roles of Food Provisioning Rates and Parental Brooding. *The Condor*, *103*(1), 108-117. https://doi.org/10.1093/condor/103.1.108

Schreiber, J. & Kissling, W.D. (2005). Factors affecting the breeding success of Arctic Terns Sterna paradisaea in a colony at Kaldbaksbotnur, Faroe Islands. *Atlantic seabirds*, *7*(3), 97- 105.

Skarphéðinsson, K.H. (2018). Kría Sterna paradisaea https://www.ni.is/is/biota/animalia/chordata/aves/charadriiformes/kria-sterna-paradisaea

Skarphéðinsson, K.H., Katrínardóttir, B., Guðmundsson, G.A., & Auhage, S.N.V. (2016). FJÖLRIT Náttúrufræðistofnunar nr. 55. Mikilvæg Fuglasvæði á Íslandi. Náttúrufræðistofnun Íslands.

Suddaby, D. & Ratcliffe, N. (1997). The Effects of Fluctuating Food Availability on Breeding Arctic Terns (Sterna Paradisaea). *The Auk*, *114*(3), 524–530. https://doi.org/10.2307/4089260

Sutherland W.J., 1996. Ecological Census Techniques. A Handbook. University of East Anglia. Cambridge University Press.

Thompson, D.R., Lilliendahl, K., Sólmundsson, J., Furness, R.W., Waldron, S. & Phillips, R.A. (1999). Trophic Relationships among Six Species of Icelandic Seabirds as Determined through Stable Isotope Analysis. *The Condor*, *101*, 898-903. 10.2307/1370085.

Umhverfisráðuneytið. (1992). Iceland: national report to UNCED. Reykjavík: Ministry of the Environment.

Vigfúsdóttir, F. (2012). Drivers of productivity in a subarctic seabird: Arctic Terns in Iceland. Doctoral dissertation. University of East Anglia, UK.

Vigfúsdóttir, F., Gunnarsson, T.G., & Gill, J.A. (2013). Annual and between colony variation in productivity of Arctic Terns in West Iceland. *Bird Study*, *60*(3), 1-9. https://doi.org/10.1080/00063657.2013.811214

Valtýsson, H.Þ, & Jónsson, S. (2018). *Impacts of a Changing Climate on Icelandic Marine Stocks.* In: Mueter, F.J., Baker, M.R., Dressel, S.C., & Hollowed, A.B. (eds.*), Impacts of a Changing Environment on the Dynamics of High-latitude Fish and Fisheries.* Alaska Sea Grant, University of Alaska Fairbanks. https://doi.org/10.4027/icedhlff.2018.01

Walsh, P.M., Avery, M.I. & Heubeck, M. (1990). *Seabird numbers and breeding success in 1989.* Report no. 1071, Nature Conservancy Council, Peterborough, United Kingdom.

Walsh, P.M., Halley, D.J., Harris, M.P., del Nivo, A., Sim, I.M.W. & Tasker, M.L. (1995). Seabird monitoring handbook for Britain and Ireland. JNCC/RSPB/ITE/Seabird Group, Peterborough.

Wanless, S., Harris, M.P., Redman, P. & Speakman, J. (2005). Low fish quality as a probable cause of a major seabird breeding failure in the North Sea. *Marine Ecology Progress Series 294*, 1-8. DOI: 10.3354/meps294001

Þorsteinsson, Þ. & Thorstensen, S. (2014). Fuglar í Hrísey á Eyjafirði. Talning sumarið 2014 með samanburði við talningar 1994 og 2004. Unnið fyrir Umhverfisnefnd Akureyrar.

APPENDIX

Table 1. *Inventory of surveys of Arctic tern colonies, intended for periodic updates.*

ID	County	Town/house	Location	GPS	Date	Breed. pairs 2020-2021	Eider colony
5	Borgarlandi	Borg	Borgareyri	65.478302, -22.023665	24.6.2020	10-15	
6	Reykhólasveit	Hrísthóll	Hríshólsvatns	65.530749, -22.081006	24.6.2020	1-3	
7	Reykhólasveit	Miðhús	Islands	65.462677, -22.129441	25.6.2020	100-200	X
8	Reykhólasveit	Reykhólar	Einir	65.443213, -22.185151	25.6.2020	3	
9	Reykhólasveit	Reykhólar	Langavatn	65.443291, -22.198438	25.6.2020	6	
10	Reykhólasveit	Árbær	island	65.484244, -22.392550	25.6.2020	21	Not sure
12	Reykhólasveit	Hofstaðir	sea shore	65.549419, -22.158743	24.6.2020	2	
15	Kollafjörður	Múli	house and estuary	65.611505, -22.508596	24.6.2020	2	
16	Hjarðarnes	Fossá	Hrúthólmi	65.542024, -23.140423	24.6.2020	50-70	
18	Brjánslækur	Seftjörn	field by house	65.526241, -23.193306	24.6.2020	80	
19	Brjánslækur	Brjánslækur 2	field by house	65.524605, -23.198065	24.6.2020	100-150	
20	Barðaströnd	Rauðsdalur	sea shore	65.488771, -23.291366	24.6.2020	6-10	
21	Barðaströnd	Birkimelur	by the road	65.520758, -23.403352	24.6.2020	10	
22	Barðaströnd	Innri-Múli	sheephouse	65.487821, -23.462032	24.6.2020	14	
23	Barðaströnd	Litlahlíð	gravel down house	65.477659, -23.520168	24.6.2020	1	
24	Barðaströnd	Litlahlíð	Hliðarskers	65.473875, -23.539563	24.6.2020	5	
25	Barðaströnd	Miðhlíð	by the road	65.471694, -23.573339	24.6.2020	2	
27	Barðaströnd	Fit	by the house	65.467458, -23.648975	24.6.2020	1	
30	Rauðasandi	Máberg	Skógardalsár	65.465806, -23.942978	24.6.2020	1	
31	Rauðasandi	Lambavatn	by house and fields	65.488726, -24.083979	24.6.2020	700	
35	Hvallátur	Ásgarður	by house	65.528881, -24.458072	4.6.2020	700	
39	Patreksfjörður	Hænuvík	fields	65.613064, -24.200341	22.6.2021	700	
40	Gjögrabót	Hótel Látrabjarg	field at Ásveg	65.583193, -24.133838	22.6.2021	300	
47	Patreksfjörður	Skeiðseyri	by the road	65.532015,	24.6.2020	2-5	

				-23.785973			
48	Tálknafjörður	Bær	Church and campsite		24.6.2020	0?	
50	Arnarfirði	Hvestudalur	between roads and seashore	65.707816, -23.696598	23.6.2020	3-5	
51	Arnarfirði	Hvestudalur	by the house and fields	65.703816, -23.696415	23.6.2020	20-25	
52	Bíldudalur	Lítla eyri	Golf course and fields over the eider farm	65.676782, -23.612499	23.6.2020	120-150	X
53	Arnarfirði	Otrardalur	by road	65.663802, -23.561837	23.6.2020	7	
54	Arnarfirði	Foss	peninsula, fields and sea shore	65.603203, -23.542841	23.6.2020	630	X
55	Arnarfirði	Reykjarfjörður	by road and seashore	65.622544, -23.472127	23.6.2020	1	
58	Arnarfirði	Auðkúla	sea shore	65.759132, -23.472424	4.6.2020	700	X
60	Dýrafjörður	Hólar	Sandasandar-Hólalón	65.872012, -23.552899	16.6.2020	30-50	
61	Dýrafjörður	Sandakerling	airport	65.875809, -23.539374	16.6.2020	10-15	
62	Dýrafjörður	Hvammur	around the houses	65.858010, -23.410382	16.6.2020	10	
65	Dýrafjörður	Höfði	sea shore	65.878585, -23.440173	16.6.2020	21	
66	Dýrafjörður	Neðri-Hjarðardalur	Hjarðardalsárósar	65.882859, -23.443833	16.6.2020	25-35	
67	Dýrafjörður	Mýrar	Mýramelur	65.897168, -23.507604	18.6.2020	100-120	X
69	Dýrafjörður	Alviðra	sheep house	65.926833, -23.604528	18.6.2020	5	
70	Ingjaldssandur	Sæból	sea shore	66.057812, -23.700191	18.6.2020	50-70	
72	Önundarfjörður	Þórustaðir	by road	66.015147, -23.458797	16.6.2020	40-60	X
73	Önundarfjörður	Holt	Holtsoddi	66.013516, -23.439741	16.6.2020	300-400	X
75	Önundarfjörður	Innri Veðrará	eider farm	66.003036, -23.399866	30.6.2020	21	X
76	Bolungarvíkurbær	Sandur	Sandur	66.145929, -23.235575	11.6.2020	150-190	X
77	Bolungarvíkurbær	Miðdalur	by road	66.121679, -23.258004	11.6.2020	20-30	
78	Skutulsfjörður	Suðurtangi	gravel road	66.066428, -23.123672	18.6.2020	350	
80	Skutulsfjörður	Bónus	old fields	66.060539, -23.175745	18.6.2020	90-100	
82	Skutulsfjörður	Skipeyri	airport	66.054853, -23.147929	17.6.2020	20-25	
84	Skutulsfjörður	Heimabær	field close to houses	66.094901, -23.049576	17.6.2020	320	
85	Suðavik	Langeyri	Langeyrartjörn	66.022995, -22.990891	17.6.2020	120-150	

86	Álftafjörður	Dvergastein	by road	65.998892, -23.039659	17.6.2020	5	
89	Hestfjörður	botn	sea shore and estuary	65.908426, -22.987591	19.6.2020	20-25	
91	Skötufjörður	Kleifar	by road	65.893011, -22.851132	19.6.2020	10-20	
93	Ísafjarðardjúp	Ögur	by road	66.042012, -22.732365	19.6.2020	3	
94	Ísafjarðardjúp	Ögurhólmar	around lake	66.043093, -22.681723	15.6.2021	35	X
95	Ísafjarðardjúp	Strandsel	by road	66.018769, -22.665549	19.6.2020	3	

ID	County	Town/house	Location	GPS	Date	Bred. pairs 2020-2021	Eider colony
96	Ísafjarðardjúpi	Þernuvík	Eider farm	65.979215, -22.595186	19.6.2020	210	X
97	Mjóafjörður	Látur	by road	65.951829, -22.584468	19.6.2020	5	
98	Mjóafjörður	Hrútey	Eider farm	65.925521, -22.572605	6.6.2020	280	X
100	Ísafjarðardjúpi	Reykjanes	sea shore	65.928614, -22.428200	6.6.2020	20	
101	Ísafjarðardjúpi	Svansvík	sea shore	65.882796, -22.427279	19.6.2020	10	
102	Ísafjörður	Gjörvidalur	Gjörvidalsá	65.785111, -22.557315	19.6.2020	12	
104	Ísafjörður	Múli	Múli	65.829040, -22.441954	19.6.2020	5	
105	Langadalsströnd	Arngerðareyri	sea shore	65.894071, -22.381497	19.6.2020	10	
106	Langadalsströnd	Nauteyri	Smelting facility	65.933628, -22.377257	19.6.2020	5-10	
107	Langadalsströnd	Nauteyri	estuary	65.934676, -22.376469	19.6.2020	8	
108	Langadalsströnd	Hamar	by road	65.989550, -22.400939	19.6.2020	6	
109	Langadalsströnd	Melgraseyri	Melgraseyri-gravel	66.024623, -22.460175	19.6.2020	10	
112	Ísafjarðardjúpi	Æðey	old fields-islands-house	66.099286, -22.661738	20.6.2020	402	X
124	Ísafjarðardjúpi	Vígur	close to houses	66.048387, -22.828788	27.6.2021	600-700	X
134	Ófeigsfjörður	Eyðibýli	houses	66.050667, -21.705333	16.6.2021	20-35	
137	Ingólsfjörður	Eyri	old factory	66.022728, -21.632830	16.6.2021	2	
139	Ingólsfjörður	Munaðarnes	Sjálberg	66.083477, -21.596779	16.6.2021	35-50	
142	Norðurfjörður	Norðurfjörður 2	by road	66.051326, -21.563244	16.6.2021	1	
143	Trékyllisvík	Árnes	Árneskirkju 1	66.011936, -21.510541	16.6.2021	300-400	

144	Trékyllisvík	Árnes	Árnesey	66.020586, -21.486418	16.6.2021	100	X
145	Trékyllisvík	Finnbogastaðir	field	66.013630, -21.487482	16.6.2021	30-50	
147	Trékyllisvík	Litla Ávík	sheep house	66.021591, -21.424686	16.6.2021	2	
150	Reykjarfjörður	Djúpavík	by road	65.945032, -21.560463	16.6.2021	20-30	
151	Reykjarfjörður	Djúpavík	old pier	65.944794, -21.556347	16.6.2021	2	
152	Kaldbaksvík	Kaldbakur	between road and seashore	65.877005, -21.314338	16.6.2021	1	
153	Kaldbaksvík	Kaldbaksvatn	between two roads	65.871370, -21.325046	16.6.2021	3	
154	Kaldbaksvík	Svansbuð	summerhouse	65.871566, -21.311409	16.6.2021	10	
156	Selströnd	Bjarnarnes	by road	65.730505, -21.371526	16.6.2021	35	
157	Selströnd	Bakkagerði/Bær	field, by road	65.706772, -21.417411	23.6.2020	500-600	
158	Selströnd	Gautshamar	Kokkálsvík	65.690913, -21.497734	23.6.2020	10	
159	Selströnd	Hafnarhólmur	summer houses	65.691856, -21.501706	23.6.2020	2	
160	Selströnd	Hafnarhólmur	by road	65.691894, -21.498092	23.6.2020	2	
161	Selströnd	Vík	harbor area	65.692269, -21.508375	23.6.2020	2	
164	Steingrímsfirði	Hella	fields	65.713494, -21.606861	23.6.2020	1	
166	Steingrímsfirði	Bassastaðir	Krossholt	65.766011, -21.694839	23.6.2020	14	
167	Steingrímsfirði	Stakkanes	Sjóarhólmar	65.769356, -21.779222	23.6.2020	40-70	X
169	Steingrímsfirði	Ytri-Ós	Stakkamýri	65.727108, -21.697967	23.6.2020	20-28	
171	Steingrímsfirði	Skeljavík	Skeljavíkurgrundir	65.685111, -21.673558	23.6.2020	60-90	
172	Steingrímsfirði	Víðidalsá	Víðidalsá	65.681669, -21.684678	23.6.2020	210	
173	Steingrímsfirði	Víðidalsá	Víðidalsárhólma	65.678181, -21.664475	23.6.2020	30-50	
175	Steingrímsfirði	Hrófá	Hrófárhólma	65.668856, -21.659111	23.6.2020	4-7	
176	Steingrímsfirði	Hrófá	Hólmanes	65.669150, -21.664889	23.6.2020	140	
177	Steingrímsfirði	Hrófá	Hrófá	65.659869, -21.665567	23.6.2020	30-42	
178	Steingrímsfirði	Tungugröf	Hvaley, Tungugrafartangar and islands	65.656669, -21.654361	23.6.2020	42	X
179	Steingrímsfirði	Húsavík	Hrafnsnes	65.653097, -21.641836	23.6.2020	30-50	X
180	Steingrímsfirði	Húsavík	Húsavíkurmöl	65.644181, -21.637492	23.6.2020	70	

181	Steingrímsfirði	Heiðarbær	sea shore	65.641138, -21.606509	25.6.2020	100-150	
182	Steingrímsfirði	Kirkjuból	Orrustutangi	65.641875, -21.580889	23.6.2020	25-42	
183	Steingrímsfirði	Kirkjuból	Langitangi	65.639933, -21.568058	23.6.2020	8-14	
184	Steingrímsfirði	Kirkjuból	Stekkjarhöfði	65.638828, -21.559303	23.6.2020	8-14	
185	Steingrímsfirði	Heydalsá	Naustavík	65.639114, -21.536000	23.6.2020	8-14	
186	Steingrímsfirði	Heydalsá	malarkrús V	65.639372, -21.526683	23.6.2020	56	
187	Steingrímsfirði	Heydalsá	Heydalsár	65.637267, -21.523692	23.6.2020	8-14	
188	Steingrímsfirði	Tröllatunga	Tröllutunguá	65.632867, -21.686314	23.6.2020	35-50	
189	Steingrímsfirði	Smáhamrar	from road down to the sea	65.638843, -21.485475	25.6.2020	700-900	
191	Kollafirði	Litla Fjarðarhorn	by road	65.564378, -21.483233	25.6.2020	15-20	
192	Kollafirði	Undraland	by road-fields	65.557127, -21.474622	25.6.2020	15-20	
193	Kollafirði	Broddanes	Hostel	65.598670, -21.363432	25.6.2020	250	X
197	Kollafirði	Broddanes	Broddadalsá 2, sheephouse	65.598790, -21.340000	25.6.2020	5-10	