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BACHELOR THESIS

Optimizing Predator Exclosures for Little Terns

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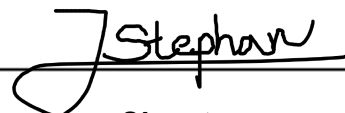
Optimizing Predator Exclosures for Little Terns

Declaration:

I hereby declare that this bachelor thesis has been written independently, has not previously been submitted for examination purposes, that no other aids than those indicated have been used, and that literal and analogous quotations are marked as such.

Freising, 29.08.2025

Location, Date

A handwritten signature in black ink, appearing to read 'J. Stephan', written over a horizontal line.

Signature

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Abstract

This bachelor thesis investigates the factors influencing the breeding success of Little Terns and other shorebirds within predator exclosures at three study sites in the Danish Wadden Sea: Blåvandshuk, Lakolk Strand on Rømø, and Grønningen on Fanø. The research focused on sand drift dynamics, habitat characteristics, decoy effects, predator pressure, and human disturbance.

A standardized sampling design was applied at Blåvandshuk and Lakolk Strand to monitor changes in sand drift and surface cover composition. Moreover, environmental parameters and Little Tern responses to 3D-printed decoys were recorded at Blåvandshuk. In addition, nest monitoring at all three study sites provided insights into breeding success and nesting habitat preferences. Predator pressure was assessed by an artificial nest experiment at Blåvandshuk and Lakolk Strand. Finally, surveys of beach visitors and dog counts at Blåvandshuk quantified awareness of the seasonal dog leash law and potential human disturbances.

Results showed that both Lakolk Strand and Blåvandshuk were affected by sand drift, with Blåvandshuk more severely exposed due to a higher proportion of bare sand. Little Terns showed a preference for shell-rich, sparsely vegetated backshore areas within predator exclosures. The 3D-printed decoys effectively attracted Little Terns, but did not lead to nesting, likely due to more suitable habitat elsewhere. Observations of eight fledged chicks at Grønningen, together with one fledged chick from Juvre Sand on Rømø represented the only breeding success of Little Terns in the Danish Wadden Sea in 2025, marking the least successful breeding season on record. Artificial nest experiments revealed high predation rates at Blåvandshuk, mainly by red foxes and corvids. Predation rates were much lower at Lakolk Strand, highlighting the effectiveness of ongoing predator control on Rømø. Human disturbance, especially from off-leash dogs, remains a major threat to resting and breeding shorebirds at Blåvandshuk.

Altogether, the study demonstrates that safeguarding Little Terns and other coastal breeding birds within predator exclosures depends on coordinated habitat management, predator control, and regulation of human activities.

1. Introduction

1.1 The Little Tern (*Sternula albifrons*)

The Little Tern is the smallest European tern species (Cramp, 1985, p.120) and "...gives the impression of a small, white, over-active and almost aggressive coastal bird..." (Olsen & Larsson, 1995, p. 128). The species can be identified by its small size, grey and white plumage, strongly forked tail, and a white forehead paired with a black crown and nape (Chandler & Wilds, 1994, p. 61). The Little Tern, belonging to the order *Charadriiformes* and the family *Laridae*, was formerly classified under the genus *Sterna* but has been reclassified into the genus *Sternula* (BirdLife International, 2018). Six subspecies are currently recognized. The nominate subspecies, *Sternula albifrons albifrons*, occurs across Europe, with a range extending from western Asia to eastern Nepal. Presumably it is present in Kenya and parts of the western Indian Ocean as well. The wintering grounds of this race include the coasts from Eastern Africa to Western India. (Gochfeld & Burger, 1996, p. 657) European Little Terns winter along the West African coast from Mauritania to Ghana (Bønløkke et al., 2006).

As a colonial ground-nesting species that lays its eggs in shallow scrapes on fragmented shell, gravel, or sandy substrates near the mean high tide-line (Glutz von Blotzheim & Bauer, 1982, p. 752), it is prone to egg loss due to extreme high tides occurring in early summer (O'Connell et al., 2014, p. 19). Additionally, foreshore development and climate change-driven sea level rise threatens the species by causing loss and degradation of its beach nesting habitats (BirdLife International, 2019). Moreover, nest predation by mammals and birds poses a notable risk. However, human disturbance is by far the most significant threat to colonies. (Norman & Saunders, 1969, p. 10) Therefore, Little Terns are highly reliant on conservation efforts, particularly habitat improvement, predator control, and visitor management. (Natural England & RSPB, 2019, p. 394).

Globally the Little Tern is classified as a species of „Least Concern“ with a decreasing population trend according to „The IUCN Red List of Threatened Species 2019“ (BirdLife International, 2019). The Little Tern is listed in Appendix II of the Convention on Migratory Species and is protected under the African-Eurasian Waterbird Agreement. It is also included in Annex II of the Bern Convention and Annex I of the EU Birds Directive. (BirdLife International, 2019) This obliges member states to take specific conservation efforts to safeguard the breeding success and survival of this species (European Union, 2009, p. L 20/9, Article 4).

1.2 Literature Review

1.2.1 Distribution in Denmark

Denmark is centrally located within the northern European breeding range of the Little Tern. The species breeds in small, scattered colonies, mainly at coastal sites across most of the country. It is rarely found breeding inland at large shallow lakes. The Danish population was estimated at an average of 410 breeding pairs during 1998-2003 (Bønløkke et al., 2006). During the period 2006-2023, when the Little Tern has been monitored under the „NOVANA“ program, the population has shown an increasing trend. In 2021 the Danish population peaked with 630-644 pairs that were counted in bird protection areas designated for the species. However, the results from the 2023 monitoring suggest a decline in the population since 2021 to only 506-507 pairs. (Nielsen et al., 2024)

1.2.2 Breeding Ecology

The breeding period of Little Terns is quite consistent throughout the entire European breeding range. (Glutz von Blotzheim & Bauer, 1982, p. 753) They arrive from their wintering grounds in April and May (Cramp 1985, p. 129). Upon arrival, egg laying in Europe starts in early May and can continue until late July. Replacement clutches can be found until early August. (U. Berthelsen, personal communication, 2025)

Little Terns generally remain faithful to the same breeding site. The strong site fidelity of Danish-ringed adult breeding birds is evident with 59% returning to their original breeding location. Only 19% move two to ten kilometers away, another 19% move 11-100 km, and only 4% move more than 100 km. The average movement distance for adult breeding birds is just 13 km, significantly less than the dispersal distance of chicks. (Bønløkke et al., 2006)

Territory establishment and nest site selection happens around three to four weeks after return. (Rittinghaus, 1969; Brichetti & Isenmann, n.d., as cited in Glutz von Blotzheim & Bauer, 1982, p. 752) Courtship and pairing begins promptly after returning to the breeding grounds. Little Terns have a monogamous breeding season, and site fidelity can lead to partners staying together for several years. (Glutz von Blotzheim & Bauer, 1982, p. 752)

Courtship behaviour consists of male birds doing aerial displays while calling and carrying fish to attract a mate. Female birds will chase the males up high before they land back on the beach, where the female may accept the fish offered. This ritual may continue until the female is sufficiently assured of the male's provisioning abilities. Mating involves the female in a crouched position while the male mounts her to achieve cloacal contact. Although each copulatory event is brief, multiple copulations may occur throughout the day. (Lewis, 1921 & Little Tern Project, n.d.)

Following successful copulation, the female proceeds to lay eggs in a simple scrape on the ground. Nest scrapes in loose sand measure approximately 10.5 cm in diameter and 2.5 cm in depth (Borodulina, 1960, as cited in Glutz von Blotzheim & Bauer, 1982, p. 752). On firm substrates such as shell fragments or gravel, the nest is often barely visible. It typically lacks any lining but may contain individual cockle or clam shell valves and small stones, which are always smaller than the eggs. More rarely, fragments of dry stalks or stems, sheep droppings, or similar materials are present. (Glutz von Blotzheim & Bauer, 1982, p. 752).

A full clutch consists of three but usually only two eggs are laid. (Cheah & Ng, 2008 & Wee, 2006) The eggs are pale grayish white to pale clay-colored with very delicate markings consisting of evenly distributed dark brown spots and small blotches, along with similarly fine gray to violet underlying spots (Dementjew, n.d. & Schönwetter 1963 as cited in Glutz von Blotzheim & Bauer, 1982, p. 753) An egg measures about 31.99 x 23.88 millimeters. (F. Groebbels, 1942, as cited in Glutz von Blotzheim & Bauer, 1982, p. 753)

Nests are typically found on shell fragments, pebble, or sandy substrates near the mean high tide line, occasionally occurring among washed-up debris, low-lying stems of sea sandwort (*Honckenya peploides*), or sparsely distributed grass tufts (Glutz von Blotzheim & Bauer, 1982, p. 752). According to Großkopf (1962) and Rittinghaus (1964) they prefer nesting sites on sand and shell-covered areas that are largely free of vegetation. If such sites change due to increasing vegetation growth accompanied by dune formation other suitable areas are colonized. Newly formed attractive habitats are likely to be occupied immediately, even if the original breeding site has not lost any of its ecological appeal. (Großkopf, 1962, p. 91; Rittinghaus, 1969 as cited in Glutz von Blotzheim & Bauer, 1982, p. 752)

Little Terns usually nest in small to medium-sized colonies, with 42% consisting of single-pair to small-group (1-5 pairs) colonies and only 5% comprising more than 40 pairs. Colonies rarely exceed 100 pairs in total. The species often forms synchronous subcolonies, which are usually monospecific. (del Hoyo et al., 1996, p. 657). In the Wadden Sea colonies usually consist of 15 to 30 breeding pairs. (U. Berthelsen, personal communication, 2025)

Little Terns raise only one brood per breeding season, however in the event of clutch loss, one or occasionally two replacement clutches may be laid. In this case the beginning of egg-laying starts four to nine days after the loss, depending on the stage of incubation and the timing within the breeding season. (Großkopf, 1968; Schmidt, 1981, as cited in Glutz von Blotzheim & Bauer, 1982) Danish ringing data includes several instances of re-laying following the loss of the first clutch. Of 31 recorded replacement clutches, 55% were laid at the same site, 19% within 3 km, and 26% more than 9 km from the original site. (Bønløkke et al., 2006) The size and success of replacement clutches are decreasing significantly as the laying period progresses (Johnson et al., 2024, p.18 & Borodulina, 1960 as cited in Glutz von Blotzheim & Bauer, 1982, p. 753).

After the nestlings have fledged, both parents continue to provide food until the fledglings are capable of independent foraging. According to Benjamin Dudding the feeding frequency per chick is 1.74 per hour and 3.32 fish per hour and nest (Dudding, 2024). Their diet consists mainly of fish, but they also feed on crustaceans, insects, annelids, and molluscs (del Hoyo et al., 1996, p. 657).

During the first one to two days after hatching, the chicks are already quite mobile, making short excursions away from the nest but returning when they hear the parents' cooing calls. If left undisturbed, they remain close to the nest site, where they are brooded and fed for about the first three days. When their bond to the nest site diminishes, the brood disperses, and the chicks often become widely scattered. (Cramp 1985, p. 127)



Figure 1: Little Tern chick in nest. Photo: Thomas Bregnballe, n.d.

At approximately 20 days old, the chicks begin to make their first short flights. By around 23 days, they start practicing their diving skills (Tomkins, 1959; Nadler, 1976; Nisbet, as cited in Cramp, 1985, p. 127).

Just like other tern species, Little Terns typically wander around after the breeding season, either alone if the breeding attempt has failed or together with their fledged chicks (U. Berthelsen, personal communication, 2025). From Denmark, the birds migrate southwest along Europe's west coast. The main migration begins in August, when 43% of the Danish-ringed breeding Little Terns have been recovered south of Denmark. In September, all recoveries are south of Denmark, namely from France or Portugal. (Bønløkke et al., 2006) By late November and early December, they arrive in their wintering grounds in Mauritania and Senegal, before beginning their northward migration again in late March and April (Cramp, 1985, p. 127; U. Berthelsen, personal communication, 2025).

1.2.3 Threats

The Little Tern faces a range of significant threats that have contributed to its population decline, including the loss and degradation of its beach nesting habitats, climate change, predation, and human disturbance. (BirdLife International, 2019; Norman & Saunders, 1969, p. 10)

Habitat loss and degradation through the development of foreshore poses a significant threat to the Little Tern. Relative sea level rises predicted due to climate change are also threatening beach nesting habitats (BirdLife International, 2019; Natural England, & RSPB, 2019). Increasingly frequent anomalous summer weather events, combined with elevated spring tides, can result in the inundation of nesting sites, leading to nest failure and the loss of chicks through flooding. (O'Connell et al., 2014, p. 19; Little Tern Project, n.d.)



Figure 2: Flooding of a Little Tern nest. Photo: Wez Smith, 2017.

In addition, predation represents a persistent threat to the breeding success of Little Terns, with both mammalian and avian predators exerting varying levels of impact across colonies and seasons (del Hoyo et al., 1996, p. 657; BirdLife International, 2019).

In European populations the most common predators of Little Terns include the red fox (*Vulpes vulpes*), corvids and gulls, all of which pose significant threats to eggs and chicks. Corvids, particularly the Hooded Crow (*Corvus cornix*) and Rook (*Corvus frugilegus*), are known to prey on Little Tern eggs and chicks, with predation pressure often highest during the early egg-laying stage when nests are most vulnerable. (del Hoyo et al., 1996, p. 657; Johnson et al., 2024) Gulls, including species such as the Common Gull (*Larus canus*), Herring Gull (*Larus argentatus*), Lesser Black-backed Gull (*Larus fuscus*), Great Black-backed Gull (*Larus marinus*), and Black-headed Gull (*Chroicocephalus ridibundus*), have been documented preying on Little Tern eggs, chicks, and occasionally adults, posing a significant threat, particularly in coastal colonies with high gull densities. (Kenny et al. 2021, pp. 35-36, Doyle et al., 2013)

Less frequent sources of predation include birds of prey, Brown Rats (*Rattus norvegicus*), American Mink (*Mustela vison*), Beech Martens (*Martes foina*), Raccoon Dogs (*Nyctereutes procyonoides*) and incidental trampling by livestock-grazing. (Johnson et al., 2024; Koffijberg et al., 2016; U. Berthelsen, personal communication, 2025)

The Kestrel (*Falco tinnunculus*) is recognized as the most frequent bird of prey targeting Little Tern chicks. Other species that prey on chicks and occasionally on adult Little Terns include the Common Buzzard (*Buteo buteo*), Eurasian Sparrowhawk (*Accipiter nisus*), Peregrine Falcon (*Falco peregrinus*) and Merlin (*Falco columbarius*). The intensity of predation varies across regions and tends to increase during peak chick-rearing periods. (Johnson et al., 2024; Doyle et al., 2013)



Figure 3: Kestrel preying on Little Tern chicks. Photo: Hayley Nunn, 2025.

Disturbance is widely recognized as negatively affecting the breeding success of Little Terns. It can cause incubating adults to abandon their nests temporarily, leaving eggs and chicks exposed to thermal stress, predation, and sand drift (del Hoyo, Fasola, Sanchez Guzman, & Roselaar, 2002). Human recreational activities, particularly the presence of walkers and off-leash dogs, are a common source of disturbance when they occur too close to nesting sites (Little Tern Project, n.d.; Johnson et al., 2024).

Moreover, increasing coastal recreation pressure has not only intensified direct disturbance but also contributed to broader predation management challenges, including the formation of fewer but larger colonies, which in turn amplify so-called “honey-pot” effects and make them an easier target for predators (Natural England & RSPB, 2019, p. 400).

Additionally, Little Tern eggs are vulnerable to being buried by wind-blown sand during strong winds, which can contribute to reduced hatching success in exposed nesting sites (Morris, 1979, p. 105). The complex interplay of threats and often interlinked effects underscore the urgent need for integrated, site-specific management strategies (Natural England, & RSPB, 2019, p. 400).

1.2.4 Conservation Methods

Since the Little Tern is listed in Appendix II of the Convention on Migratory Species, protected under the African-Eurasian Waterbird Agreement (AEWA), included in Annex II of the Bern Convention, and Annex I of the EU Birds Directive, member states are legally obligated to undertake targeted conservation measures to ensure the breeding success and long-term survival of the species (BirdLife International, 2019; European Union, 2009, p. L 20/9, Article 4).

Little Terns have benefited from a range of conservation measures, including the employment of colony wardens, temporary fencing, predator control, and habitat creation or enhancement (Natural England & RSPB, 2019, p. 398). However, management challenges persist. Increasing recreational pressure, coastal changes, and higher predation rates, resulting from more densely populated breeding colonies, raise the question of whether current conservation efforts will be successful in the long term and which improvements may be necessary (Natural England & RSPB, 2019, p. 398).

In Denmark the species is listed as „Vulnerable“ according to the „Den Danske Rødliste 2030“ (Aarhus Universitet, 2023) while the conservation status was evaluated as „unfavorable-decreasing“ (Pihl et al., 2006, p. 110).

Therefore, in 2015 the Wadden Sea National Park began installing temporary fenced-off areas every year, aimed at safeguarding the breeding success of Kentish Plovers and Little Terns. In total four fenced-off areas are being used in the Danish Wadden Sea and have shown great success, even though results are fluctuating every year. (J. Frikke, personal communication, 2025)

The fenced-off areas are set up each year, prior to the breeding season in late March and taken down in mid-August. This is done by volunteers, which are being supervised by John Frikke and Kim Fischer. (K. Fischer, personal communication, 2025)

Furthermore, the National Park Wadden Sea developed a Predator Control Project that engaged 70 voluntary hunters to target and remove specific predators. The regulation project includes seven out of nine bird protection areas on the Danish Wadden Sea islands and mainland. Particular focus is placed on the Red Fox, Raccoon Dog, American Mink, and Hooded Crow. (Ryttergaard Jensen & Frikke, n.d)

1.3 Key Questions & Objectives

Although the Little Tern is a species that has been extensively studied, there remains a lack of published research concerning the challenges and colony dynamics of fenced-off breeding areas in the Danish Wadden Sea. Therefore, Blåvandshuk was selected as the primary study site to investigate the following key questions:

- Are beach visitors aware of the seasonal dog leash law?
- Is there a preferred location for Little Terns within the predator enclosure?
- To what extent do the decoys attract Little Terns?
- What is the level of predation pressure?
- How to optimize predator enclosures for Little Terns?

Multiple research methods were used to address the study objectives. To assess the public knowledge of the seasonal dog leash law and raise public awareness about coastal breeding birds, a survey targeting beach visitors was conducted. Moreover, a standardized sampling design was applied to collect data on key environmental parameters, the spatial distribution, and the behaviour of Little Terns within the predator enclosures. Additionally, 3D-printed Little Tern decoys were deployed to investigate their influence in attracting Little Terns to the designated fenced-off areas. To identify the main predators and understand environmental factors influencing predation, a standardized design was used to monitor predation events and related variables. Finally, the effectiveness of the fenced-off areas was evaluated in terms of breeding success and predator exclusion.

2. Materials & Methods

2.1 Study Areas

The predator enclosure at Blåvandshuk was designated as the primary study site, while the predator enclosures at Rømø (Lakolk Strand) and Fanø (Grønningen) were included as comparative sites and sources of supplementary data.

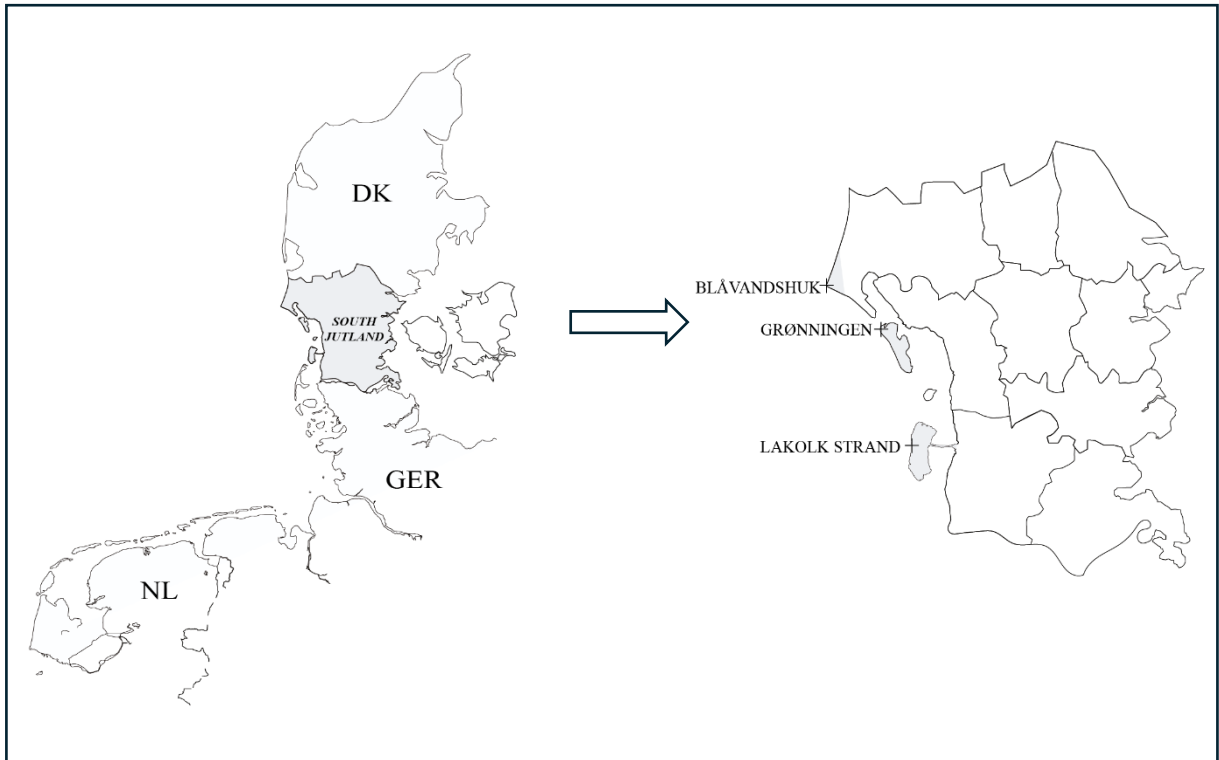


Figure 4: Study Area Map. Own illustration, 2025.

2.1.1 Blåvand, Blåvandshuk

Blåvand is a small coastal town located in Varde Municipality in southwestern Denmark. It lies at the very western edge of the country, making it a notable landmark for visitors. Though the town itself has a relatively small permanent population, numbering just a few hundred residents, it sees a dramatic increase in activity during the holiday seasons, with more than 30,000 tourists per day during the summer months. (Højlund, 2025; Blåvand Grundejerforening, 2023) Blåvand's tourism plays a central role in Varde's economy, generating approximately 7 billion Danish kroner (DKK) a year, which is equal to about 938 million euros (EUR). (Højlund, 2025).

The area is particularly well-known for its lighthouse, “*Blåvandshuk Fyr*”, which stands as a symbol of the region. Visitors also come to experience the nearby military bunkers from World War II and the surrounding nature, which is rich in flora and fauna. The area serves as a crucial hub on the East Atlantic Flyway, linking Africa and Southern Europe with the Nordic and Arctic regions. At Blåvand Bird Station, ornithologists track the migration patterns of birds passing the headland and conduct standardized bird ringing. (Nationalpark Vadehavet, 2024, p. 9; The Travel Book, 2021)

Blåvandshuk is an area located within the boundaries of the Danish Defence Training Area in Oksbøl. It is also part of the Wadden Sea National Park and North Sea Nature Park. Furthermore, it is designated as both a Natura 2000 and Ramsar site, reflecting its high conservation value and the need for coordinated protection of its diverse habitats and species. The area represents a significant intersection of natural heritage and recreational use. However, the growing influx of tourists poses ecological concerns, particularly regarding the disturbance of resting and nesting migratory birds. (J. Frikke, personal communication, 2025)

To mitigate the impacts and protect vulnerable coastal breeding birds, the installation of temporary fenced-off areas at Blåvandshuk was necessary (Clausen et al., 2023, p. 135) and done since 2021 (K. Fischer, personal communication, 2025). The exact location and shape is varying every year, since the habitat is ever changing due to the high dynamics of the coastline (K. Fischer, personal communication, 2025).

Two types of fencing are used. The perimeter fence serves to keep people and dogs at a distance from the nesting sites and consists of a single strand of wire, accompanied by signage prohibiting entry. The signs, written in both Danish and German state: “Birds with eggs and young. Please do not disturb.” The single wire provides minimal protection, as people, dogs or predators can easily step over or under it. Additionally, four signs with information about coastal breeding birds are placed on each corner of the perimeter fence.

Within the perimeter fence a predator enclosure is installed to deter mammalian predators and safeguard adult birds, chicks and nests. It consists of three main components, an electrified mesh and two additional electrified wires positioned in front of it. The upper wire is intended to prevent predators such as foxes from jumping over, while the lower wire serves to inhibit burrowing attempts beneath the mesh. It is powered by a battery with an integrated energizer, kept charged by a solar panel, and grounded via a metal rod to complete the electric circuit.



Figure 5: Setting up the predator enclosure. Own photo, 2025.

This year, the original predator enclosure was extended westward with the addition of a second electrified mesh and wire system to include the first vegetated line of dunes (see Figure 6), which chicks have used as shelter in recent years (U. Berthelsen, personal communication, 2025). In addition, the fencing was equipped with upward-bent wires to prevent avian predators from perch hunting (see Appendix 1). In the westernmost part of the predator enclosure, 18 Little Tern decoys were installed to attract coastal breeding birds to the area least prone to flooding. Moreover, 15 hideouts were placed to offer protection from aerial predators and sand drift. Another new feature was the coordinate system (see Figure 12), which was used to monitor the location and activities of Little Terns, the sand drift and the change of environmental parameters inside the predator enclosure. Additionally, 50 kilograms of shells and four drift-wood logs were placed near the decoys to improve the habitat by reducing sand drift (see Figure 14).

This year, the perimeter fence enclosed an area of 2.94 hectares, while the original predator enclosure covered 0.88 hectares. The western extension measured around 0.19 hectares.

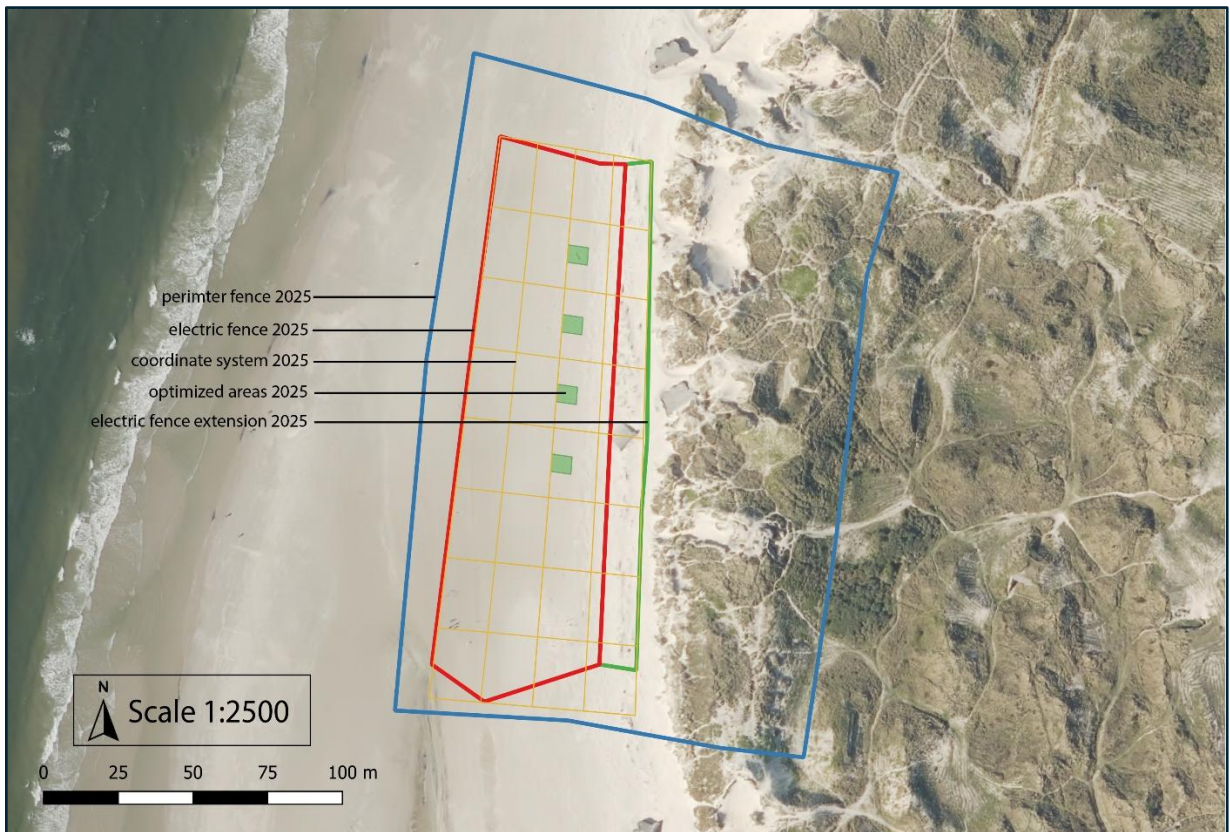


Figure 6: Fenced-off Area at Blåvandshuk. Own map, 2025.

2.1.2 Rømø, Lakolk Strand

Rømø is the largest island in the Danish Wadden Sea region, covering 129 square kilometers, which includes sandy shores and parts of the tidal flats to the east. Around 560 people live on the island that has gradually emerged from the sea. (Nationalpark Vadehavet, 2024, p.41) It is characterized by dynamic coastal processes that continue to shape its landscape (Tønder Kommune et al., 2018, p.19), featuring primarily sandy beaches with dry dune heaths and salt marshes (Søltoft, 2024, p.34). The island is gradually expanding westward as the North Sea deposits substantial volumes of sand along the shoreline, which are slowly being taken over by vegetation (Nationalpark Vadehavet, 2024, p. 42).

The Rømø Dam, build in 1948, established a permanent 9.2-kilometre connection to the mainland (Nationalpark Vadehavet, 2024, p. 43), and allows tourism to play a central role in Rømø's contemporary identity (Søltoft, 2024, p. 28). On the busiest days a total of up to 16,800 vehicles can passage the Rømø Dam.

With approximately 1.9 million day visitors annually compared to 1.2 million overnight stays, day-trippers constitute a clear majority, accounting for 61% of all visitors, while the remaining 39% stay on the island for multiple days. (Kyst og Naturturisme, 2021, p. 33). Around 80% of overnight guests on Rømø are German tourists, with 50% of bookings involving travelers bringing dogs (Tønder Kommune et al., 2018, p. 25). In 2016, day tourism on Rømø generated an estimated turnover of 250 million DKK, equivalent to about 33.5 million EUR, while total tourism revenue was approximately 987 million DKK, or around 132 million EUR (Tønder Kommune et al., 2018, p.27).

Most tourists identify the island's natural environment as their primary reason for visiting (Tønder Kommune et al., 2018, p. 25). Sønderstrand in the south is the landmark of the island and the largest beach in Europe, it is up to three kilometres wide. Another popular destination north of the island is Lakolk Strand, which has been a favored bathing spot since the 1800s and spans over 700 meters in width. Beyond their recreational appeal, these beaches provide vital habitats for rare breeding birds such as plovers and terns. (Nationalpark Vadehavet, 2024, p. 42)

The growing popularity of Rømø's beaches (Tønder Kommune et al., 2018, p. 25), combined with an average of approximately 700 private vehicles driving daily on Lakolk Strand (Tønder Kommune, 2021, p. 6), is raising environmental concerns due to the area's importance as a resting and nesting ground for rare and vulnerable bird species (J. Frikke, personal communication, 2025).



Figure 7: Tourism on Lakolk Strand. Photo: Destination Sønderjylland, n.d.

Given these pressures on the habitat, fencing for coastal breeding birds became a measure to support species conservation on Lakolk Strand. The fencing system was initially installed in 2018 by the Wadden Sea National Park aimed at enhancing nesting success of Kentish Plovers and Little Terns. (Balson, C. 2022, p. 8)

The fenced-off area is approximately 1 kilometer south of Mærskhjørn Lå, which is a narrow inlet frequently visited by foraging coastal birds, especially in the breeding season (Clausen et al., 2023, p. 159). The perimeter fence and predator enclosure used this year at Lakolk had the same features as the one in Blåvand, but without the westward extension. To help attract coastal breeding birds to the area with the lowest risk of flooding, 17 Little Tern decoys and four Common Tern decoys were placed in the westernmost part of the predator enclosure. In contrast to Blåvandshuk the coordinate system was used solely to monitor sand drift and the change of environmental parameters within the predator enclosure. No driftwood, shells, or artificial hideouts were introduced.

The perimeter fence covered an area of around 17.60 hectares, while the predator enclosure was about 2.33 hectares in size.

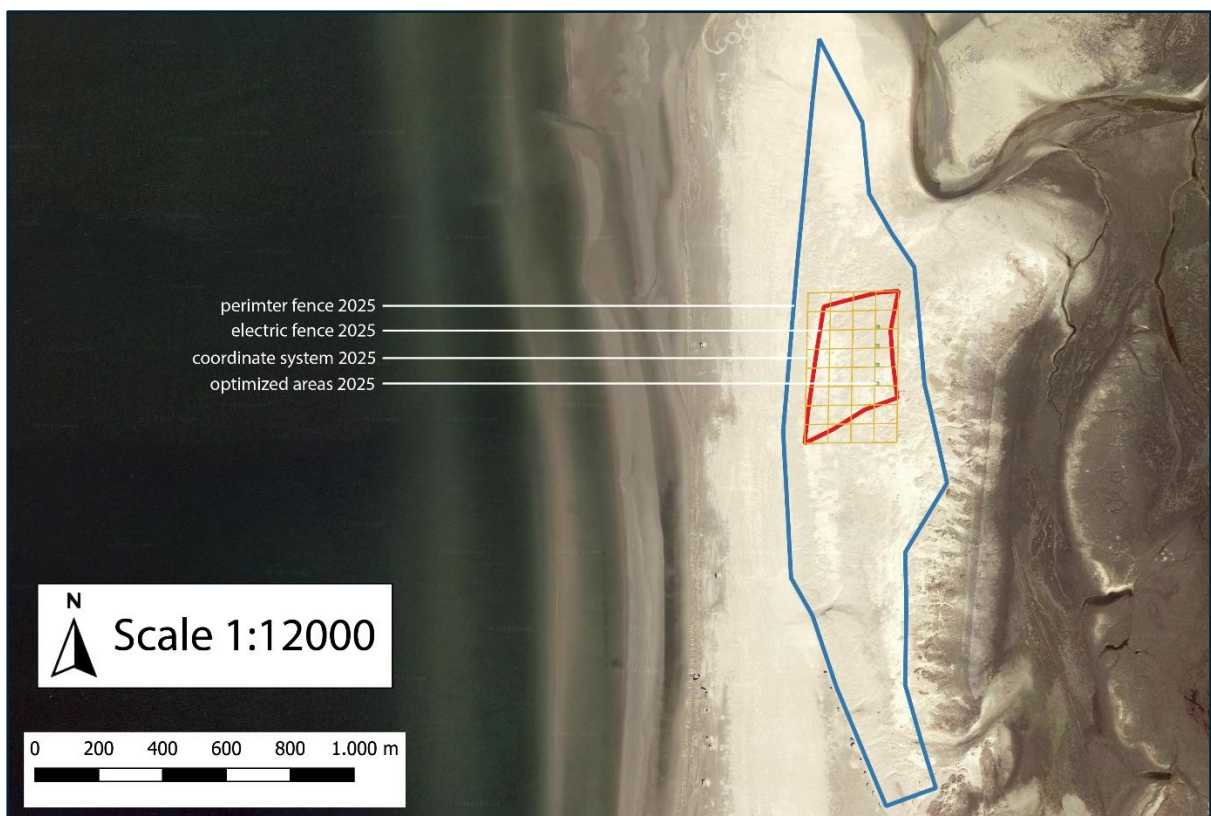


Figure 8: Fenced-off area at Lakolk Strand. Own Map, 2025.

2.1.3 *Fanø, Grønningen*

Fanø is Denmark's smallest municipality at 56 square kilometres and is home to approximately 3,500 residents. Geologically young, Fanø formed around 8,000 years ago as a sandbank, like the neighboring island Rømø. The island's dynamic coastline features a 15-kilometre-long beach, notably wide at its northern and southern ends, bordered by continuous dune systems that shelter valuable dune flats and heathlands. (Nationalpark Vadehavet, 2024, p. 17-19).

Tourism is a significant economic sector for Fanø, accounting for 41% of the municipality's total supply of goods and services in 2022. German tourists constitute the largest group of international visitors, with numbers increasing in recent years. The main factors attracting tourists are the island's atmosphere, beaches, and the North Sea. (Fanø Kommune, n.d.) Despite a robust tourism industry, Fanø has successfully preserved much of its natural environment through dedicated conservation efforts. (Nationalpark Vadehavet, 2024, p. 17).

Upon arrival by ferry from Esbjerg, visitors are welcomed by the historic charm of Nordby, characterized by old houses lining the narrow streets (Vadehavskysten, n.d.). The central landscape is punctuated by Fanø Klitplantage, a forested area established to combat sand drift. Moving eastward, the terrain transitions into salt marshes and extensive reed beds along the coast. Notable natural features include Søren Jessens Sand, offering a rare desert-like landscape, and the southern tip, Hønen, which hosts tidal flats, dunes, and salt marshes. The diverse range of terrestrial and marine habitats support a rich variety of plant and animal species. The island hosts some of the largest bird concentrations in the Wadden Sea during migration periods, alongside several rare and resident species. Within the moist depressions of the dunes crossleaved heath and marsh gentian hosts the Alcon blue butterfly. (Nationalpark Vadehavet, 2024, p. 17-20)

Søren Jessens Strand was originally a sandbank that gradually merged with Fanø during the 1960s. The distinctive natural area, measuring approximately 90,000 square meters, was once home to the largest colony of Little Terns in Denmark and is vegetated by salt marshes on its eastern side. (Kuhlman & Øster, 2024) Since the coastal breeding birds at Søren Jessens Sand are exposed to disturbance from human activities and at risk of predation by mammals, especially foxes, installing fencing is considered an important protective measure. (Clausen et al., p.153)

Since fencing on Søren Jessens Sand proved impractical due to repeated flooding, it was relocated to Grønningen in 2015. This area consists of coastal dunes and meadows stretching from Nordby around the northern tip of Fanø. The low-lying, saline-influenced zones along the coast are covered by coastal meadows or salt marshes, which gradually give way to dry grassland on higher ground. In the northwestern corner of Grønningen, the coastal meadows are intersected by a network of tidal creeks and salt pans.



Figure 9: Grønningen. Photo: Søren Vinding, n.d

For centuries, Grønningen has been grazed by livestock, which has maintained low-growing vegetation and prevented the coastal meadows from becoming overgrown with Common Reed (*Phragmites australis*). This management regime has also preserved a diverse flora, comprising not only typical coastal meadow species but also rarer species, including Baltic Gentian (*Gentianella uliginosa*), Seaside Centaury (*Centaurium littorale*) and Early Marsh Orchid (*Dactylorhiza incarnata*). The open terrain also supports diverse populations of invertebrates, with species such as Yellow Meadow Ant (*Lasius flavus*), Large Heath (*Coenonympha tullia*), and Northern Dune Tiger Beetle (*Cicindela hybrida*). The birdlife of Grønningen is particularly rich, with nearly 200 recorded species. Despite broader declines, Pied Avocets (*Recurvirostra avosetta*), Northern Lapwings (*Vanellus vanellus*), and various other waders still nest here. (Brodde, 2020)

The fencing consists of an electrified mesh, supplemented by an additional electrified wire to the west, primarily to prevent cattle from trampling nests. This year, the electrified mesh covered an area of approximately 0.32 hectares, while the electrified wire enclosed about 0.50 hectares.



Figure 10: Fenced-off Area at Grønningen. Own map, 2025.

2.2 Coordinate Systems inside Predator Exclosures

The coordinate system served as the foundation for three types of data collection within the predator exclosures, including the recording of locations and activities of individual Little Terns, the measurement of sand drift, and the monitoring of each location's surface cover composition. Each coordinate system consisted of 45 wooden poles, each 60 centimeters long. The wooden poles were arranged in equal-sized rectangles, resulting in 32 individual locations. These locations were divided into four zones (A, B, C, D), each marked with a specific color. The poles in each zone were labeled accordingly, using the letters "A" to "D" from west to east, and the numbers "1" to "8" from north to south. Additionally, each pole was marked with black lines at five-centimeter intervals, starting from the top and extending downward to resemble a 30-centimeter ruler. The poles were hammered into the sand up to the zero-centimeter mark.



Figure 11: Wooden poles for the coordinate systems. Own photo, 2025.

2.2.1 Blåvand, Blåvandshuk

At Blåvandshuk each location measured approximately 23 meters in length and 15 meters in width.

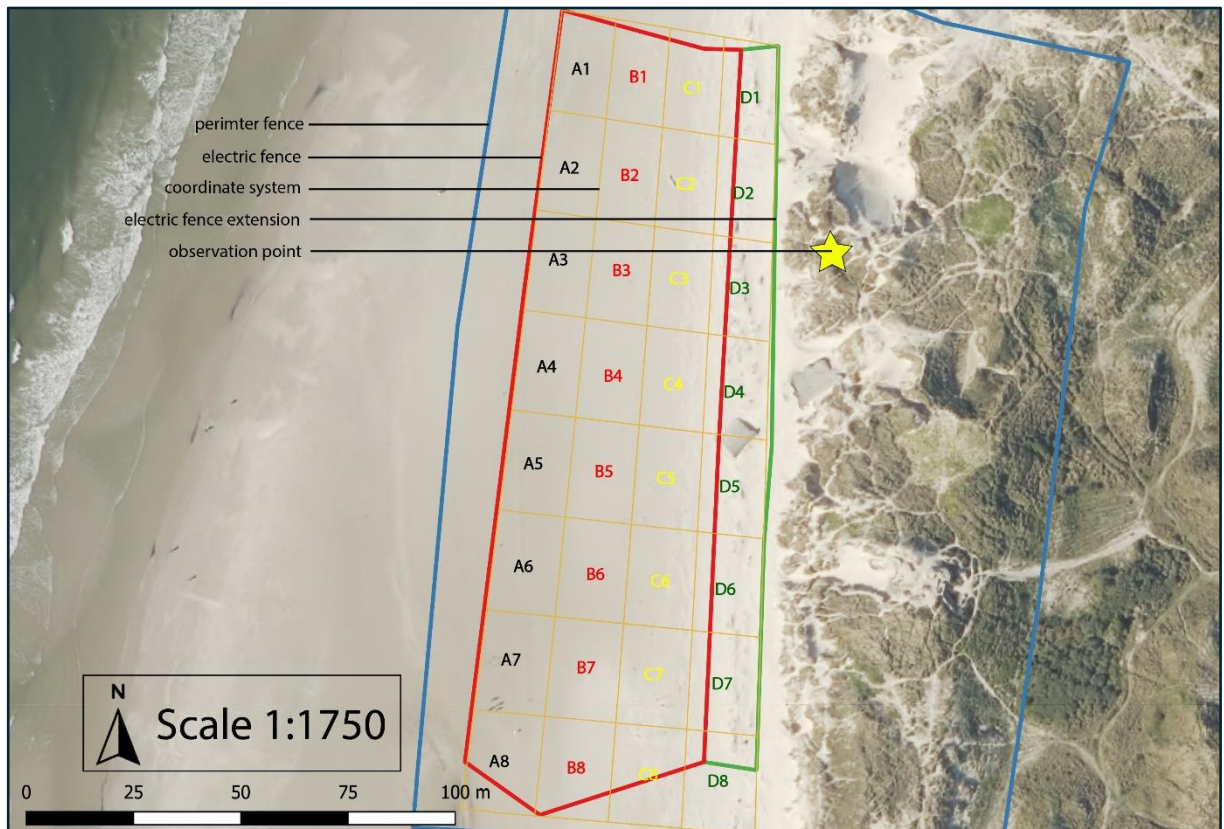


Figure 12: Coordinate system at Blåvandshuk. Own map, 2025.

2.2.2 Rømø, Lakolk Strand

At Lakolk Strand every location was about 29 meters long and 35 meters wide.

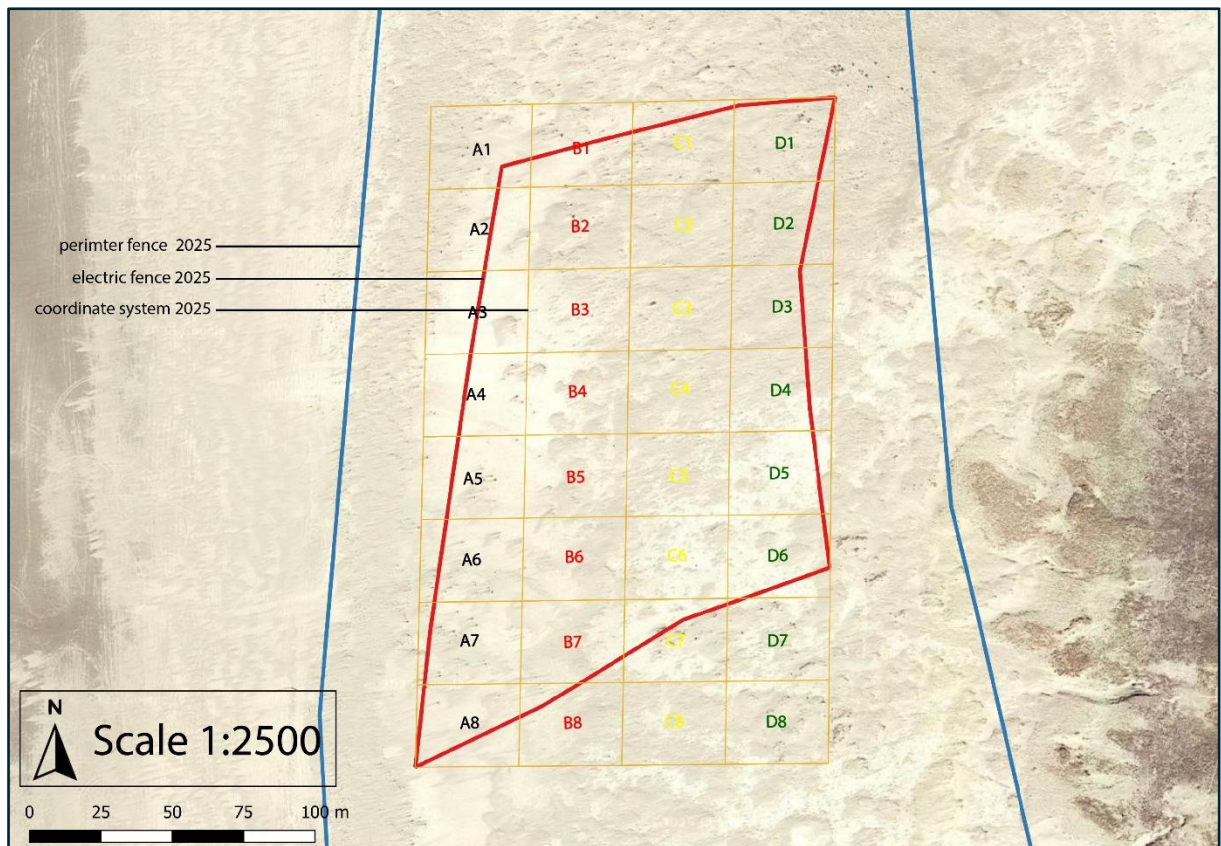


Figure 13: Coordinate system at Lakolk Strand. Own map, 2025.

2.3 Optimized Areas

The optimized areas consisting of decoys, driftwood, and shells were located in the westernmost section of the original predator enclosures (see Figure 14). Each of these areas measured five meters in length and width, with approximately 20 meters of spacing between them.

2.3.1 Blåvand, Blåvandshuk

At Blåvandshuk, each optimized area contained four to five 3D-printed Little Tern decoys, resulting in a total of 18 decoys. Additionally, each area was equipped with one log of driftwood, one hideout, and approximately 12.5 kilograms of shells.

2.3.2 Rømø, Lakolk Strand

At Lakolk Strand, the optimized areas featured a total of 18 Little Tern decoys, including three 3D-printed decoys and 15 store-bought decoys made of plastic. Additionally, three wooden Common Tern decoys were placed. Each optimized area contained five to six decoys in total.



Figure 14: Optimized Area. Own photo, 2025.

2.3.3 3D-Printed Little Tern Decoys

The decoys were designed, produced, and strategically installed to attract Little Terns to areas with minimal disturbance, predation and flood risk.

The first prototype Little Tern decoy was created with the help of the website “*hyper3d.ai*” where uploaded photos can be turned into 3D-models. The prototype was refined in *Bambu Studio* to enhance its realism by adjusting the size, shape, and beak, and by adding legs and primaries. Additionally, a base was designed and added to allow secure anchoring in the ground using tent pegs. A total of 21 decoys were printed using a Bambu Lab X1C 3D printer, consuming a total of 2 kg white polylactic acid (PLA) filament, which is a biodegradable material derived from renewable resources such as corn or sugarcane (Carbios, 2023). To reduce the need for support structures during printing, and thereby minimize filament usage, the decoys were printed in halves. These halves were later assembled using epoxy resin. Once the epoxy resin had cured, a layer of primer was applied to improve the durability of the paint. The decoys were painted using a water-based acrylic lacquer (see Appendix 2).

Finally, they were positioned in groups of four to five, including single birds and pairs in different postures. The decoys were spaced approximately two meters apart and oriented in various directions, generally facing between west and north.



Figure 15: 3D-printed decoy halves. Own photo, 2025.

2.3.4 Hideouts

The hideouts provided protection against aerial predators and harsh weather conditions. They were constructed from 15 second-hand concrete tubes, each measuring 1 meter in length and 20 centimeters in diameter. The tubes were cut into 50-centimeter sections, coated with a layer of tile cement, and rolled in sand to better blend into the surrounding landscape (see Appendix 3 and 4).

2.3.5 Driftwood & Shells

To reduce sand drift, four driftwood logs were collected from the beach at Blávandshuk, each approximately two meters long and 30 centimeters in diameter. Additionally, around 50 kilograms of shells, primarily cockles, were gathered.

2.4 Sand Drift Measurement & Surface Cover Composition Estimation

Beginning on 28 April 2025, bi-weekly measurements of sand drift and surface cover composition were conducted at Blávandshuk and Lakolk Strand to monitor sand drift dynamics and changes in habitat conditions until 1 July 2025. The results of each measurement and estimation were recorded on field sheets (see Appendix 5) before being entered into an Excel spreadsheet for analysis in RStudio.

2.4.1 Sand Drift Measurement (SDM)

Sand drift dynamics were assessed by measuring the height of sand at each pole within the coordinate systems, which were subdivided into five Sand Drift Measurement Zones (SDM-Zones A, B, C, D, and D1; see Appendix 6). The average standard deviation of sand height was calculated for each SDM-Zone to identify the most dynamic SDM-Zones within the predator exclosures. To assess the total levels of sand drift per study site the standard deviation of each SDM-Zone was averaged across all measurement periods.

2.4.2 Surface Cover Composition Estimation (SCCE)

Surface cover composition was estimated in percentages for each location across the coordinate systems. It was distinguished between three cover types, including vegetation, shell, and sand. The total surface cover composition averages per study site were calculated by averaging the percentage of each cover type across all locations and measurement periods. To determine the normalized total surface cover composition of each study site, the total site-level averages were summed and rescaled to 100%, while maintaining the relative proportions among the cover types.

2.5 Records of Location & Activity (ROLA)

To investigate the environmental factors influencing the spatial distribution and behaviour of Little Terns in response to the 3D-printed decoys, the recording of locations and activities were conducted from 01 May to 30 June 2025 at Blåvandshuk. The Scan Sampling method (Altmann, 1974, p. 259) was used to collect data on each individual Little Tern within the predator exclosure at ten-minute intervals. The records were carried out daily for two hours starting at sunrise, provided weather and military conditions allowed. On rainy or windy mornings when rainfall exceeded 2 mm per hour, wind speeds surpassed 10 m/s or the access to the observation site was restricted due to military training, the data collection was suspended. Observations were carried out from the highest dune crest (see Figure 12) by scanning the predator exclosure from north to south every ten minutes using Vortex 10x42 Diamondback HD binoculars. The presence of Little Terns along with their locations and activities within the coordinate system, and when possible, their individual nest or ring numbers were recorded. If a ringed Little Tern was observed, every effort was made to read the ring using either a Swarovski ATM 65 HD 25–50x spotting scope or a NIKON COOLPIX P1000 camera.

A field sheet was designed to record the date, time, environmental parameters, location, and behaviour of each Little Tern observed landing inside the predator exclosure (see Appendix 7). All completed field sheets were transferred into an Excel spreadsheet for analysis in RStudio.

To assess temporal trends in abundance all observations were analyzed in semi-monthly trends, with daily counts averaged for each half-month period. The average number of Little Terns observed per ten-minute interval was calculated across the entire study period to evaluate patterns in activity shortly after sunrise. Counting all landings at each location throughout the study period allowed identification of the preferred locations by Little Terns. By calculating the relative percentages of all recorded behaviours, it was possible to determine the primary use of the predator enclosure. Activity patterns in the optimized areas were evaluated through tallying the number of each recorded behaviour per location.

The number of Little Terns observed per location was analyzed to test whether the presence of decoys increased landings. Locations with zero observations were added to the dataset to ensure all potential sites were represented. A Poisson regression model was fitted, using the actual number of landings per location as the response variable and decoy presence as the predictor. Statistical significance of the decoy effect was assessed using the model's built-in Wald z-test. From the fitted model, the expected average number of landings was predicted for both decoy and non-decoy locations, providing a model-based estimate of the effect size.

To investigate the preference of Little Terns for surface cover composition within the predator enclosure, the percentage cover of sand, shell, and vegetation was averaged across all measurement periods at the ten most frequently visited locations.

2.6 Nest Monitoring

At Blåvandshuk, the fenced-off area and the surrounding beach were monitored almost daily to record new nests and check the survival status of existing nests. The area was scanned from the observation point using binoculars and a spotting scope to detect breeding-related behaviours or incubating birds. For each nest found, the date, nest ID, surface cover composition, distance to the nearest electric fence or wire, and distance to the +1.00 m high tide line were noted into an Excel spreadsheet for analysis in RStudio. When the breeding pair stopped visiting the nest, the survival status of the eggs was checked and recorded.

The predator enclosure at Lakolk Strand was monitored bi-weekly during the SDM and SCCE, to detect new nests. It was done using binoculars while walking along the SDM zones, stopping at each pole and systematically scanning from left to right to detect breeding-related behaviours or incubating birds. The status of new nests, the survival of existing nests, and overall breeding success of the fenced-off area were additionally assessed by John Frikke, who monitored the fenced-off area almost weekly.

At Grønningen the fenced-off area was inspected once on 19 June 2025, to document existing Little Tern nests within the predator enclosure. Each nest was given a nest ID, the surface cover composition was estimated, the distance to the nearest electric fence or wire and to the +1.00 m high tide line was recorded. The data was entered into the same Excel spreadsheet as used for the nesting sites of Blåvandshuk and later analyzed in RStudio. Kim Fischer visited the fenced-off area almost daily, exclusively monitoring the status of new nests, the survival of existing nests, and overall breeding success.

2.7 Artificial Nests

An experimental setup using artificial nests was implemented at Blåvandshuk and Lakolk Strand, to investigate predation pressure on coastal breeding birds and to identify the main predators as well as the environmental parameters influencing predation rates.

A total of 54 artificial nests were used, with 30 nests placed at Blåvandshuk and 24 at Lakolk Strand. They were arranged along three coastal succession gradients at both study sites. At Blåvandshuk each gradient covered five habitat types. The selected habitat types included bare sand, shell-rich sand, embryo dunes, foredunes, and semi-fixed dunes. At Lakolk Strand each gradient consisted of four habitat types, including bare sand, shell-rich sand, embryo dunes, salt marsh or fore dunes. Each habitat type contained one artificial nest, at both study sites. The gradients were located over 300 meters away from the predator enclosures to reduce the risk of drawing predators toward the fenced-off area. The gradients were shifted 50 meters to the south after two weeks, to prevent predators from learning the fixed location of the artificial nests. Each contained two Japanese quail (*Coturnix japonica*) eggs and one wax egg designed to record bite marks. To document predator presence and activity, one motion-triggered camera trap was installed at each habitat type along the gradients.

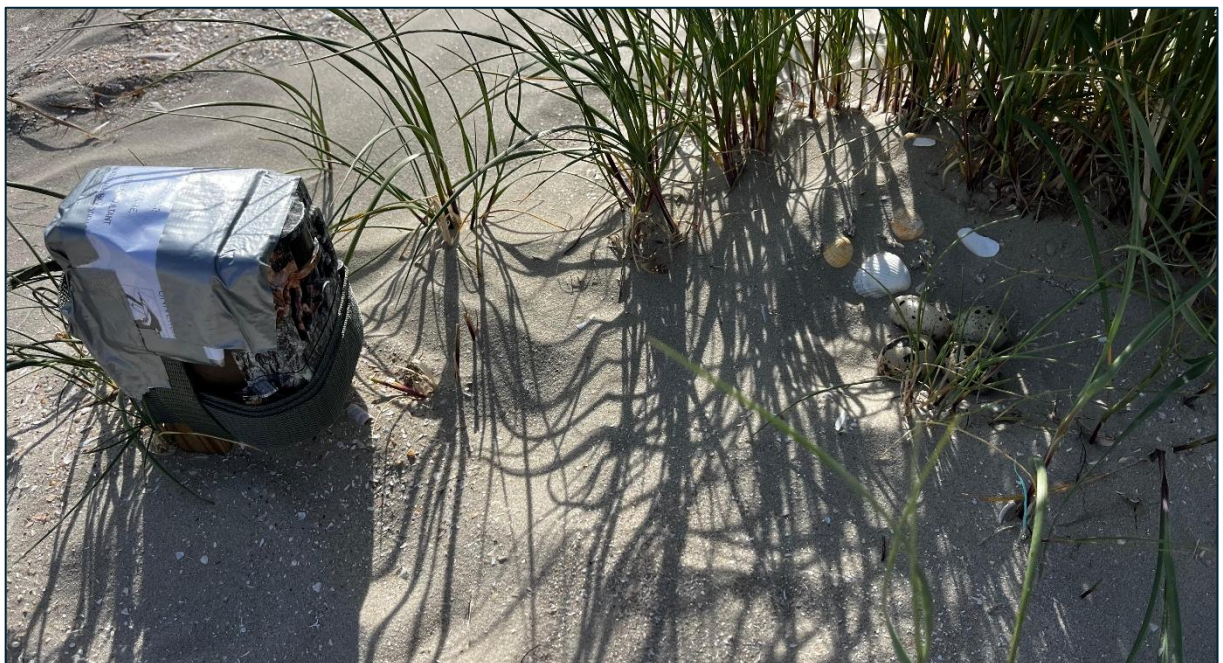


Figure 16: Artificial nest with camera trap. Own photo, 2025.

When a quail or wax egg was missing, destroyed, or showed bite marks, the nest was classified as predated. Predators were identified either through camera trap images or by characteristic bite marks on the wax eggs. Small dot-shaped punctures were attributed to avian predation, whereas deep, paired puncture marks or scratches on both sides of the wax egg were attributed to mammalian predation. Further distinction among avian predators was only possible with camera trap evidence, while differentiation among mammalian predators also relied on the size and spacing of the bite marks.

The experiment was conducted over a period of four weeks, with nests being checked once after 14 days. The results were recorded in an Excel spreadsheet and analyzed using RStudio.

A logistic regression model was initially considered to assess the relative influence of habitat type, distance to water, and vegetation cover on nest predation. However, small sample sizes in some categories led to unstable estimates, preventing reliable identification of the strongest predictor for predation. Instead, Fisher's exact tests were used to evaluate the overall association between each categorical variable and predation.

2.8 Survey

A short survey, targeting primarily tourists, was conducted at the beach entrance of Blåvandshuk to evaluate the knowledge of beach visitors regarding the seasonal dog leash law, assess the social perception of fenced-off areas, and raise public awareness of coastal breeding birds (see Appendix 8). The survey included the following questions:

- Are you a local resident or a tourist?
- How old are you?
- Did you read the information sign about Little Terns at the entrance?
- Do you have the urge to get close to the fenced-off area?
- Would you like to see more informational signs on the beach?
- Do you have a dog with you?
- Are you aware that dogs must be kept on a leash from April 1st to September 30th?
- Do you feel personally responsible for protecting nature?

The survey was carried out over a four-day period, from April 1st to April 4th, 2025. The results were recorded on field sheets and later entered into an Excel spreadsheet for analysis using RStudio.

2.9 Dog Counts

During the recording of location and activity, all dogs passing the fenced area were counted and classified according to leash status in order to quantify potential disturbances and non-compliance with the seasonal dog-leash law.

3. Results

3.1 Sand Drift Measurement

The results indicate substantial sand drift at both locations. However, the dynamics differ between the sites, with peak sand movement concentrated in distinct SDM zones.

3.1.1 Blåvandshuk

At Blåvandshuk, the D1 zone showed the highest variability, with a standard deviation of 7.89, indicating the area with the most sand drift. This was followed by the D2 zone (6.86), the C zone (6.16), and the B zone (5.65), which also showed notable sand movements. The A zone was the most stable, with the lowest standard deviation of 1.68. The average standard deviation across all zones was 5.65, reflecting relatively high levels of sand drift.

3.1.2 Lakolk Strand

On Rømø at Lakolk Strand the C zone had the greatest variability (4.57). This was followed by the A zone (3.84) and the B zone (3.13), which also showed considerable variability, though to a lesser degree. The D1 (1.49) and D2 (1.25) zones were the most stable with the lowest variability values. The average standard deviation across all zones was 2.86, indicating lower levels of sand drift compared to Blåvandshuk.

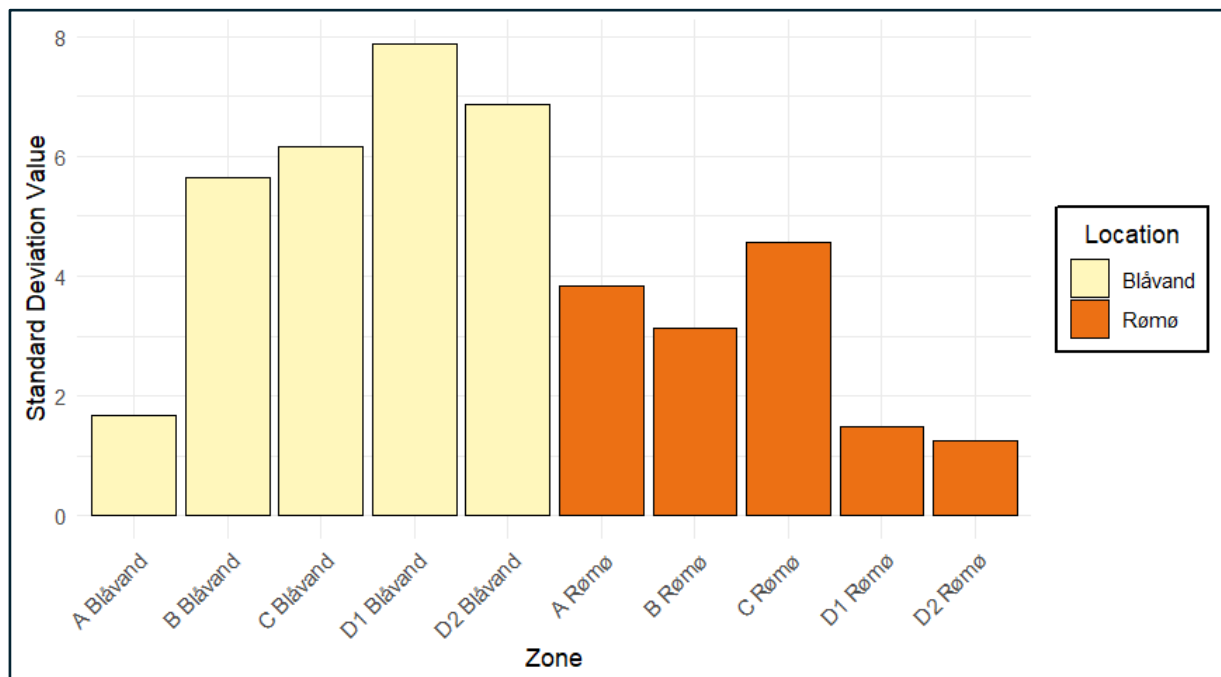


Figure 17: Standard deviation per SDM zone. Own illustration, 2025.

3.2 Surface Cover Composition Estimation

The two study sites, Blåvandshuk and Lakolk Strand, differ markedly in their vegetation and shell cover.

At Blåvandshuk, the vegetation cover across all locations is relatively low, ranging from 0.0% to 13.8%. Whereas at Lakolk Strand the percentage is much higher, spanning 14.9% to 38.7%. Similarly, shell cover shows contrasting patterns, with Blåvandshuk values ranging from 0.0% to 53.8%, while Lakolk ranges more narrowly between 14.1% and 39.5%. At both sites, however, sand remains the dominant cover. At Blåvandshuk, sand percentages range widely from 46.2% to 96.2%. While Lakolk Strand exhibits a narrower range from 64.1% to 84.5%. This suggests consistently high sand cover dominance across all locations at both sites, while also indicating that Blåvandshuk exhibits greater variability in surface cover composition.

3.2.1 Blåvandshuk

Zone A (A1–A8) shows an average vegetation cover of 7.66%, shell cover of 20.0%, and sand cover at 70.64%. Zone B (B1–B8) is characterized by the absence of vegetation (0.0%) but relatively high shell content (33.94%), while sand cover is somewhat reduced (66.06%). Zone C (C1–C8) is similarly devoid of vegetation (0.0%) but exhibits very low shell content (7.02%), resulting in the highest sand dominance at the site (92.99%). Finally, Zone D (D1–D8) presents modest vegetation cover (6.87%) and no shell content (0.0%), coupled with a very high proportion of sand (93.15%). This highlights a strong spatial variability at Blåvandshuk, with zones ranging from shell-dominated (Zone B) to sand-dominated (Zones A, C and D). The normalized total surface cover composition consisted of 81.06% sand, 15.30% shell and 3.64% vegetation (see Appendix 9).

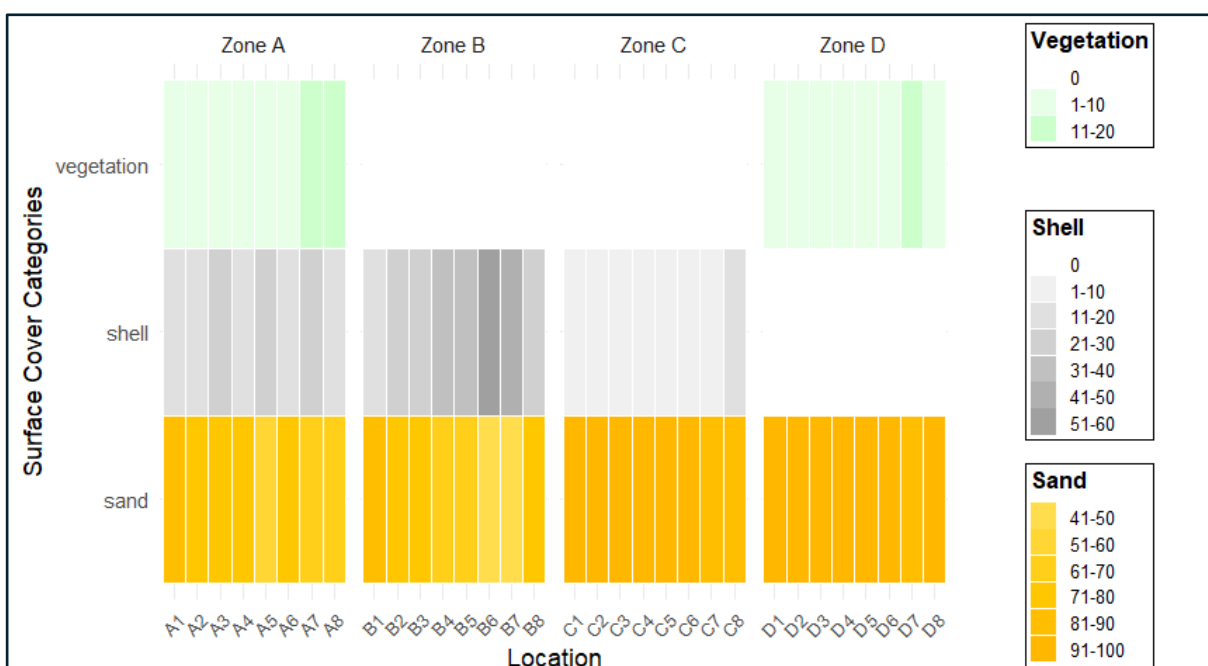


Figure 18: Average surface cover composition at Blåvandshuk. Own illustration, 2025.

3.2.2 Lakolk Strand

Zone A exhibits relatively high vegetation (28.18%) and shell cover (27.16%), with sand cover averaging 75.81%. Zone B displays lower vegetation (21.96%) and slightly less shell (24.40%) and sand cover (73.70%). Zone C shows a return to higher vegetation (26.46%) and shell levels (26.50%), with sand cover at 74.08%. Finally, Zone D has moderate vegetation (22.82%) and the lowest shell cover of the Lakolk zones (21.86%), while sand remains consistently high (73.86%). Unlike Blåvandshuk, the study site shows more balanced proportions of vegetation, shell and sand cover across all zones. The normalized total surface cover composition was more evenly distributed, with sand covering 59.89%, shell 20.10%, and vegetation 20.01% (see Appendix 9).

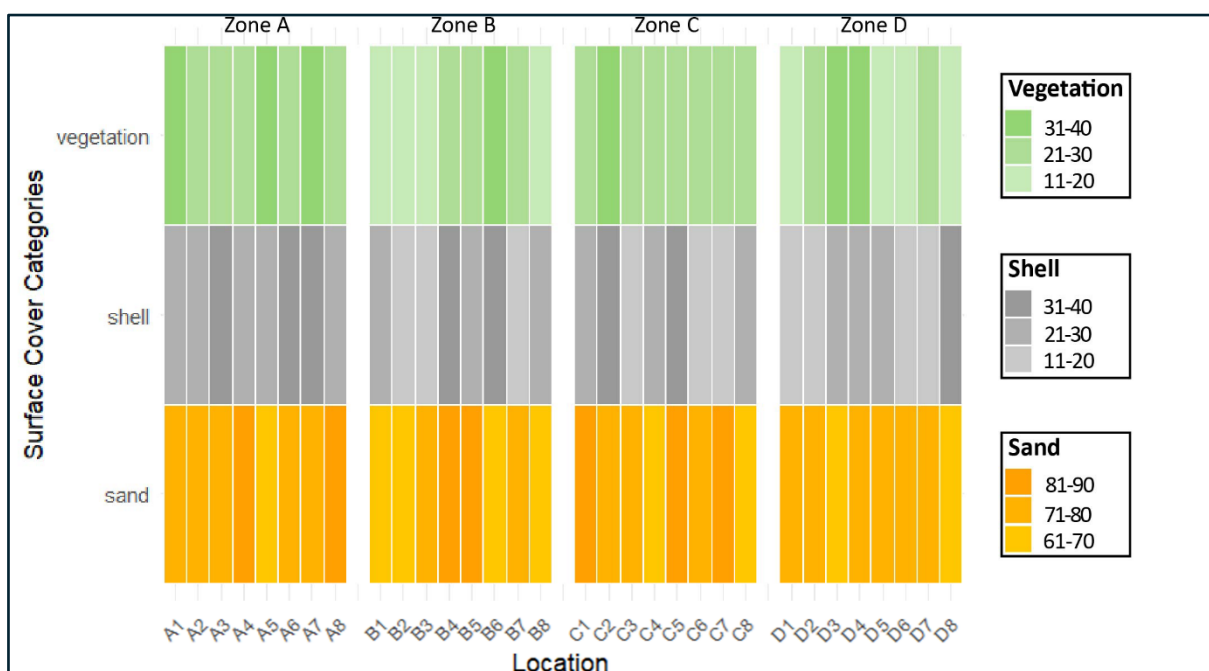


Figure 19: Average surface cover composition at Lakolk Strand. Own illustration, 2025.

3.3 Records of Location & Activity

A total of 68 hours was conducted to record the locations and activities of Little Terns within the predator enclosure at Blåvandshuk.

The semi-monthly trends in Little Tern numbers show a clear decline over the study period. During the first half of May (01.05.–15.05.2025), an average of 17.1 Little Terns landings were observed per day. This number decreased to 9.31 in the second half of May (16.05.–30.05.2025). In June, the Little Terns were nearly absent, with only 0.27 landings recorded per day in both the first (01.06.–15.06.2025) and second halves of the month (16.06.–30.06.2025). These results highlight an early-season peak followed by a rapid decline in daily Little Tern numbers.

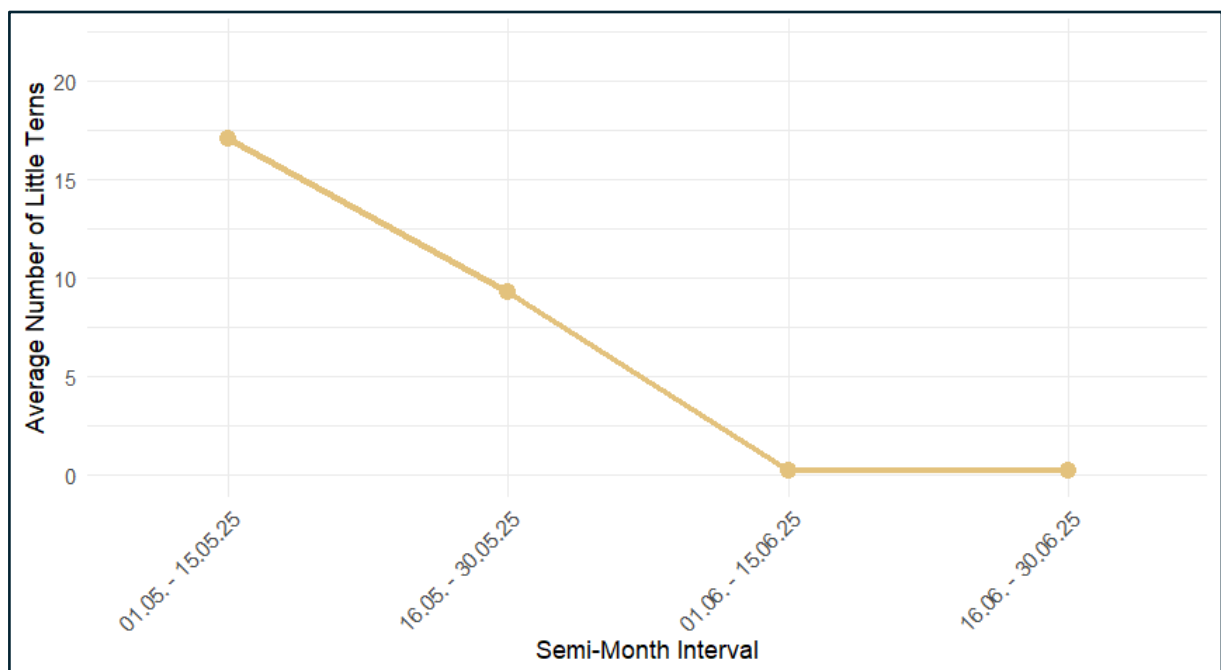


Figure 20: Semi-monthly trends in Little Tern Numbers. Own illustration, 2025.

The average number of Little Tern observations across the 10-minute intervals shows moderate variation in activity. Observations were highest at 20 minutes after sunrise (3.38 Little Tern landings on average), followed by 40 minutes (2.75) and 60 minutes (2.33), indicating slight peaks in activity shortly after sunrise (see Appendix 10). Other intervals show more consistent, lower activity ranging between 1.38 and 2.12 landings on average. Overall, the Little Tern activity appears relatively evenly distributed during the first two hours after sunrise, with the most notable increase occurring within the first hour.

A total of 19 locations were used by Little Terns, while several others recorded no landings. The three most visited locations were A3 (80 landings), A4 (58), and A2 (51), representing the preferred locations. They were followed by A5 (42), A6 (31), C5 (30), A7 (28), C2 (27), C3 (22), and C4 (21), all of which indicate moderate use compared to the top three sites. Other locations with fewer landings include B2 (18), B5 (16), A8 (15), B3 (12), A1 (9), B4 (6), B7 (4), B6 (2), and B8 (1). The locations B1, C1, C6-C8, and D1-D8 remained unused throughout the study period.

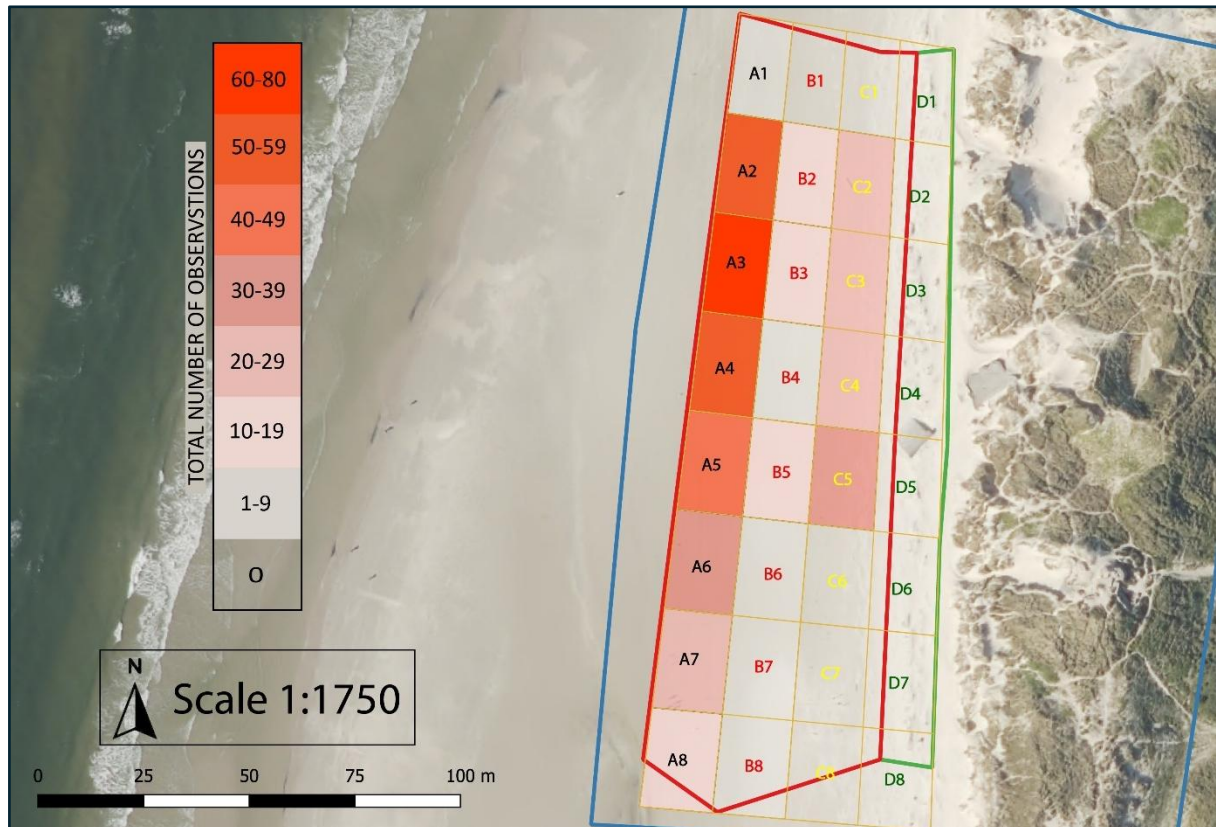


Figure 21: Heatmap showing the most frequently used locations by Little Terns. Own illustration, 2025.

The observed behaviours were dominated by resting (331 occurrences), which accounted for roughly 70% of all recorded activities. Courtship behaviour (58) was the second most frequent recorded activity at approximately 12%, followed by scrape making (50) at about 11%. Incubation (20, $\approx 4\%$), comfort behaviour (8, $\approx 2\%$), and flying due to disturbance (6, $\approx 1\%$) were the least frequently observed activities. These results indicate that the predator enclosure at Blåvandshuk was primarily used as a resting site, while also serving as a location for courtship display. The Little Terns seemed to test the habitat by making scrapes but chose to lay their eggs elsewhere. They flew due to disturbance from occasional military vehicles driving at high speeds close to the human fence.

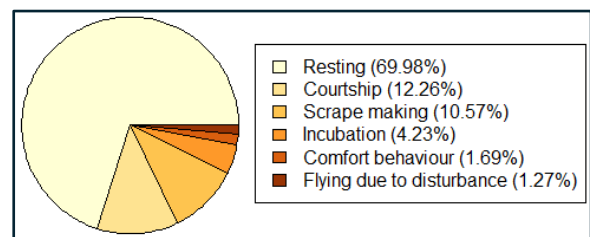


Figure 22: Percentage distribution of recorded activities. Own illustration, 2025.

In the optimized areas (C2-C5) Little Terns were observed engaging primarily in resting behaviour (77 observations), making it by far the most frequent activity (see Appendix 11). Courtship behaviour was observed 22 times, with nine of these involving Little Terns offering fish to decoys (see Appendix 12). Comfort behaviour was rare, occurring only once. This suggests that, during the observation period, the optimized areas were used as resting and courtship sites.

Across all locations, a Poisson regression model fitted to the actual number of landings showed that locations with decoys had substantially more Little Tern landings than those without. The predicted average number of landings was 25 for decoy locations (C2-C5) and 13.3 for non-decoy locations, representing an 88% increase (effect ratio = 1.88). The model confirmed that this difference was highly statistically significant ($p < 0.001$), indicating that the increased landings were very unlikely to be due to chance. Further evidence is shown when comparing only the C-locations. All C-locations without decoys (C1, C6-C8) had zero observed Little Terns, while locations with decoys (C2-C5) had an average of 25 landings each. This clear separation of landings between decoy and non-decoy locations within the same zone reinforces that the decoys were highly effective at attracting Little Terns.

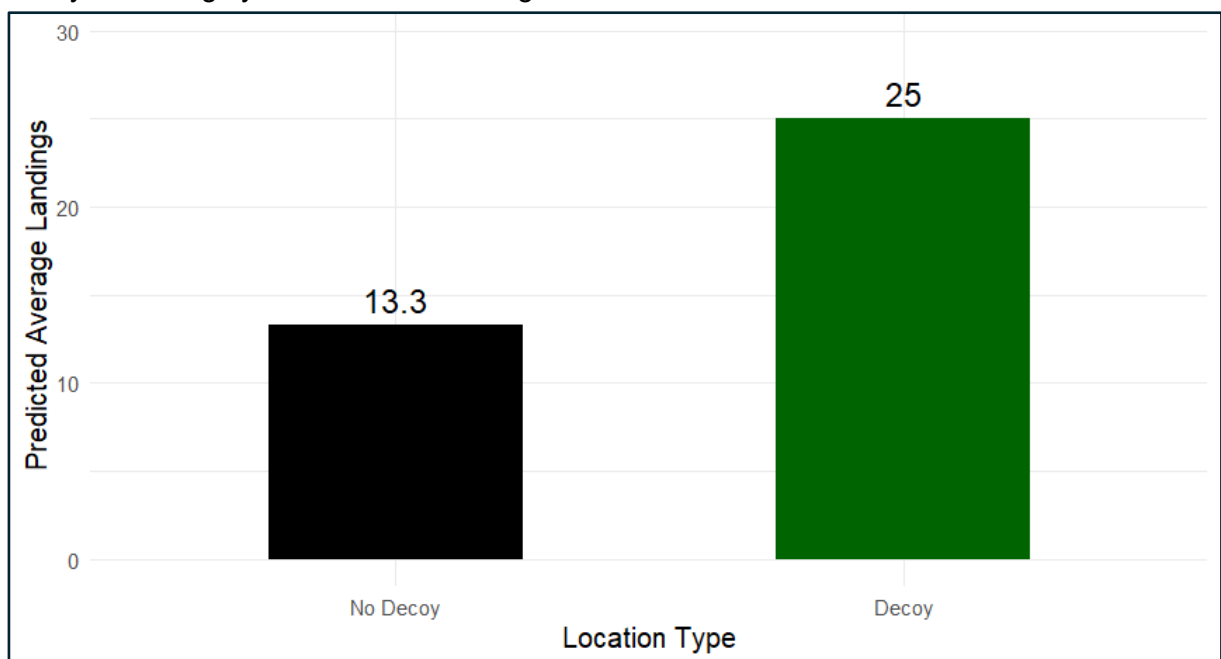


Figure 23: Predicted Little Tern landings by decoy presence. Own illustration, 2025.

The average surface cover composition at the top 10 most visited locations by Little Terns was dominated by sand, with smaller proportions of shell and minimal vegetation. Across these locations, sand cover ranged from 79% to 95%, whereas shell and vegetation contributed much smaller proportions. Shell cover varied between 5% and 20%, while vegetation was generally minimal, with averages below 2.2%.

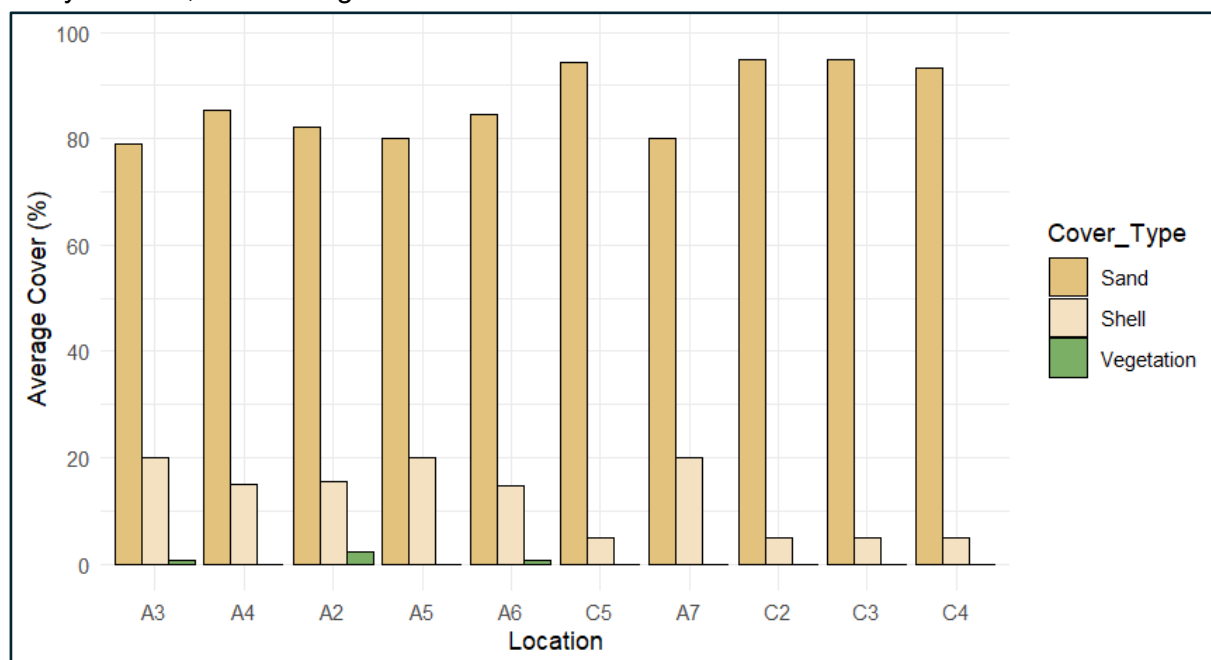


Figure 24: Average surface cover composition at the top 10 most visited locations by Little Terns. Own illustration, 2025.

3.4 Nest Monitoring

Across the three study sites, a total of 16 Little Tern nests were recorded, with two located at Blåvandshuk (see Appendix 13) and 14 at Grønningen on Fanø (see Appendix 14). No nests were found at Lakolk Strand on Rømø. Both nests at Blåvandshuk were predated within a five-day period, most likely by corvids or red foxes. The colony at Grønningen was partially flooded on the night between 23 and 24 June 2025, due to a westerly storm. Only a few nests survived this flooding event, and eight chicks ultimately fledged.

The analysis of environmental parameters across the 16 nest sites revealed clear patterns in surface cover composition and spatial distribution. On average, nests were situated 15.6 meters from the nearest electrified fence or wire and 41.6 meters from the +1.00 meter high tide line, indicating a relatively consistent placement on the backshore of the beach within predator exclosures. Surface cover composition was strongly dominated by shells, which accounted for an average cover of 82.8%, while sand cover contributed 16.9%. Vegetation cover was minimal at only 0.3% (see Appendix 15). These results indicate that Little Terns chose to nest predominantly in areas with shell-rich sand and almost no vegetation, highlighting a potential preference in habitat selection for nest sites.

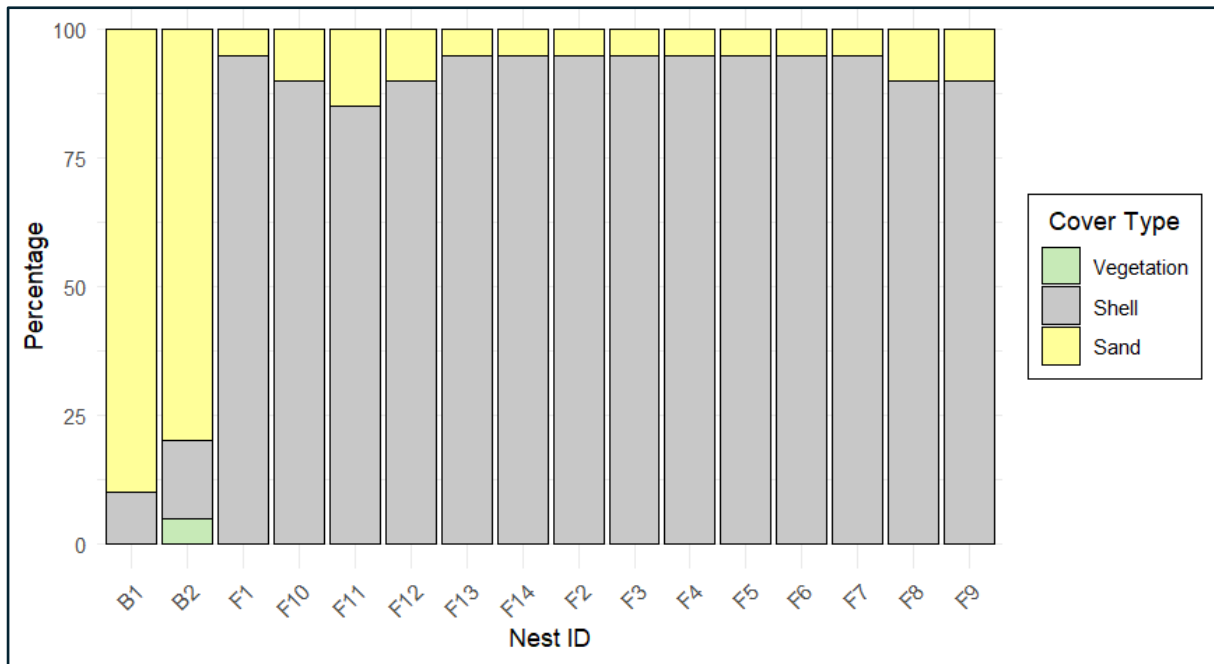


Figure 25: Surface cover composition of nest sites. Own illustration, 2025.

Additional observations across the fenced-off areas at the study sites included a variety of breeding, resting, and foraging birds. At Lakolk Strand, the predator enclosure hosted three to five breeding pairs of Common Ringed Plovers (*Charadrius hiaticula*) and Kentish Plovers (*Anarhynchus alexandrinus*), although breeding success remains unknown (J. Frikke, personal communication, 2025).

At Grønningen on Fanø, twelve breeding pairs of Common Gulls and one pair of Herring Gull were present and observed preying on other species eggs and chicks. Arctic Terns made around fifty breeding attempts at this site, but only five chicks successfully fledged. Four breeding pairs of Oystercatchers were recorded, resulting in the successful fledging of four chicks. (K. Fischer and J. Frikke, personal communication, 2025)

At Blåvandshuk nine breeding attempts by Common Ringed Plovers were recorded, with four of them inside the predator enclosure and five of them outside the fenced-off area. Of the nests outside the electric fence, four were predated, most likely by red foxes and corvids, and one was flooded. Inside the fence, two nests were predated by corvids, one by a red fox, and one was abandoned due to sand drift. Therefore, 90.91% of all nets were predated demonstrating a very high predation pressure.

The predator enclosure. at Blåvandshuk was visited almost daily by resting or foraging White Wagtails, Barn Swallows, and Hooded Crows. Additionally, an Oystercatcher (*Haematopus longirostris*) made two scrapes but abandoned the study site (see Appendix 16). Moreover, a Bar-tailed Godwit (*Limosa lapponica*) was observed resting, and a Common Raven (*Corvus corax*) was observed preying on a Common Ringed Plover nest (see Appendix 17).

3.5 Artificial Nests

At Blåvandshuk, 63% of the nests were predated, while 37% had an unknown predation status due to sand drift. All nests that were not affected by sand drift were predated.

At Lakolk Strand, 12.5% of nests were predated, 25% were not, and 62.5% had an unknown status due to sand drift or not recovered nests. Only 33.3% of the artificial nests with known status were predated.

Predation patterns differed markedly between the two study locations. In Blåvand mammalian predation was entirely due to foxes (see Appendix 18), which accounted for 15 predated nests. Avian predation, mainly by corvids (see Appendix 19), was responsible for four predation events. In Rømø all mammalian predation was also attributable to foxes, with 2 nests predated. Avian predation, most likely by a Common Gull, affected only 1 nest.

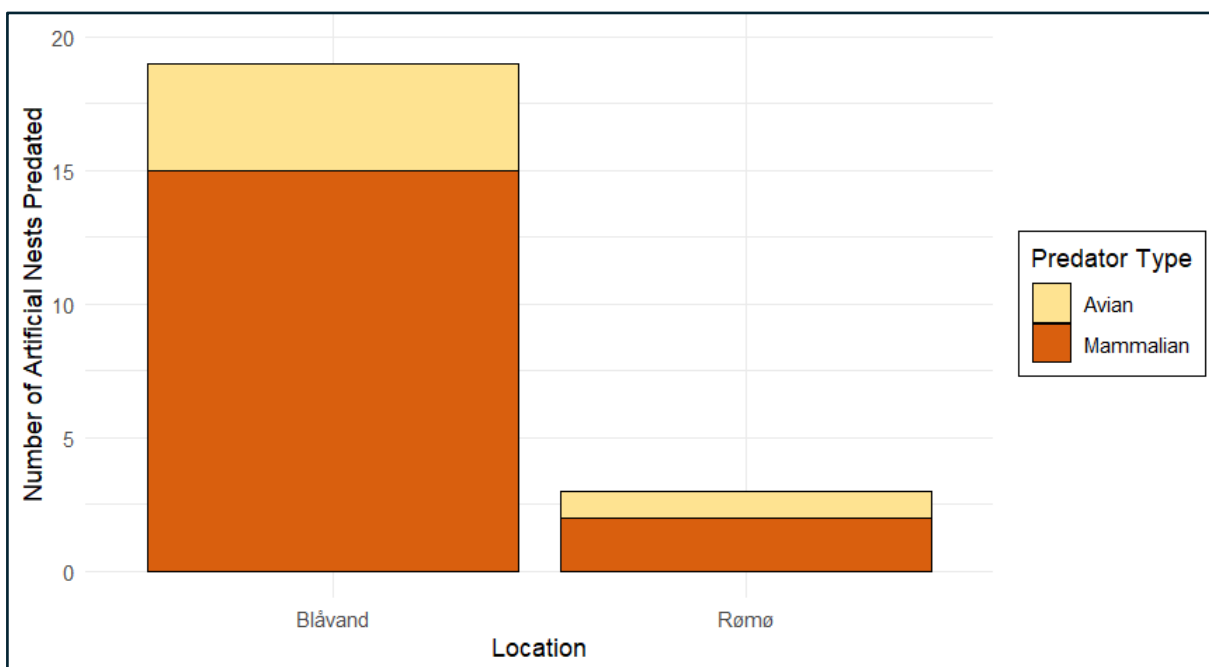


Figure 26: Predation patterns at Blåvand and Rømø. Own illustration, 2025.

Fisher's Exact Test results indicated that predation rates varied significantly among habitat types ($p = 0.032$), distance to water categories ($p = 0.033$), and vegetation cover categories ($p = 0.048$). This suggests that habitat characteristics influence nest predation risk. By including sand drift as a variable in the analysis, it became evident that areas with high sand drift experienced significantly lower predation ($p = 0.004$). Predation was particularly high in semi-fixed dunes (100%), moderate in fore dunes (40%) and embryo dunes (29%), and relatively low in salt marsh (20%), shell-rich sand (17%), and blanc sand (16%) (see Appendix 20).

3.6 Survey

A total of 107 individuals were interviewed, with an overall average age of 48.5 years. Of these, 15 respondents were locals and 92 were tourists.

The local participants had an average age of 58.7 years. None of the locals (0%) reported having read the informational sign at the beach entrance regarding the Little Tern, and only a small proportion (6.7%) reported feeling attracted by the fenced-off area. The majority (60%) expressed interest in additional informational signs on the beach, whereas 40% did not. Twenty percent had a dog with them, whereas 80% did not. Among dog owners, 86.7% were aware that dogs are required to be kept on a leash from April 1 to September 30, compared to 13.3% who were unaware of this regulation. All local respondents (100%) reported feeling responsible for protecting nature.

The tourist respondents had an average age of 46.7 years. Only a small fraction (7.6%) reported having read the informational sign at the entrance about the Little Tern, while the majority (92.4%) had not. Twelve percent felt attracted by the fenced-off area, whereas 88% did not. Interest in additional informational signs was high, with 90.2% indicating a desire for more information and 9.8% expressing no interest. Thirteen percent reported having a dog with them and 87% did not. Of the dog owners, 72.8% were aware of the leash requirement, whereas 27.2% were not. Nearly all tourists (98.9%) reported feeling responsible for protecting nature, with only 1.1% indicating otherwise.

Overall, the patterns of awareness and engagement were broadly similar among both groups. However, tourists tended to show slightly higher interest in additional informational signs, whereas locals demonstrated greater familiarity with the dog leash law (see Appendix 21).

3.7 Dog Counts

A total of 52 dogs were recorded, of which 23 were off-leash. This result represents a 44.2% rate of non-compliance with the seasonal dog leash law.

4. Discussion

4.1 Sand Drift Measurements & Surface Cover Composition Estimation

The variability in sand height across both study sites reflects the dynamic coastal landscapes in which they are located. It is important to acknowledge that the measurements obtained with wooden poles are punctual and cannot represent the absolute sand drift levels across the entire predator exclosures. However, the SDM Zones effectively capture trends of sand movement, allowing relatively precise assumptions for broader patterns.

When comparing the average standard deviation across all zones between the two sites, it becomes evident that the predator exclosure at Blåvandshuk (5.65) is exposed to considerably more sand drift than Lakolk Strand (2.86). This represents a 97.6% higher average sand drift at Blåvandshuk, underscoring a clear difference between the two sites. This large discrepancy in sand drift levels can be explained by differences in surface cover composition. Locations with little vegetation and shell cover were more exposed to sand movement, while areas with higher cover showed greater stability. That indicates, the more surface area covered by bare sand, the more prone it is to drift. This finding aligns with the normalized total surface cover of each site. The normalized total surface cover at Blåvandshuk predator exclosure consisted of 81.06% sand compared to 59.89% at Lakolk Strand. Thus, the higher sand drift at Blåvandshuk is a logical consequence of its markedly higher proportion of bare sand surfaces. Sand drift was particularly extreme in the D1 zone at Blåvandshuk, with a standard deviation of 7.89, making it impossible to maintain the intended westward predator exclosure. Therefore, installation in this zone is not recommended in the future unless daily maintenance by at least two people can be guaranteed.

To reduce sand drift at Blåvandshuk and enhance the future breeding habitat, planting species such as sea rocket (*Cakile maritima*) or common glasswort (*Salicornia europaea*) within the perimeter fence could be beneficial. This approach would allow the predator exclosure to remain largely free of dense vegetation, maintaining its attractiveness to Little Terns. At the same time, it could reduce sand drift within the predator exclosure and increase local biodiversity (Naturadb, n.d.).

Another potential strategy to decrease sand drift is the use of temporary anti-sand-drift fences. Two 30 cm tall fences with 50% porosity, spaced 0.3-0.6 m apart, can reduce wind speeds by up to 65% near the first fence. A noticeable reduction remains over 7 to 8 m downwind. (Wang et al., 2017, 2022). Fences could be constructed from locally available organic materials, such as pruned branches, and strategically placed inside the perimeter fence.

An additional approach to mitigate sand drift is distributing large quantities of shells inside the predator exclosure. This could reduce sand drift and enhance the habitat for Little Terns. The measure would require either volunteer or municipal support using small machinery.

The combined implementation of, planting vegetation, installing anti-sand-drift fences, and distributing shells, prior to the breeding season could increase the reproductive success of coastal breeding birds inside the predator exclosure at Blåvandshuk.



Figure 27: Proposal for the fenced-off Area at Blåvandshuk. Own map, 2025.

4.2 Records of Location & Activity

The slightly higher Little Tern activity observed within the predator exclosure in the first hour after sunrise can be explained by the general tendency of birds to be more active during the hour centered at sunrise or in the following hour (Robbins, 1981, p. 275). However, these results only show a trend for the first two hours after sunrise. To determine at what time of day activity is highest, observation periods would have needed to be consistently distributed across the entire day.

The early-season peak in Little Tern observations within the predator exclosure during the first half of May (average 17.1 observations/day) can be attributed to the beginning of the breeding season and the search for suitable nesting sites. The decline in the second half of May to an average of 9.31 observations/day suggests that many individuals that initially inspected the site decided against nesting at Blåvandshuk.

The near absence of Little Terns in June (0.27 observations/day) further indicates that the majority abandoned the area altogether. This pronounced downward trend strongly suggests that the habitat inside the enclosure was not suitable for breeding this year. This interpretation is supported by activity data, as the birds primarily used the site for resting (70%) and courtship (12%). While scrape making (11%) indicates that some individuals might have tested the habitat's potential, the lack of follow-through, with only two breeding attempts, demonstrates general rejection of the study site.

The most visited locations by Little Terns, such as A2, A3, and A4, had slightly higher vegetation and shell cover compared to less visited locations like C3 and C4, suggesting that even minor differences in surface cover may influence habitat selection.

The 3D-printed decoys proved highly effective in attracting Little Terns, increasing landings by 88% in decoy areas compared to non-decoy areas. Although decoys successfully attracted Little Terns (see Appendix 22), they did not lead to nesting, most likely because more suitable habitats were available elsewhere.

4.3 Nest Monitoring

The 16 recorded Little Tern nests indicate a preference for shell-rich and sparsely vegetated habitats within a predator enclosure, that is located on the backshore of the beach. However, more data is needed to confirm this.

Unfortunately, the eight fledged chicks from Grønningen on Fanø, together with one fledged chick from Juvre Sand on Rømø, represent the only successful Little Tern reproduction in the Danish Wadden Sea this year. This marks the least successful breeding season on record (K. Fischer & U. Berthelsen, personal communication, 2025) and underlines the importance of continued and adaptive conservation measures.

The high predation rates of the two Little Tern and nine Common Ringed Plover nests at Blåvandshuk highlight a key management concern. Considering that predation at this site was primarily by red foxes and corvids, targeted removal or deterrence of these species could be justified. Integrating Blåvandshuk into the existing predator control program of the National Park Wadden Sea would therefore be a logical step to improve breeding success in future seasons.

Repeated recordings of red fox tracks inside the predator enclosure at Blåvandshuk clearly demonstrate that the electric fence did not maintain a sufficient and consistent voltage. Multiple tracks indicate that red foxes were able to squeeze through the lowest meshes of the fence (see Appendix 23). Notably, one was even captured on a camera trap pulling repeatedly on the lowest electrified wire, apparently tolerating the electric shock (see Appendix 24).

This provides strong evidence that the voltage level was inadequate. On the evening prior, the fence was measured at 0.2 A and 0.2 kV. While the current of 0.2 A is sufficient, a voltage of only 0.2 kV is far too low to prevent red fox intrusion. A minimum voltage of 4 kV is generally recommended for effective deterrence (Hansen, n.d.).

The low voltage observed is most likely due to the sandy soil, which often exhibits a low moisture content and high resistivity, reducing the return path of electric current and decreasing fence efficacy. One possible solution is to install at least three ground rods instead of one, each 1.8 to 2.4 meters deep and spaced approximately 3 meters apart. This would ensure proper grounding and increase fence performance. (Zareba Systems, n.d.) Applying conductive slurries, out of water and bentonite clay, around the ground rods can further enhance grounding efficiency (Booher, 2021).

The absence of breeding Little Terns at Lakolk Strand may be attributable to habitat changes, particularly increased vegetation growth and dune formation. Therefore, it should be considered to relocate the predator enclosure within the perimeter fence to a more open area with less vegetation and sand rich in shells.

4.4 Artificial Nests

The high predation rates recorded in the artificial nest experiment further emphasize the importance of predator control at Blåvandshuk and simultaneously demonstrate the success of ongoing predator management on Rømmø. While all artificial nests unaffected by sand drift at Blåvandshuk were predated (100%), only a third (33%) were predated at Lakolk Strand. Across both study sites, foxes accounted for 17 predation events, corvids for four, and a single predation event was most likely caused by a Common Gull, highlighting these species as the main predators of concern.

Environmental parameters such as habitat type, distance to water, vegetation cover, and sand drift significantly influenced predation risk. However, these effects must be interpreted with caution, as many parameters are interdependent. For example, habitat types closer to the water had gradually less vegetation and were more prone to sand drift, which in turn reduced the likelihood of predation simply by burying nests. This interrelationship explains why sand drift showed the strongest statistical effect ($p = 0.004$), as it directly reduced predation by covering nests, rather than influencing predator behaviour itself.

Consequently, no definitive conclusion can be made regarding which environmental parameter most strongly affects predation risk. Instead, the results reveal general trends that require further study with more frequent nest checks. Daily monitoring and clearing of sand from artificial nests would have been necessary to isolate the true influence of environmental parameters on predation risk. Importantly, the results also reinforce that increased vegetation reduces exposure to sand drift.

4.5 Survey

Survey results for both tourists and locals revealed very low engagement with the informational signs, with only 0% of locals and 7.6% of tourists reporting to have read them. This can likely be explained by the poor positioning of the signs, placed on the back of the beach entry information boards and thus more visible when exiting the beach rather than entering. Nevertheless, there is clear interest in additional signage, with 60% of locals and 90.2% of tourists expressing a desire for more information. Therefore, placing a second information sign at a more strategic location would be highly beneficial. Positioning it on the beach along the row of poles marking the military training area is ideal, as this lies directly along the approach to the predator enclosure for most beach visitors. Both groups showed high awareness of the leash law among dog owners (86.7% of locals, 72.8% of tourists). It is important to note that, while knowledge of the law is generally strong, it does not necessarily translate into compliance on the beach.

4.6 Dog Counts

The observed 52 dogs, with 23 being off-leash represents a 44.2% non-compliance. This indicates a significant gap between awareness and behaviour, emphasizing the need for stricter enforcement and clearer communication. To address this, multiple signs specifically about the dog leash law could be placed at key access points to and on the beach (see Appendix 25), explicitly stating the 2000 DKK fine for violations. Such measures could both increase compliance and reduce disturbance pressure on sensitive resting and breeding coastal birds.

It should be emphasized that the observed dog counts do not represent the actual number of off-leash dogs, since the counts were conducted in the early mornings when human activity is very low.

5. Conclusion

This study highlights the complex interplay of environmental factors, predator pressure, and human disturbance that determine the quality of predator exclosures within coastal habitats for Little Terns and other breeding shorebirds.

Sand drift was identified as a key driver influencing habitat stability. The predator exclosure at Blåvandshuk experienced significantly higher levels of sand drift than the one at Lakolk Strand, due to its greater proportion of bare sand. Mitigation strategies such as planting vegetation, installing anti-sand-drift fences, and distributing shells could reduce sand drift, improve habitat quality, and potentially increase reproductive success at Blåvandshuk. While planting vegetation and installing anti-sand-drift fences might require too much effort to be practical, creating a shell bed appears feasible and demonstrates the most effective way to enhance the habitat.

Predation remains a critical threat, with red foxes and corvids identified as the primary nest predators. The insufficient voltage of the electric fence at Blåvandshuk highlights the need for improved predator deterrence measures, including better grounding and integration into the predator control program of the Wadden Sea National Park. The artificial nest experiments provided additional evidence supporting the implementation of an adaptive predator management.

Observations of Little Tern activity and nest placement suggest a habitat preference for sparsely vegetated, shell-rich areas on the backshore of the beach within a predator exclosure. The low breeding success in the current season underscores both the fragility of these habitats and the urgent need for continued conservation efforts in the Danish Wadden Sea.

Human disturbance, particularly from off-leash dogs, represents an additional challenge, highlighting the importance of increased signage, enforcement, and public engagement.

Overall, the findings highlight that effective conservation of Little Terns and other coastal breeding birds within predator exclosures requires an integrated approach addressing habitat enhancement, predator management, and beach visitor behaviour. An adaptive management strategy, guided by continued monitoring, is essential to enhance breeding success and safeguard these vulnerable coastal bird populations. The continued use of predator exclosures is necessary, while the use of hideouts and 3D-printed decoys is recommended to attract Little Terns into safe breeding habitats in the Danish Wadden Sea.

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Appendix

Appendix 1: Anti-perch hunting wires



Appendix 2: Painting decoys



Appendix 3: Cutting concrete tubes



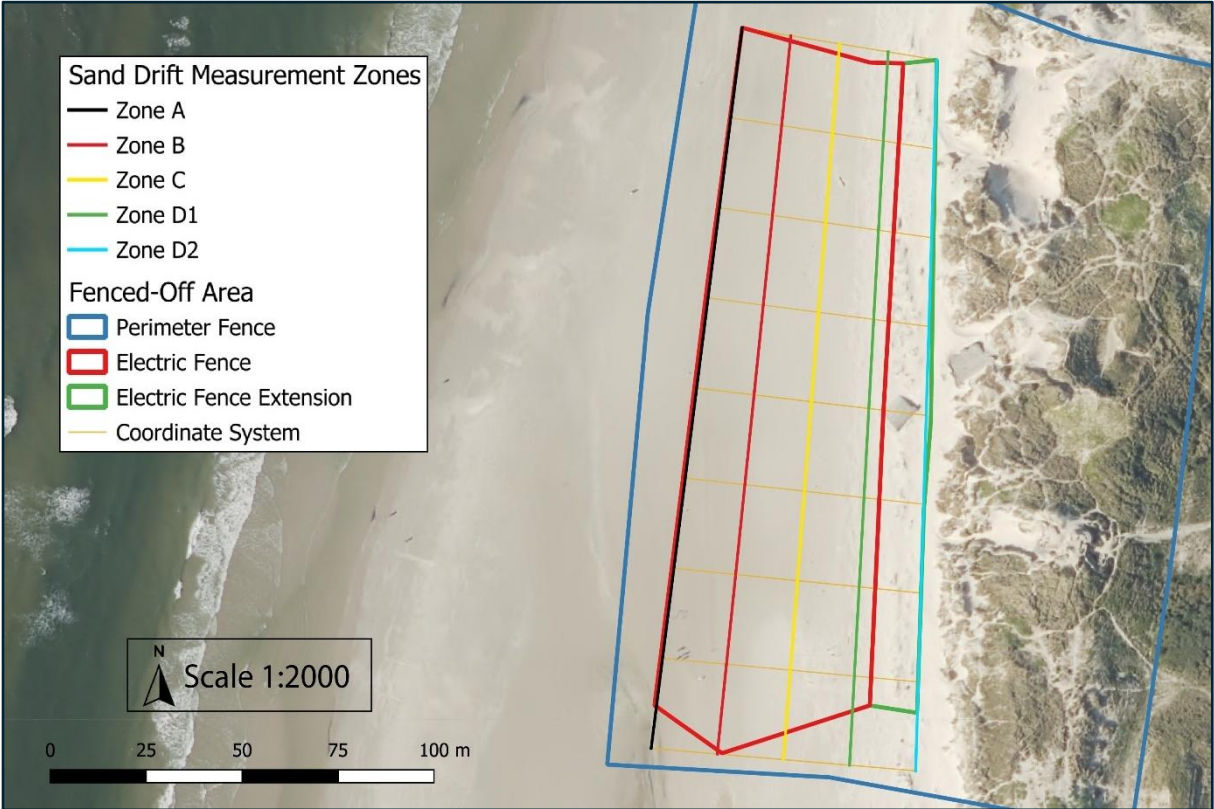
Appendix 4: Decorating concrete tubes with sand



Appendix 5: Field sheet for SDM & SCCE



Appendix 6: SDM zones



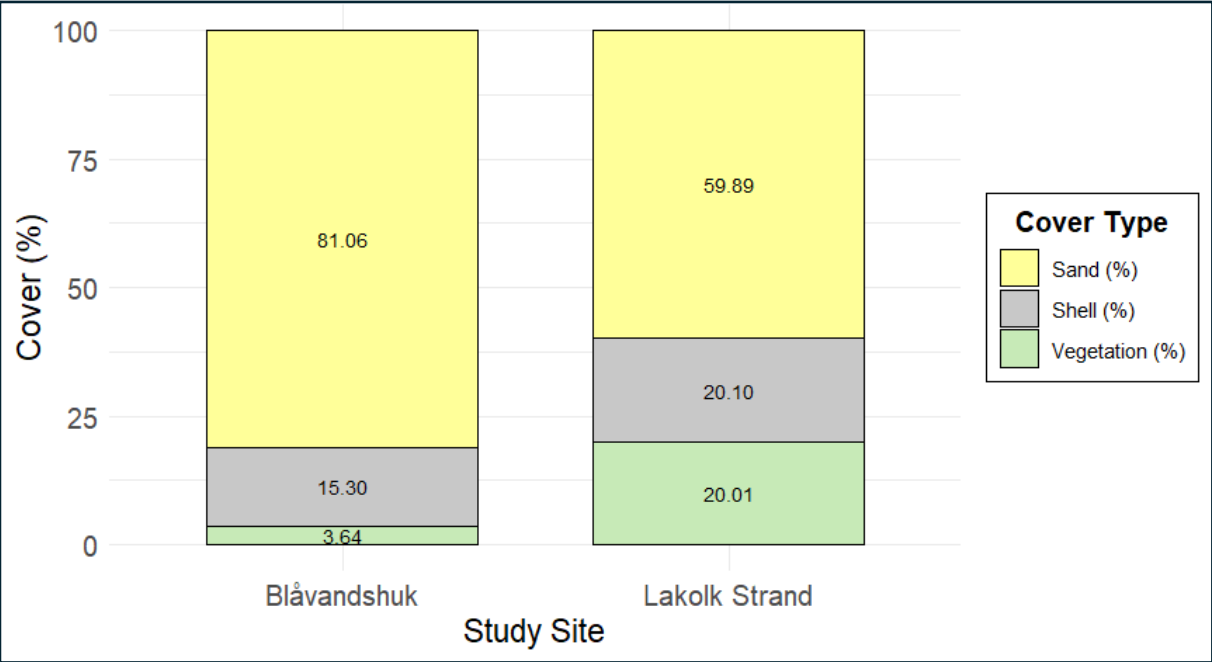
Appendix 7: Field sheet for ROLA

	A	B	C	D	E	F	G	H
1	Records of location & activity	Codes for Activity & ID	Observer, Date, Weather	Time	Nest ID / Individual ID	Location	Activity	Notes
2	2h from sunrise	foraging = FG	JS, 01.05.08, 3/4/5	06:50	NN	A2	R	
3	2h midday	incubation of eggs = I	"	"	NN	A2	R	
4	2h before sunset	defending colony = D	"	"	NN	A2	R	
5		hiding = H	"	"	NN	C5	R	
6		roosting = R	"	"	NN	C5	R	
7		flying due to disturbance = FD	"	"	U5P	A5	S	up - p. 10/11/12, left 10/11/12
8		comfort behaviour = CF	"	"	NN	A5	R	
9		brooding = B	"	"	NN	A5	R	
10		courtship behaviour = CS	"	07:00	NN	A6	R	
11		feeding chicks = FC	"	"	NN	A6	R	
12		making scrape = S	"	"	NN	C4	CS	
13			"	"	NN	A6	R	
14			"	"	NN	A6	R	
15		N23 = nest 23	"	"	NN	C3	CS	fish to decay
16		NN = no name (no ID)	"	"	NN	C3	R	
17		Ring-A34 = metal ring	"	"	NN	C3	R	
18		CNN = colour-ring no name	"	"	NN	B5	R	
19		U02 = colour-ring number	"	"	NN	B5	R	

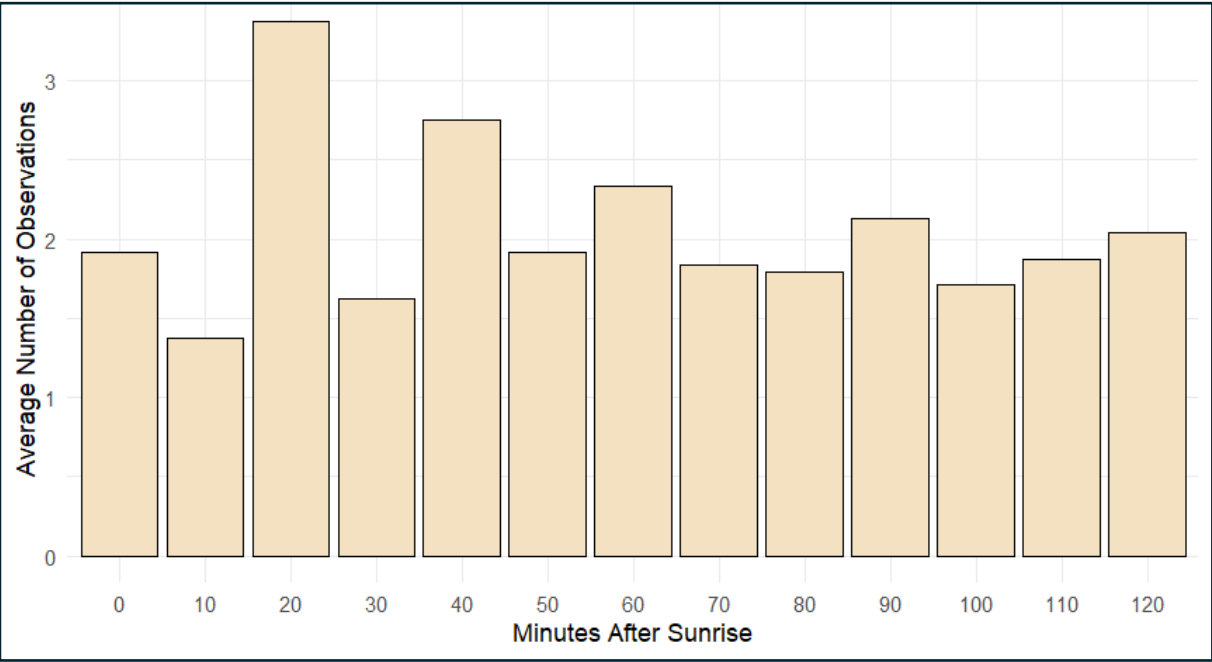
Appendix 8: Survey with beach visitors



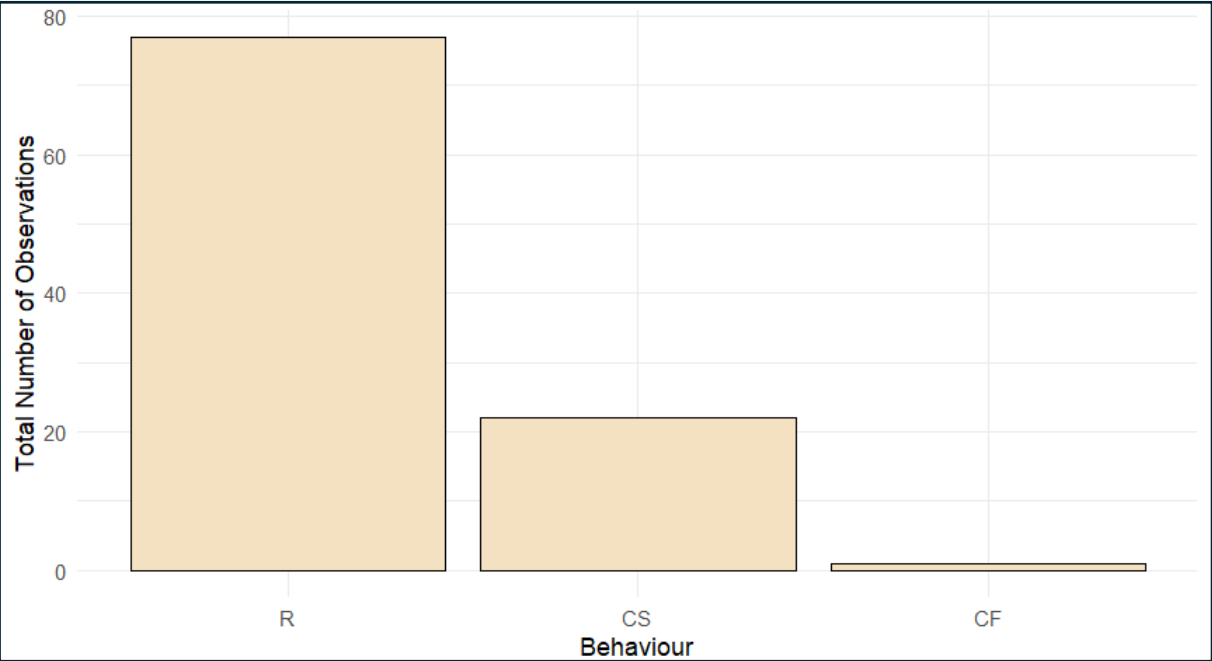
Appendix 9: Normalized total surface cover composition



Appendix 10: Average number of observations per ten-minute interval



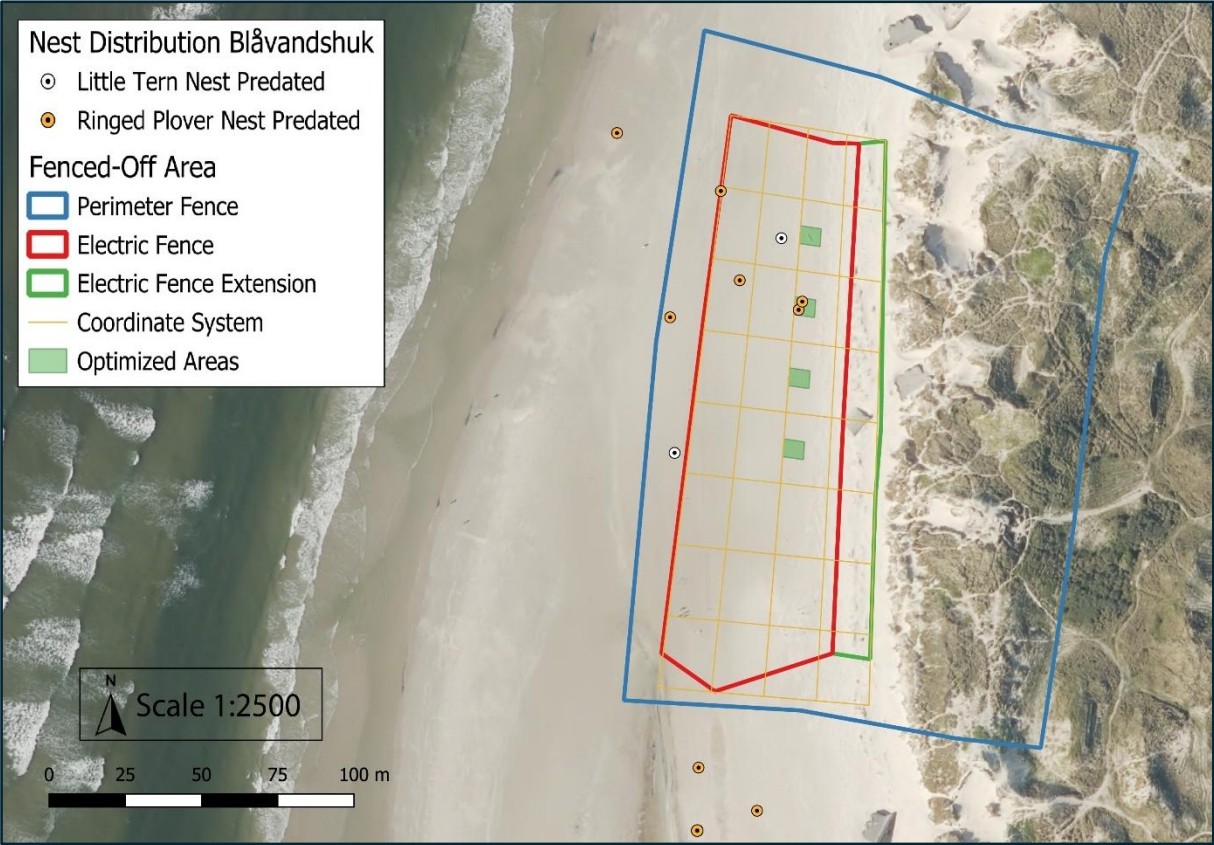
Appendix 11: Most common Little Tern behaviours in optimized areas



Appendix 12: Little Tern offering fish to a decoy



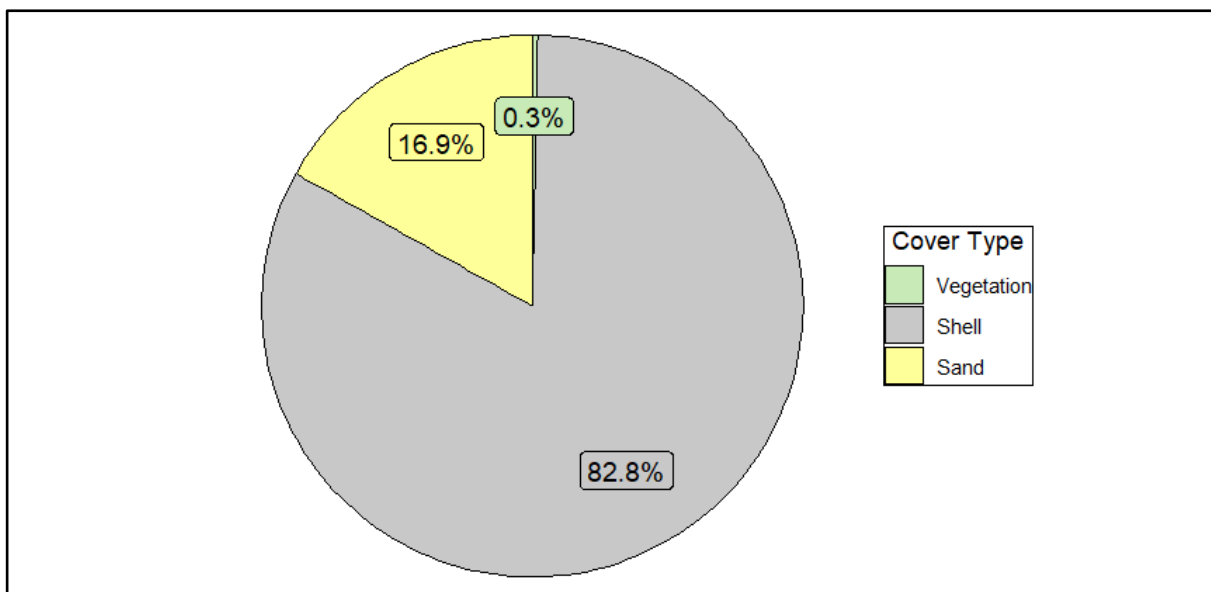
Appendix 13: Nest distribution at Blåvandshuk



Appendix 14: Nest distribution at Grønningen



Appendix 15: Average Surface Cover Composition of Nest Sites



Appendix 16: An Oystercatcher making a scrape



Appendix 17: Raven predating on Common Ringed Plover nest



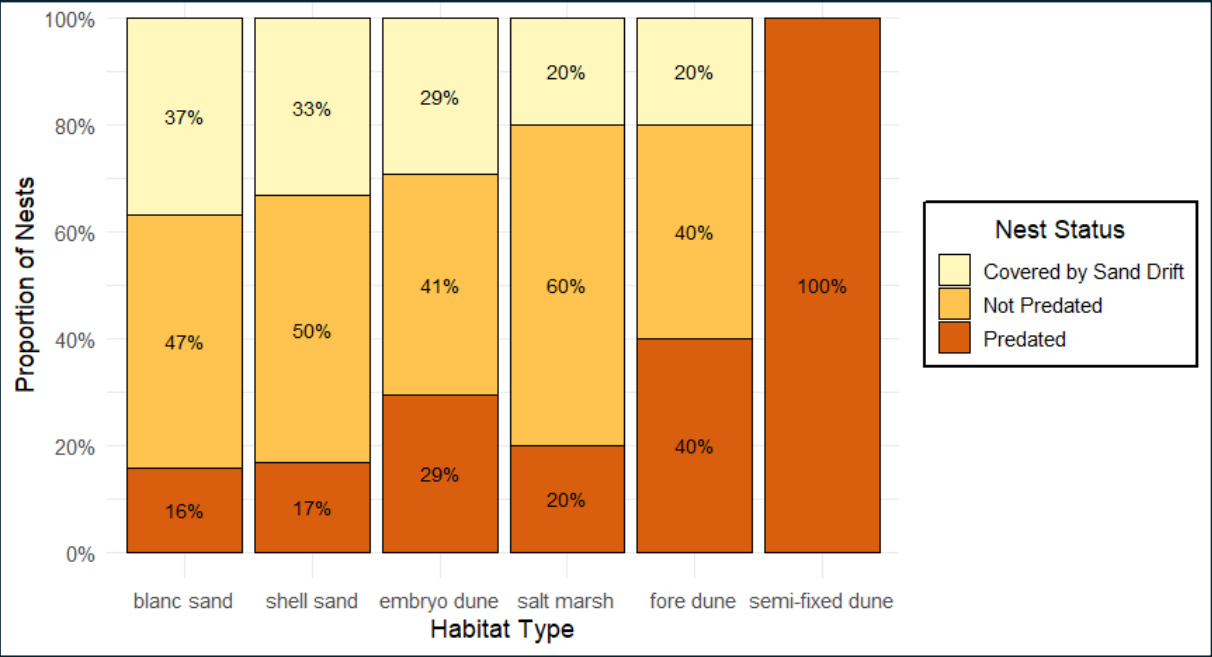
Appendix 18: Red Fox predating artificial nest



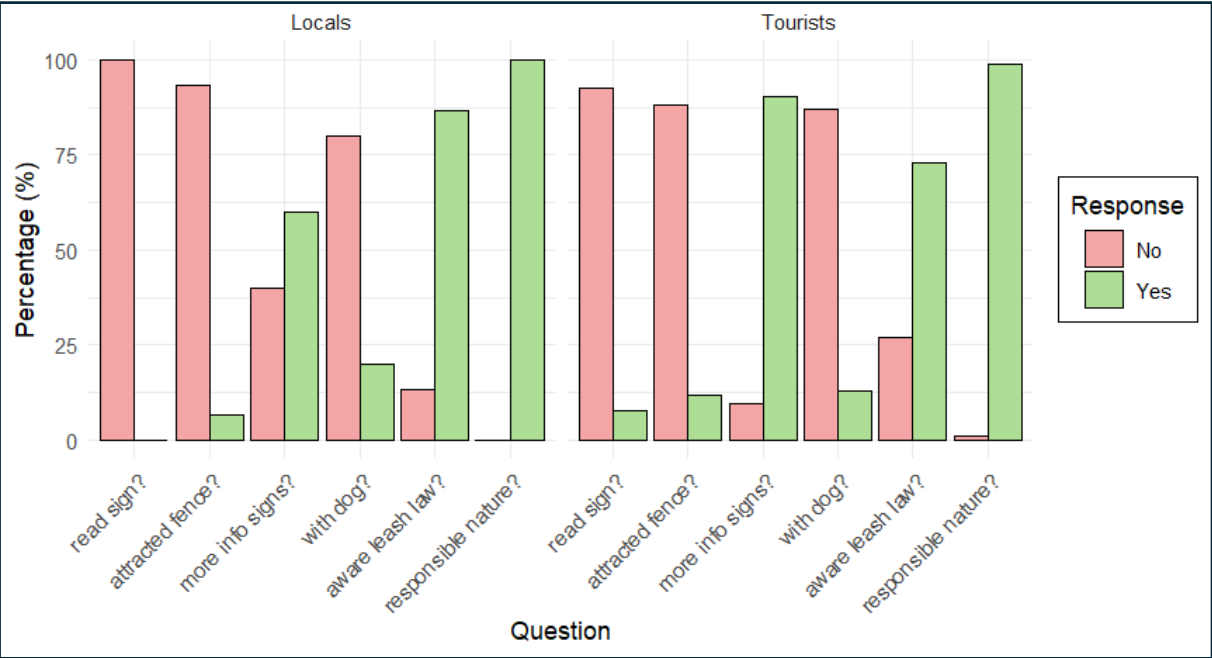
Appendix 19: Hooded Crow predating artificial nest



Appendix 20: Predation and sand drift per habitat type



Appendix 21: Survey response percentages per group



Appendix 22: Little Terns attracted by decoys



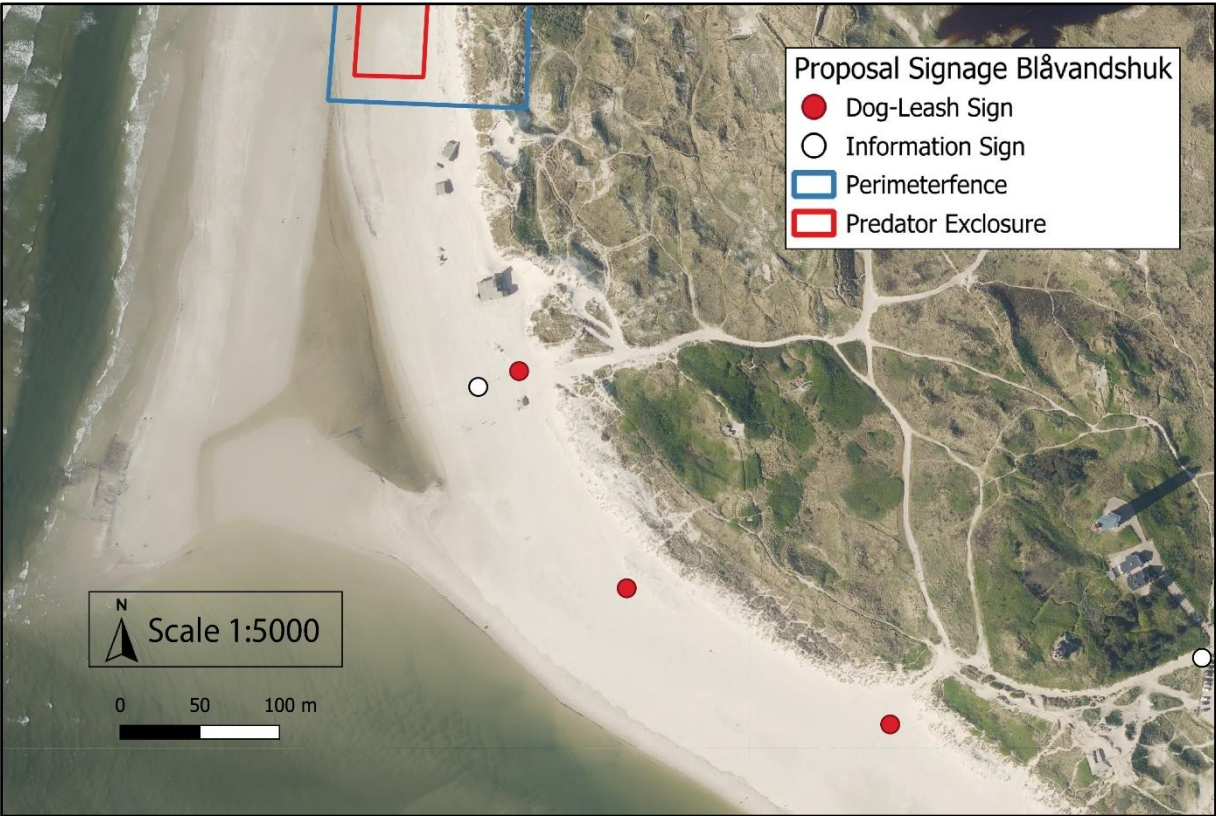
Appendix 23: Red fox tracks



Appendix 24: Red fox pulling on electrified wire



Appendix 25: Proposal for strategic sign placement



Appendix 26: Red fox inside predator exclosure



Appendix 27: Common Ringed Plover breeding in one of the optimized areas (C3)

