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Do the barrier islands of the Po Delta constitute an ecological trap for colonising Slender-billed Gulls *Larus genei*?

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Abstract The Slender-billed Gull *(Larus genei)* breeds with a scattered distribution on an extensive nesting area, ranging from India and Afghanistan in the East to the Iberian Peninsula in the West, including the Mediterranean and the Black Sea. A number of habitats are used for breeding, such as sand-spits and beaches along coasts and islands of land-locked seas, steppe lakes, but also brackish or freshwater lagoons near river deltas. Sea level rise dramatically affects coastal sites, thus being the greatest threat to the survival of many seabird species, including gulls. This note describes habitat selection, breeding success and causes of failure of Slender-billed Gulls during their colonisation of the northern Po Delta (NE Italy) during 2018–2022. Slender-billed Gulls colonised the northern Po Delta in 2018. Six colonies were found during the study period. Birds used both natural barrier islands and artificial dredge islands. Productivity in the first five years after the colonisation event was zero, mostly due to colony sites being flooded by high tides and storms. If Slender-billed Gulls will switch to nest in nearby fish farms, these could provide plenty of suitable breeding sites, safe from tidal flooding and with very low predation pressure, allowing sufficient productivity. At the moment, Slender-billed Gulls are unsuccessful in colonising the barrier islands of the Po Delta.

Keywords: breeding, drones, habitat selection, productivity, sea level rise

Összefoglalás A vékonycsőrű sirály *(Larus genei)* elszórtan költ egy hatalmas fészkelő területen, India keleti részétől és Afganisztántól az Ibériai-félsziget nyugati részéig, beleértve a Mediterráneumot és a Fekete-tengert. Számos élőhelyet használnak költésre, például homokpadokat, tengerpartokat, beltengerek szigeteit, sztyeppei tavakat, sós vagy édesvízi lagúnákat a folyódelták közelében. A tengerszint emelkedése drámaian érinti a part menti területeket, így ez jelenti a legnagyobb veszélyt számos tengeri madárfaj, köztük a sirályok túlélésére. Ez a cikk a vékonycsőrű sirályok élőhely-kiválasztását, költési sikerét és kudarcának okait írja le a 2018–2022 közötti időszakban, a Pó-delta északi részén (Észak-Olaszország) való kolonizációjuk során. A vékonycsőrű sirályok 2018-ban kolonizálták a Pó-delta északi részét. A vizsgálati időszak alatt a felmérők hat telepet találtak. A madarak a költéshez természetes gátszigeteket és mesterséges kotrószigeteket egyaránt használtak. A megtelepedéstől számított öt évben a költési siker nulla volt, főként a dagály és viharok által elárasztott költőhelyek miatt. A vékonycsőrű sirályok a közeli halgazdaságok területén találhatnának megfelelő költőhelyet, ezek ugyanis védettek az árapály-áradásoktól, és a predációs nyomás is nagyon alacsony, a körülmények megfelelő költéssikert tennének lehetővé. Jelenleg a vékonycsőrű sirályok sikertelenek a Pó-delta kolonizálásában.

Kulcsszavak: költés, drónok, élőhely kiválasztása, termékenység, tengerszint emelkedés

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Introduction

The Slender-billed Gull *(Larus genei)* breeds with a scattered distribution covering an extensive nesting area, ranging from India and Afghanistan in the East to the Iberian Peninsula in the West, including the Mediterranean and the Black Sea (BirdLife International 2022). The estimated global population size of the species is 120,000–140,000 individuals (Wetlands International 2022) with an uncertain trend. Overall, about 63,000 individuals are estimated to reside in Europe, where the species is decreasing and classified as Vulnerable (BirdLife International 2021). A number of habitats are used for breeding, such as sand-spits and beaches along coasts and islands of land-locked seas, steppe lakes, but also brackish or freshwater lagoons near river deltas (Keller *et al.* 2020, BirdLife International 2022).

The population inhabiting Italy, where the species started breeding in 1976 with 34 pairs in Sardinia, amounted to 3,000–5,000 pairs during 2006–2012 (Brichetti & Fracasso 2018), with a patchy distribution pattern including breeding sites in Sardinia and along the Adriatic coastline, both in the south (Apulia) and in the north (Emilia-Romagna). More recent estimates give a figure of 1,500–2,000 pairs, with a declining trend (De Faveri 2022).

Along the northern Adriatic coastline (NE Italy), the Slender-billed Gull traditionally bred on brackish lagoons (Valli di Comacchio), saltpans (Saline di Cervia) and fish farms (Valle Bertuzzi) (Brichetti & Fracasso 2018). From 2015, Slender-billed Gulls has started to spread north, colonising some recently built artificial marsh islands in the open lagoons of the southern Po Delta, south of the Po di Goro River, in 2017. From 2018, they spread further northward, settling on barrier islands of the northern Po Delta in the Veneto Region (Valle *et al*. 2022), which had never been used before by the species (Scarton *et al*. 2005, 2018).

This study describes habitat selection, breeding success and causes of failure of Slender-billed Gulls during their colonisation of the northern Po Delta during the 2018–2022 period.

Material and Methods

Study Site

We conducted the breeding bird surveys in 2018–2022 in the wetlands of the Po Delta located north of the Po di Goro river (hereafter “northern Po Delta”), in the Veneto Region, between the mouth of Adige river (45°09’ N, 12°20’ E) to the north and the Po di Goro River (44°47’ N, 12°24’ E) to the south, along a 50 km long section of coastline. Apart from the Po river and its branches, the Po Delta is characterised by a number of shallow brackish lagoons separated from the mainland by twenty-four fish farms and by thirty barrier islands (Day *et al.* 2019).

One important morphological feature of the Northern Adriatic is that it experiences high tides of more than 1 m as compared to most of the Mediterranean Sea where the mean tidal range does not exceed 20–30 cm. The combined effects of high tides, storm surge and the seiche phenomenon (i.e. free oscillations of the water body caused by winds, which can persist for several days) produce in the northern Adriatic the highest sea level extremes of the whole Mediterranean (Medvedev *et al*. 2020, Šepić *et al.* 2022). Moreover, recent studies show that the relative sea level rise is the major driver of the increase in the frequency of floods observed over the last century (Ferrarin *et al.* 2022). Extreme high tides occurring in late spring may have disastrous effects on the reproductive success of waders and seabirds nesting in the Gulf of Venice at saltmarshes, dredge islands and other low-elevation sites such as barrier islands (Scarton & Valle 2015). Tidal levels used in the present paper refer to a tidal gauge located in the lagoon of Venice, about 40 km far from the study site (Comune di Venezia 2022).

The community of breeding gulls and terns of the northern Po Delta is one of the largest in the Mediterranean, with ca. 7,000 pairs in 2015–2018 (Valle & Verza 2020). Due to its importance for birds, the area is listed as a Special Protection Area (IT3270023 – Delta del Po) under the European Union 147/09 Birds Directive.

We studied Slender-billed Gulls as part of a long-term monitoring program of breeding waterbirds (Scarton *et al.* 2005, 2018, Valle & Verza 2020). The barrier islands of the northern Po Delta are historically used for breeding by a few waterbird species: Eurasian Oystercatcher *Haematopus ostralegus*, Kentish Plover *Charadrius alexandrinus*, Yellow-legged Gull *Larus michahellis*, and Little Tern *Sternula albifrons* (Valle & Scarton 1999), but some species, other than the Slender-billed Gull, recently settled: Pied Avocet *Recurvirostra avosetta*, Sandwich Tern *Thalasseus sandvicensis*, and Common Tern *Sterna hirundo* (Valle & Verza 2020). Predators of eggs, chicks or adults include Red Foxes *Vulpes vulpes*, Marsh Harriers *Circus aeruginosus*, Montagu's Harriers *Circus pygargus*, and Yellow-legged Gulls (Valle & Scarton 1999).

Field data collection

In each year, all the barrier islands along with the lagoons laying behind were surveyed by boat and by drone for nesting colonies. Once a colony was discovered, we used small drones to count nesting pairs, to assess habitat selection and to estimate the reproductive success (Valle & Scarton 2021a, 2021b). Colonies were monitored during the peak breeding season (mid-May – mid-July) by weekly drone flights from laying to fledging or failure. Surveys took place between 08:30 and 17:30 hours (but diurnal periods of extreme temperatures, such as early morning or noon, were avoided), avoiding days with unusually high tides, strong winds and rains. All apparently active nests, i.e. those containing eggs and/or chicks, were counted. The number of breeding pairs was assumed to be the same as the number of active nests. Nests were mapped flying at elevations above ground level (AGL) higher than the agitation distance, i.e. adults opening wings in response to low AGL overflights known for the species (Valle & Scarton 2018). According to the current recommendations (Hodgson & Koh 2016), the drone was launched at least 150 m from the colony, in order to minimise disturbance to birds. The drone reached the vertical point of the colony through a lawn-mower flight pattern, flying 70 m AGL. During the next phase, the drone was slowly driven once more through a lawn-mower flight pattern to an altitude of 10 m AGL, which allowed the detection of incubating birds upon post-processing, and it slowly flew over the colony at a speed of 10 km/h. During the low-AGL survey, the different bird species

Figure 1. Close-up drone imagery during low-AGL flight aimed at locating clutches of different species in a mixed colony of Slender-billed Gulls and Sandwich Terns (Po Delta, NE Italy in 2020). Lack of disturbance by drone intrusion on Slender-billed Gulls can be inferred by the apparently indifferent chicks and adults in the foreground

1. ábra Közeli drónfelvételek alacsony AGL-szintű repülés közben, amelyek célja a vékonycsőrű sirályok és a kenti csérek alkotta vegyes kolóniájában költő fajok fészekaljainak azonosítása (Pódelta, ÉK-Olaszország 2020-ban). A drónok behatolása a vékonycsőrű sirályokat nem zavarta, amit az előtérben látható közömbös fiókák és felnőttek mutatnak

were identified on nest *(Figure 1)*. This allowed us to avoid serial ground visits except for elevation above water level (AWL) estimation, which was assessed after site abandonment by the nesting adults. Breeding success was categorised according to Valle and Scarton 2021b. Nests were categorised as (1) active (presence of eggs) or successful (presence of hatchlings) or (2) unsuccessful, when a) predated, if beak marks or yolk were found on shell, b) flooded, i.e. eggs found wet or out of nest cups after exceptionally high tides, c) deserted or infertile (eggs found after 28 days of incubation), or d) disappeared; when the cause of egg loss could not be univocally determined, e.g. when eggs disappeared following violent rainfall thus being possibly washed away. During drone surveys, the number of hatchlings was recorded for successful nests. Maximal flight time was <5 min. During the drone flight, an assistant researcher observed the colony from afar to exclude possible predation of unattended clutches and/or chicks by aerial predators (Valle & Scarton 2021a, 2021b).

Image Processing

Drone counts were performed on a personal computer using DotDotGoose's count tool v.1.3.0 (Ersts 2019) on images directly shot in the field or selected frames obtained from videos automatically stitched together using ICE (Microsoft's Image Composite Editor,

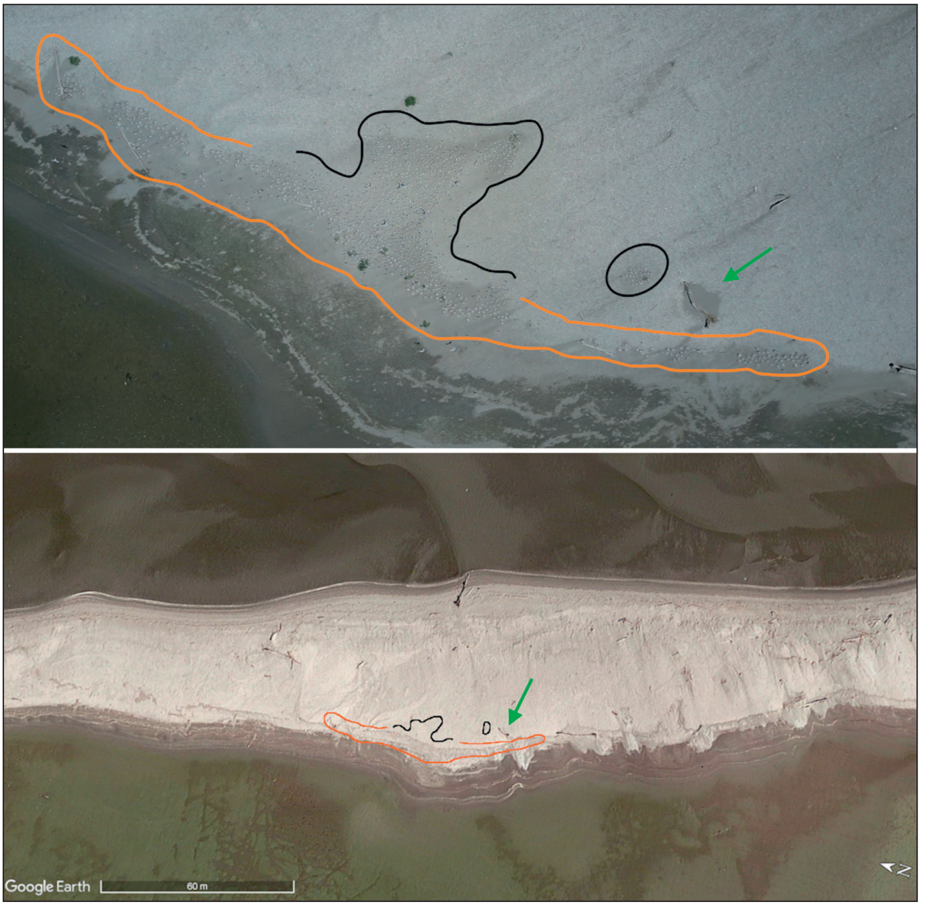

Figure 2. Upper panel: mixed colony of Slender-billed Gulls (orange line) and Sandwich Terns (black lines) in a drone image, late May 2020. Slender-billed Gulls are scattered along the shore facing the lagoon, nests being located within a few meters from the tideline. Co-present Sandwich Terns occupy the inner part of the barrier island (black encircling line). The wrecked tree trunk in the lower, right quadrant, between Sandwich Terns and Slender-billed Gulls (green arrow), is also visible in the Google Earth image in the lower panel. Lower panel: Google Earth imagery (April 2020) of the 2020 colony site of Slender-billed Gulls (orange line) and Sandwich Terns (black lines) on a barrier island in the Po Delta. The same barrier island also hosted a colony of Slender-billed Gulls both in 2018 (mixed with Sandwich Terns) and 2021 (alone)

2. ábra Felső panel: vékonycsőrű sirályok (narancssárga vonal) és kenti csérek (fekete vonalak) vegyes kolóniája drónképen, 2020 május végén. A vékonycsőrű sirályok a lagúnával szemben elszórtan helyezkednek el a part mentén, a fészkek néhány méteren belül találhatók a dagályvonaltól. A szintén jelenlevő kenti csérek a gátsziget belső részét foglalják el (fekete körvonal). Az alsó, jobb oldali kvadránsban, a kenti csér és a vékonycsőrű sirály között (zöld nyíl) található összetört fatörzs az alsó panelen lévő Google Earth képen is látható. Alsó panel: Google Earth-képek (2020 április) a 2020-as vékonycsőrű sirályok (narancssárga vonal) és kenti csér (fekete vonalak) kolóniájáról a Pó-delta egyik gátszigetén. Ugyanez a gátsziget 2018-ban (a kenti csérekkel vegyesen) és 2021-ben (egyedül) a vékonycsőrű sirály kolóniának is otthont adott release 2.0; www.microsoft.com). In the post-processing phase, a grid (10 × 10 m) was overlaid on drone imagery *(Figure 2)*, individual nests were assigned a number and counted, their fate was assessed and habitat parameters were measured grid cell-by-grid cell on serial (weekly) imagery (Valle & Scarton 2021b). Habitat choice was investigated at the nest site level, superimposing an arbitrary grid of 10 × 10 m quadrats (*sensu* Scarton & Valle 2020) in a radius of 100 m from the centre of the colony, on the drone imagery of the study islands using the free software QGIS (release 3.12.1; www.qgis.org; *Figure 2*). Each quadrat was characterised, when applicable, for the presence-absence and number of nests of Slender-billed Gulls and for the following biotic and abiotic parameters: 1–5)% of the quadrat covered by vegetation, bare sand, water surface (the latter measured both inside the islets for tidal pools and surrounding the island, i.e. the open lagoon and sea), and wrecked material. Other parameters include: 6) location, classified as "central" (the quadrat was separated from the water edge by at least another quadrat) or "peripheral" (the quadrat was at the water edge), 7–9) distance from the sea and from the lagoon, height of ground above the water level (AWL), the latter being visually estimated in four classes 0–10, 11–20, 21–30, 31–40 cm. Finally, the presence of nests of other species was also recorded. All measurements were performed by two observers who were unaware of each other's results. We planned to assess both hatching success (number of hatched chicks per nest attempt) and fledging success (number of chicks that survived to three weeks of age per nesting attempt). These surveys, which were planned to be carried out up to three weeks of age, permit only a conservative estimate of productivity, but we chose not to fly over older chicks that would be capable of flying away in response to drone intrusion (pers. obs.).

Statistics

Statistical analysis was conducted using SPSS statistics, v.20. Categorical data are presented as percentages and continuous data as mean $\pm$ 1 standard deviation. Variables were square root- or arcsin – square root-transformed as necessary to meet the assumptions of normality of the parametric tests. All tests are two-tailed, and a value of $P < 0.05$ was considered significant. Differences in count data were tested by means of a χ^2 test, those in mean values were tested using unpaired t-test. Pearson correlation coefficient was used to test correlation among variables. We investigated the relationships of the biotic and abiotic variables of quadrats with nest presence – absence by means of logistic regression. We conducted correlation analyses (Spearman's test) to reduce collinearity and the number of variables used in multivariate analyses; we retained the variable perceived as more biologically important among two or more of strongly inter-correlated variables ($r > 0.60$), since they may be considered as estimates of a single underlying factor (Sokal & Rohlf 1981). The strength of the association between Slender-billed Gulls and other nesting birds was studied using the *phi* association coefficient (Krebs 1978). This coefficient may range between –1 (complete avoidance) and +1 (complete association). The significance for each combination of two species was examined by 2 × 2 Fisher exact probability test.

Results

The first colony of Slender-billed Gulls (54 nests) settling in the northern Po Delta was found in mid-June 2018 on a barrier island, possibly as a replacement attempt by birds from a colony recently destroyed by heavy predation, located a few km further south in the southern Po Delta. Birds settled on the central part of the barrier island (1,150 m long and 70 m wide for overall 10.2 ha), connected with the mainland through a long and narrow embankment and separated from the mainland only by a narrow channel *(Figure 3)*.

They were rapidly joined by 224 pairs of Sandwich Terns possibly from the same above-mentioned site, where a colony of this species has been predated. A colony of Little Terns was found at the northern end of the colony site, but nests of this species were spaced well apart from those of Slender-billed Gulls and Sandwich Terns. Slender-billed Gulls laid 54 clutches (1.8±0.7 eggs per clutch), with a hatching success of 95% (three eggs were crashed in one nest and two more single-egg clutches were deserted) in the first week of July *(Figure 4)*. Nevertheless, none of the chicks fledged, they disappeared, probably due to predation by unknown animals.

No Slender-billed Gulls laid eggs in the study area in the 2019 breeding season, while in May 2020, 276 nests were found in the same barrier island, not far from the site of the

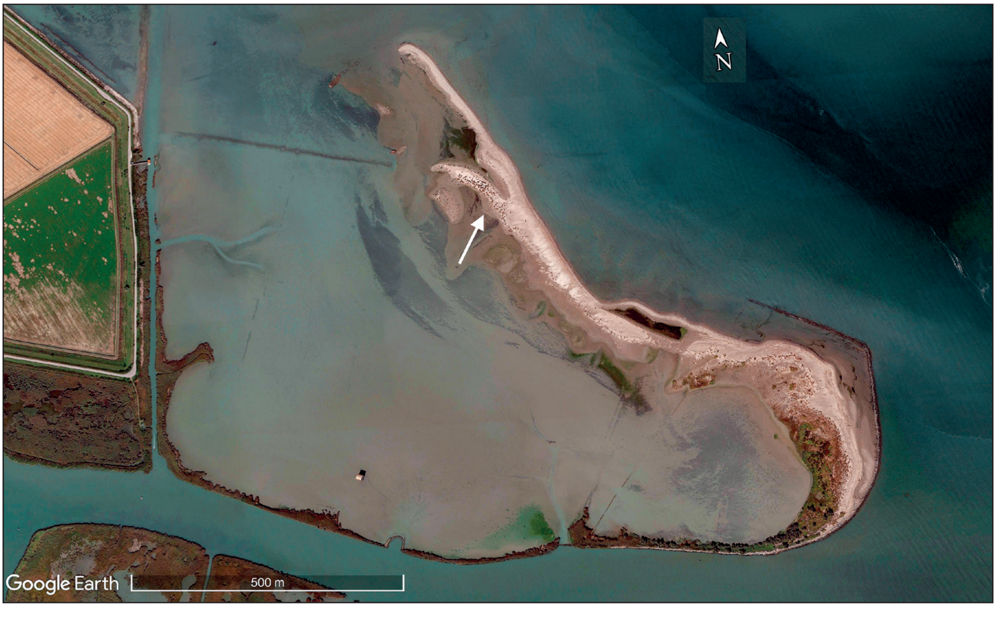

Figure 3. Location (white arrow) of the first colony of Slender-billed Gulls settling on a barrier island in the northern Po Delta (late June 2018). The colony could be reached from the mainland by mammalian predators such as the Red Fox *(Vulpes vulpes)* crossing the narrow channel on the left in the picture and then using the long dike leading to the barrier island.

3. ábra A Pó-delta északi részén található gátszigeten megtelepedő vékonycsőrű sirályok első kolóniájának helye (fehér nyíl) (2018 június vége). A kolóniát a szárazföldről emlős ragadozók, például a vörös róka *(Vulpes vulpes)* a képen bal oldali keskeny csatornán átkelve, majd a gátszigethez vezető hosszú gáttal érhették el

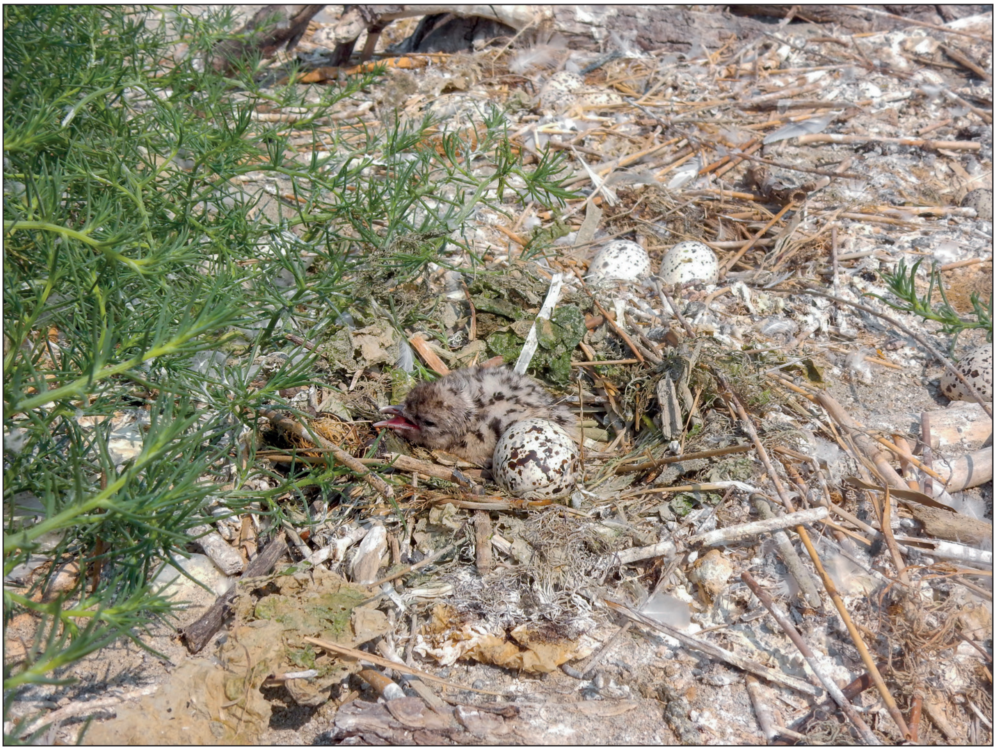

Figure 4. Nests of Slender-billed Gulls on a barrier island of the Po Delta (NE Italy) in early July 2018.
4. ábra Vékonycsőrű sirályok fészkei a Pó-delta egyik gátszigetén (Észak-Olaszország) 2018 július elején

previous year (400 m, though the barrier island had been heavily modified in shape by the winter storms). They were rapidly joined by 891 pairs of Sandwich Terns once more *(Figures 2, 3)*. A large mixed colony of Little Terns (200 pairs), Common Terns (100 pairs) and Avocets (20 pairs), and a few Kentish Plovers was adjacent (but clearly separated from Slender-billed Gulls and Sandwich Terns), whereas a couple of Oystercatcher pairs bred within 100 m. No clutch of Slender-billed Gulls was preyed upon. Eggs started to hatch in the last days of May with a hatching success of 78%, when an extreme high tide of 1.16 m flooded all remaining eggs along with chicks on 4th June.

Only 11 pairs of Slender-billed Gulls laid on the same site in 2021, near a multi-specific colony, but all clutches were quickly preyed upon possibly by Red Foxes.

In 2022, 109 pairs (distributed in two sub-colonies of 83 and 26 nests) settled on two contiguous mounds of bivalve shells, which are relicts of a formerly present dredge island *(Figure 5)*. Breeders were joined by 18 pairs of Sandwich Terns, whereas two pairs of Avocet and one of Oystercatcher laid their eggs before Slender-billed Gull settlement. All clutches were washed away on 25th May *(Figure 6)*.

In the following days, five pairs laid seven eggs (1.4±0.5 eggs per clutch) in a fish farm, settling on remnants of a mound just a few cm above water level. All clutches were washed away due to a rapid increase of water level due to torrential rain.

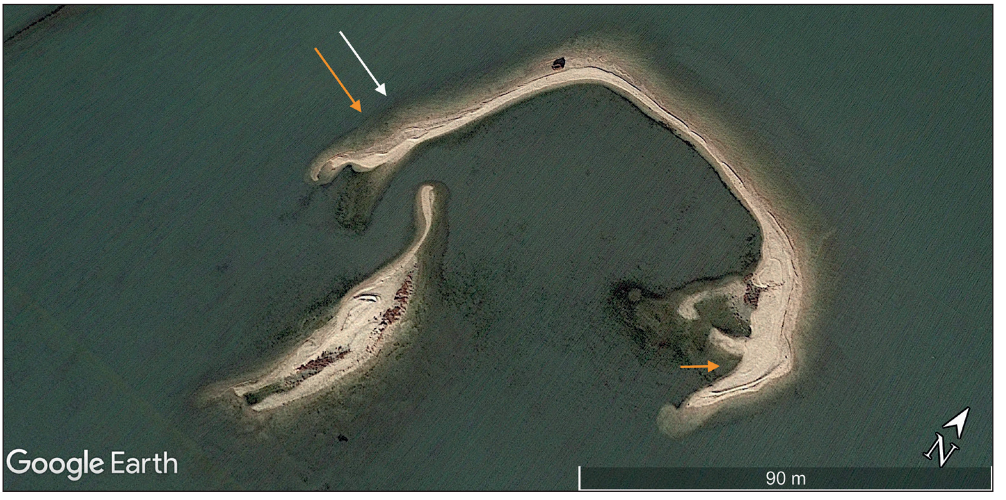

Figure 5. Google Earth imagery (October 2021) of the 2022 mixed colony site of Slender-billed Gulls (orange arrows) and Sandwich Terns (white arrow) on a barrier island in a lagoon of the Po Delta (NE Italy). The short orange arrow indicates the sub-colony showed in Figure 6.

5. ábra A Google Earth képei (2021 október) a vékonycsőrű sirályok (narancssárga nyilak) és a kenti csér (fehér nyíl) 2022-es vegyes kolóniájáról a Pó-delta lagúnájában (Észak-Olaszország) egy gátszigeten. A rövid narancssárga nyíl az 1. ábrán látható altelepet jelzi

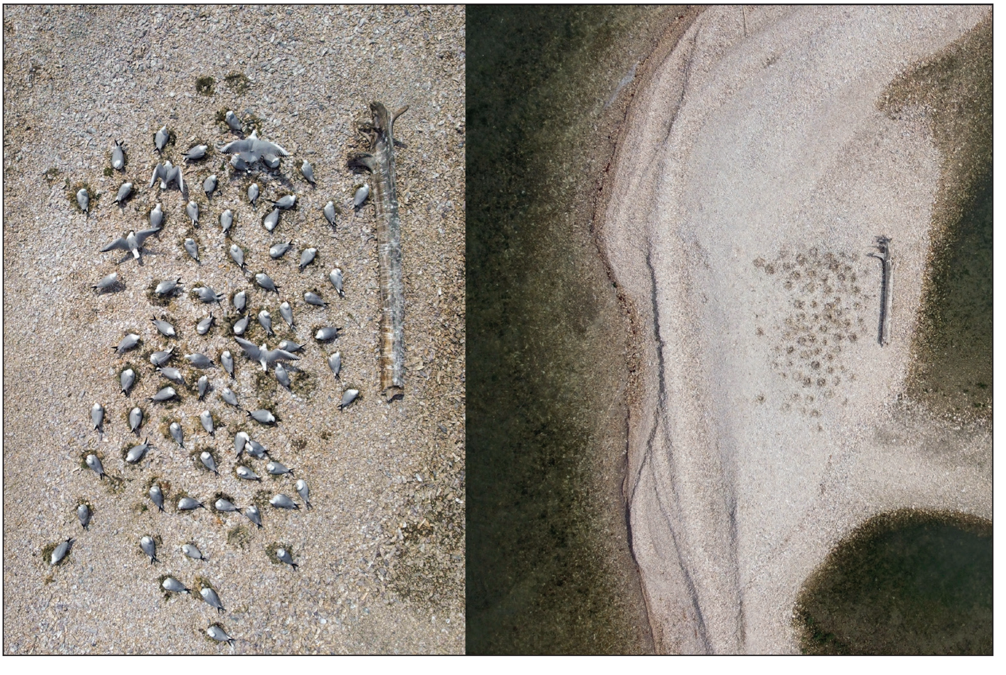

Figure 6. Drone imagery of a sub-colony of Slender-billed Gulls on a dredge island in the Po Delta (NE Italy) in late May 2022, before (left panel) and after (right panel) an extreme high tide.

6. ábra Drónfelvételek a vékonycsőrű sirályok alkolóniájáról a Pó-delta (Észak-Olaszország) kotrási szigetén 2022 májusának végén, szélsőséges dagály előtt (bal oldali panel) és után (jobb panel)

Table 1. Drone-derived imagery-based assessment of nest site selection of Slender-billed Gulls nesting in two colony sites of the northern Po Delta (NE Italy), in 2020 and 2022

1. táblázat A Pó-delta (ÉK-Olaszország) két kolóniájában fészkelő vékonycsőrű sirályok fészkelőhely-választásának drónfelvételekből származó képalapú értékelése 2020-ban és 2022-ben

Parameter / quadrats	Occupied	Non occupied	All	P
Scanno Bottonera 2020	N = 12	N = 118	N = 130	
Elevation above water level (cm) [a]	39±3	35±8	36±7	0.001
Bare sand (%) [b]	97±3	86±24	87±24	<0.001
Vegetation cover (%) [b]	2±3	1±1	1±1	0.024
Bivalve shells (%) [b]	0±0	0±0	0±0	-
Water (%) [b] – internal water = lagoon (%) [b] – external water = sea (%) [b]	1±3 1±3 0±0	14±24 7±19 7±18	13±24 7±19 6±17	<0.001 0.023 <0.001
Distance from the sea (m) [a]	50±6	26±29	28±20	<0.001
Distance from the lagoon (m) [a]	16±7	34±22	32±21	0.001
Distance from tideline (m) [a]	13±7	11±9	11±9	0.295
Wrecked tree trunk/branches (%) [c]	42	39	39	1.000
Peripheral/central location (%) [c]	8/92	32/68	30/70	0.107
Number of other breeding species [a]	0.3±0.6	0.1±0.3	0.2±0.4	<0.001
Association between with other species (%) [d] – Oystercatcher *Haematopus ostralegus* – Pied Avocet *Recurvirostra avosetta* – Kentish Plover *Charadrius alexandrinus* – Sandwich Tern *Thalasseus sandvicensis* – Common Tern *Sterna hirundo* – Little Tern *Sternula albifrons*	 0 0 0 33 0 0	 2 5 3 3 4 6	 1 5 2 5 4 5	 0.649 0.424 0.576 <0.001 0.467 0.424
Dossi Scardovari 2022	N = 3	N = 30	N = 33	*P*
Elevation above water level (cm) [a]	30±0	25±7	26±7	0.002
Bare sand (%) [b]	0±0	0±0	0±0	-
Vegetation cover (%) [b]	0±0	0±0	0±0	-
Bivalve shells (%) [b]	38±24	50±17	39±24	0.345
Water (%) [b] – internal water (%) [b] – external water (%) [b]	50±17 37±35 13±23	62±24 30±35 33±34	61±26 30±34 31±33	0.345 0.808 0.308
Wrecked tree trunk/branches (%) [c]	0.3±0.6	0.1±0.3	0.2±0.4	<0.001
Number of other breeding species [a]	0.3±0.6	0.1±0.3	0.3±0.5	0.508
Wrecked tree trunk/branches (%) [c]	67	10	15	0.053
Number of other breeding species [a]	0.3±0.6	0.1±0.3	0.2±0.4	<0.001
Association between with other species (%) [d] – Oystercatcher – Pied Avocet – Sandwich Tern	 0 0 67	 3 3 33	 3 3 3	 0.748 0.748 0.001

Environmental variables were measured at 100-m^2 quadrats occupied or not by Slender-billed Gulls. N= number of 10 × 10 m quadrats. The mean ± SD is shown. [a] *t* test carried out on the variable square root transformed. [b] *t* test carried out on the variable arc-sin square root transformed. [c] Difference tested by means of a χ^2 test on the count data. [d] Association tested by means of Cramer's Phi.

Habitat use showed only a few differences from a random pattern, as can be deduced from the distribution of nests on the barrier islands *(Figures 1, 2, 3, 6)*. We considered for the present analysis both colony sites. The site on the barrier island *(Figures 1, 2, 3)*, which hosted in different locations also the colonies of 2018 and 2021, was analysed only for the 2020 breeding season to avoid bias. In addition, we analysed separately the 2022 site *(Figures 5, 6; Table 1)*. For both colony sites, we investigated associations between species.

In the outer barrier island, used in 2020, quadrats hosting nesting Slender-billed Gull were located farther from the sea and nearer to the lagoon, contained more external water and less internal water, and had more vegetation *(Table 1)*. In addition, occupied quadrats hosted a larger number of nests of other species *(Table 1)*, since Slender-billed Gulls were associated to Sandwich Terns (Cramer's Phi = 0.559; $P = 0.001$), but not to Little Terns, Common Terns, Avocets, Oystercatchers and Kentish Plovers ($P > 0.05$ for all the comparisons).

Logistic regression analysis identified four variables as significant predictors of nest location: distance both to the sea and the rear lagoon ($B = 0.082 \pm 0.024$, Wald 11.288, $df = 1$, $P = 0.001$ and $B = -0.044 \pm 0.017$, Wald = 6.540, $df = 1$, $P = 0.011$, respectively), vegetation cover ($B = 0.662 \pm 0.166$, Wald = 15.995, $df = 1$, $P < 0.001$), and presence of Sandwich Terns ($B = 2.395 \pm 0.847$, Wald = 12.163, $df = 1$, $P < 0.000$). According to the method of variable reduction, two variables were excluded from further multivariate regression analysis: 1) Sandwich Tern presence, due to their active attraction for other breeding Laridae, which could have altered the outcome of the analysis (see Discussion), and 2) distance to the sea (to reduce collinearity). Only two variables were thus entered in a multivariate logistic model discriminating between quadrats with and without Sandwich Terns to be tested: % vegetation cover and distance to the back lagoon of quadrats. Both parameters ($B = 0.716 \pm 0.187$, Wald = 14.729, $df = 1$, $P < 0.001$ and $B = -0.058 \pm 0.24$, Wald = 5.958, $df = 1$, $P = 0.015$, respectively) were used in the multivariate stepwise binary logistic regression (correctly reclassified cases = 90.8%).

In the bivalve shell islet colony in 2022, Slender-billed Gulls selected quadrats ($N = 3$) higher above the water level in comparison to the remaining ($N = 30$) that hosted a larger number of other nesting species *(Table 1)*. Slender-billed Gulls were associated to Sandwich Terns (Cramer's Phi = 0.559; $P = 0.001$), but not to Avocets, nor to Oystercatchers. No other significant difference was found in relation to Slender-billed Gull presence. According to the method of variable reduction, Sandwich Tern presence was excluded from multivariate regression analysis (as well as number of other species, which is a function of the former) due to their active attraction for Slender-billed Gulls, which could have altered the outcome of the analysis. Thus, only elevation AWL was entered in logistic regression, but it was not significantly associated to Slender-billed Gull presence ($B = 1.825 \pm 968.388$, Wald = 0.000, $df = 1$, $P = 0.998$).

Additionally, disturbance to Slender-Billed Gulls due to drone surveys was negligible, as birds frequently ignored the flying intruder entering the colony. Breeders of other species showed different insensitivity to intruding drones: Sandwich Terns sometimes fled away on drone arrival over the sub-colonies, but they came back to nest in less than one minute. Avocets fled away on drone arrival, whereas Oystercatchers frequently attacked the drone.

Discussion

The main finding of our study is that Slender-billed Gulls are failing in their attempt to colonise the barrier islands of the northern Po Delta. Productivity in the first five years was zero, mostly due to colony sites flooded by high tides and storms. Extreme high tides have become a frequent occurrence in spring during the last decade along the northern Adriatic wetlands (data from Comune di Venezia 2022). This phenomenon, along with human disturbance in particular causing habitat loss due to construction of illegal huts, forced waterbirds which used to nest there (Oystercatchers, Little Terns, Kentish Plovers) to leave barrier islands and move into the nearby fish farms. These are not subjected to tidal excursions since water level is strictly artificially regulated (Scarton *et al*. 2018, Valle & Verza 2022).

Sea level rise dramatically affects coastal sites (Newton *et al.* 2020), thus being the greatest threat to the survival of many seabird species, including gulls and terns (Reynolds *et al*. 2015, Dias *et al*. 2019). Worldwide, it was observed that previously suitable and safe nesting sites have progressively become unstable and unreliable due to frequent flooding by extreme high tides occurring in spring, i.e. during the breeding season (Scarton & Valle 2013, Bonther *et al*. 2014, Koffijberg *et al*. 2016, Tattoni *et al*. 2020, Ritenour *et al*. 2022). Slender-billed Gulls selected open areas of barrier islands in low AWL areas free from dunes and close to the tideline. They are known to locate nests far from the sea and close to the lagoon (possibly to evade high wave during storm with strong winds), actively preferring areas with vegetation (though <5%) rather than bare areas, facing the lagoons staying behind the islands. Slender-billed Gull in the northern Adriatic are expanding in numbers, but their use of apparently suitable nesting sites such as the barrier islands led to a null reproductive output. For this reason, we deem the barrier islands to nowadays act as an ecological trap, i.e. a low-quality (in this case, in terms of reproductive output) habitat that individuals prefer according to once reliable cues, which are inducing instead a maladaptive habitat selection due to environmental changes (Hale & Swearer 2016, Sherley *et al*. 2017, Greggor *et al*. 2019). Barren, low-elevated sites, relatively far from the mainland and close to brackish lagoons are usually the preferred nesting habitats for this species due to the low interspecific competition and absence of mammalian predators (Sanz-Aguilar *et al*. 2014). The observed increase in sea level rise and spring or summer storms are nevertheless leading to more and more frequent loss of clutches, as we observed in our study area. These man-induced phenomena are taking place in a very short period, thus birds have not yet learnt to cope with them. Although our study does not formally respect the three criteria proposed by Robertson and Hutto (2006) to define an “ecological trap”, a mortality rate of 100% in each of four years may qualify as such. An intriguing question is why, after years of complete reproductive unsuccess, the gulls kept on nesting at the same colony sites. The Slender-billed Gull is typical of unstable and ephemeral habitats and shows population dynamics dominated by dispersion, breeding failures, irregular reproduction and weak interannual breeding site fidelity, with colonies that change sites almost each year (Sanz-Aguilar *et al*. 2014, Francesiaz *et al*. 2017). The Po Delta, as the French and Spanish sites, lye at the extreme western edge of the areal distribution of the species; it has been observed that many birds come from the large Black Sea populations, whereas a north African origin has been suggested for the Spanish colonies (Sanz-Aguilar *et al*. 2014, De Faveri 2022). It may thus be possible that different group of birds, in a species where group tenacity is high (Francesiaz *et al*. 2017), try each year to occupy an apparently suitable nesting site, only to move away the following year; nevertheless, we do not have ring readings to corroborate this hypothesis so far.

Another factor playing a key role in failure of colonisation of the Po Delta by Slender-billed Gulls is progressive habitat loss. The unauthorised construction of huts in the barrier islands of the Po Delta by sun-bathers and hunters has been dramatically increasing during the last 30 years: in the late nineties of the past century, only a few huts were found along the entire coastline of the Po Delta (pers. obs.), whereas up to 11 huts in a 0.5 km stretch of barrier island (from 44°52’34.80”N – 12°29’02.90”E to 44°52’20.83”N – 12°28’53.67”E) could be seen on Google Earth in the last years (https://www.google.com – imagery of September 2018). Such a high density of artefacts and related human presence by sun-bathers virtually excludes waterbirds from breeding, forcing them to alternative habitats when available.

This scenario has been made even worse by the increase in number of Red Foxes in the Po Delta over the last decade, in line with a population increase and range expansion observed for the whole of northern Italy (Bon 2017). In recent years, many observations of Red Foxes were reported not only on barrier islands connected with the mainland (where they were infrequently observed also in the past; Verza 2003), but also in outer barrier islands. In these islands, not accessible from the mainland, some reproductive periods of Red Foxes have recently been recorded (Verza & Cattozzo 2015).

Slender-billed Gulls colonising the Po Delta showed some flexibility in nest habitat adoption, settling both on outer barrier islands and on tiny bivalve shell islets in an inner lagoon. Though this flexibility was not enough to avoid breeding failure over a five-year period from colonisation, it gives a glimpse on the possible adoption of further habitat types. Dredge islands, built in the northern Po Delta over the last thirty years and those that will be built in the next years, may probably be suitable colony sites. Dredge islands or similar artificial sites are also commonly accepted and used for nesting by gulls and terns (Van Zomeren *et al*. 2019, Ritenour *et al*. 2022); sometimes, the building of artificial islands has been used as a way to compensate for the loss of previously used natural sites (Stienen *et al*. 2005, Gamblin *et al.* 2022). In southern France, the use of artificial colony sites led to an increase of 14% of Slender-billed Gulls in 2011−2017 (Schwartz *et al*. 2022), while in the lagoon of Venice, several waterbirds regularly use dredge islands to nest (Scarton & Valle 2015, Scarton 2017).

The settlement of an initial breeding colony on an artificial mound in a fish farm in 2022, despite being only a few pairs accompanied by nesting failure, is a good indicator for the species. Other larids, such as Mediterranean Gulls *Ichthyaetus melanocephalus* and Gull-billed Terns *Gelochelidon nilotica,* recently colonised the fish farms of the Po Delta, with increasing populations (Scarton *et al*. 2018, Valle & Verza 2022) and good productivity (Grussu *et al*. 2019 and *pers. obs*.). If Slender-billed Gulls will switch to nest in nearby fish farms, these could provide plenty of suitable breeding sites safe from tidal flooding and with very low predation pressure, allowing sufficient productivity. At the moment, after five years from settlement, Slender-billed Gulls are failing to colonise the barrier islands of the Po Delta.

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