

Drone assessment of habitat selection and breeding success of Gull-billed Tern *Gelochelidon nilotica* nesting on low-accessibility sites: a case study

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Abstract - The use of drones in the study of waterbird breeding biology has received considerable attention in the last years, but very few studies were made along the Mediterranean. We studied habitat selection and breeding success of the Gull-billed Tern *Gelochelidon nilotica* in two colonies inside fish farms along the Italian Adriatic coastline, using a small, commercial drone. Both colonies were located on small islets surrounded by very shallow water and clayey bottoms, thus being difficult to access. Compared with availability, the Gull-billed Terns selected quadrats higher above the water level, with a higher vegetation cover, which lay farther from the water edge, contain less water, and which are more frequently located in the center of the islands. 147 of 178 clutches (mean clutch size \pm SD: 2.61 ± 0.58) hatched 383 chicks (82.5%; 2.15 ± 1.09 chicks per nest), with large differences between the two colonies. Hatching success was 95.0% and 69.1%; the most common cause of egg loss was flooding (97.0%). Nest attendance could easily be ascertained by 30-m above ground level drone-derived imagery. The use of a drone allowed the study of some aspects of the breeding biology of the Gull Billed Tern in two breeding sites where the traditional field approach, i.e. researchers reaching the sites by boat, would have been very difficult, causing unavoidable and prolonged disturbance to the nesting adults.

Key words: disturbance, fish farms, Lagoon of Venice, nesting success, Po Delta, UAV

Riassunto - Utilizzo di un drone per lo studio della selezione dell'habitat di nidificazione e del successo riproduttivo in due colonie di Sterna zampenere *Gelochelidon nilotica* in siti di difficile accesso.

L'uso dei droni nello studio della biologia riproduttiva degli uccelli acquatici ha ricevuto una notevole attenzione negli ultimi anni, ma pochissimi studi sono stati eseguiti nel Mediterraneo. Abbiamo indagato la selezione dell'habitat e il successo riproduttivo della sterna zampenere *Gelochelidon nilotica* in due colonie poste all'interno di valli da pesca nel Nord Adriatico, utilizzando un piccolo drone. Entrambe le colonie erano situate su isolotti circondati da acque molto basse e con fondali limo-argillosi, quindi difficili da raggiungere. Rispetto alla disponibilità, la sterna zampenere ha selezionato aree poste più in alto sopra il livello dell'acqua, con una maggiore copertura vegetale, più

lontano dal bordo dell'acqua e più frequentemente al centro degli isolotti. Da 147 dei 178 nidi (covata media \pm SD: $2,61 + 0,58$ uova) sono sgusciati 383 pulcini (82,5%), con grandi differenze tra le due colonie. Il successo di schiusa nelle due colonie è stato del 95,0% e 69,1%; nel complesso la causa più comune di perdita di uova (97,0%) è stata la sommersione dei nidi. La presenza del nido e del suo contenuto è stata facilmente accertata con le immagini ottenute dal drone da 30 m di altezza. L'uso del drone ha permesso lo studio di alcuni aspetti della biologia riproduttiva della sterna zampenere in due colonie dove il tradizionale approccio sul campo, con ricercatori che raggiungono i siti in barca, sarebbe stato molto difficile, causando inevitabili e prolungati disturbi agli adulti nidificanti.

Parole chiave: Delta del Po, disturbo, Laguna di Venezia, successo riproduttivo, valli da pesca.

INTRODUCTION

The study of several aspects of the breeding ecology of seabirds, such as population size, nesting success, habitat selection may be particularly difficult for several species, given the often rough terrain where birds make their nests. Nesting sites may be virtually inaccessible, as for instance those in marshy areas or rocky islets, and expensive airplane surveys with their inherent limitations, as limited spatial resolutions of the images obtained, are often made (Afán *et al.*, 2018; Rexer-Huber *et al.*, 2020). However, if detailed information are needed, these require higher spatial and temporal resolution, both achievable only with repeated on-ground surveys or, more recently, camera traps (Brandis *et al.*, 2014). An even more important issue concerns the effects, direct and indirect, of the disturbance caused by researchers to the seabirds, both adults and chicks, and inherently associated to the field operations, such as counting nests or marking eggs and young (Götmark, 1992; Nisbet, 2000; Fair & Jones, 2010). The results of many studies on the effects of researcher activity at nesting sites are ambiguous: some authors found measurable negative effects, such as reduced fledging rates, chick growth or return rates to the nesting sites the following year (Rodway, 1996; Blackmer *et al.*, 2004; Carey, 2009; Uher-Koch *et al.*, 2015), while other did not find any significant effects between frequently visited nests and control nests, neither on short- nor on medium-term period (Fiske *et al.*, 2013; Kelly *et al.*, 2015). Quite recently, a meta-analysis study showed an unexpected, positive relationship between disturbance

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and reproductive success, particularly in coastal birds nesting on the ground; this was interpreted as due to limited predator activity around nests, probably in response to fieldworker presence and activity (Ibáñez-Álamo *et al.*, 2012).

Over the last decade, a new methodology has been proposed to count seabirds, i.e. using unmanned aerial vehicles (UAVs, or drones: Sardà-Palomera *et al.*, 2012; Marinov *et al.*, 2016; Rush *et al.*, 2018; Hodgson *et al.*, 2018; Valle & Scarton, 2019a, 2019b; Choi *et al.*, 2020; Mapes *et al.*, 2020). There is a growing body of evidence suggesting that drones cause less disturbance than traditional monitoring methods (Hodgson & Koh, 2016; Mulero-Pázmány *et al.*, 2016; Reintsma *et al.*, 2018, but see Valle & Scarton, 2019a). Moreover, they are increasingly used to study the reproductive biology of waterbirds at dangerous or almost inaccessible sites, such as the enormous wetlands of the Okavango Delta (Francis *et al.*, 2020), or some rocky islets amidst the middle of the Pacific Ocean (Inaccessible Island: McClelland *et al.*, 2016). On a European perspective, drones have proven to be fundamental in censusing Great White Heron *Ardea alba* nests scattered through large Polish reedbeds (Zbyryt, 2019) or in evaluating colony settlement and nesting success of Black-headed Gull *Chroicocephalus ridibundus* at Spanish saltmarshes (Sardà-Palomera *et al.*, 2017).

Quite surprisingly, the use of this boosting technology seems to be still little adopted in Italy, at least judging from the scientific literature: we were able to find just one paper (Sartori & D'Alterio, 2016) dealing with drone counts made at a large heronry in NE Italy. After that, several works have been recently published, dealing with the use of drone for studying some aspects of the breeding ecology of the European Oystercatcher *Haematopus ostralegus* (Valle & Scarton, 2019a), the Common Redshank *Tringa totanus* (Valle & Scarton, 2019b), the Pied Avocet *Recurvirostra avosetta* (Scarton & Valle, 2020), or the disturbance caused to several waterbirds (Valle & Scarton, 2018). Drones were also used to count heron colonies in Tuscany, Central Italy (P. Giovacchini, pers. com.); it is very likely other experiences have been made elsewhere in Italy, with results confined so far to the so-called grey literature.

The present study aims to assess the feasibility of drone assessment of habitat selection and breeding success of Gull-billed Tern *Gelochelidon nilotica*, hereafter GBT, nesting on sites of very low accessibility; we report also possible limitations and recommendations about the use of drones for the study of this species.

STUDY AREA AND METHODS

The fieldwork was performed throughout the breeding season 2018 in two fish farms, which are called “valli da pesca” in Italian, respectively located in the Lagoon of Venice and in the Po Delta, along the Adriatic coastline in north-eastern Italy, which spans from 45°28' N, 12°35' E in the North until 44°47' N, 12°23' E to the South.

This 100 km long coastline is characterized by several shallow lagoons, from a few hundred hectares to several

hundreds of square kilometers; these lagoons are scattered with hundreds of marsh islands and are bordered, along the inner side, by about thirty fish farms, each one ranging in size from 100 ha to 1,400 ha (Scarton *et al.*, 2018; Day *et al.*, 2019). Despite their name, most of the fish farms are currently managed almost exclusively for hunting gamebirds, ducks in particular; for this purpose, water level inside the fish farms are tightly regulated, small islands are made with sediments dredged from the adjacent channels and food is extensively provided to ducks throughout the winter. The seabird community breeding in the whole study area is one of the largest around the Mediterranean, with ~20,000 pairs. Eight species of breeding gulls and terns have been recorded over the last years, including Slender-billed Gull *Larus genei*, Black-headed Gull *Chroicocephalus ridibundus*, Mediterranean Gull *Larus melanocephalus*, Yellow-legged Gull *Larus michahellis*, GBT, Sandwich Tern *Thalasseus sandvicensis*, Common Tern *Sterna hirundo*, and Little Tern *Sternula albifrons*; most of these species nest inside the fish farms too, often in the islets mentioned above, with populations ranging in size from a few hundred to several thousands of pairs (Scarton *et al.*, 2018). In this large wetland complex, the GBT is a regular breeder since 2001; over the 2001-2018 years, the population ranged between 34 and 921 pairs and the trend was of strong increase, with an annual rate of 10.5% (Grussu *et al.*, 2019).

We studied two distinct monospecific colonies, both inside fish farms:

1) the “Venice colony”, in the Lagoon of Venice, consisted of 90 pairs, located on a hearth artificial islet of 0.006 ha, about 0.1 m above the water level and with a vegetation cover of 100% (Fig. 1);

2) the “Po colony”, settled in the Po Delta, consisted of 88 pairs and was located on a hearth artificial island of 0.32 ha, 0.10-0.20 m above the water level, without vegetation cover (Fig. 2). Both islets were built to be used as a roosting site by ducks during the hunting season (September-January), but were severely eroded after being unmanaged for many years. Both colony sites were surrounded by large and shallow waterbodies, which had a very soft, clayey bottom, that made them virtually inaccessible by terrestrial predators or a walking man. On the other side, a boat approach would be extremely slow and difficult, causing severe disturbance to the breeding birds.

In order to study the habitat selection and breeding success of GBT, we performed six weekly drone surveys at 0, 1, 2, 3, 4 and 7 weeks from laying; we used an off-the-shelf, small drone (DJI Mavic pro), with a weight of 734 g and a noise level of 70.0 dB(A). The six surveys, which were carried out up to three weeks of chick 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.

According to the current recommendations (Hodgson & Koh, 2016; Valle & Scarton, 2018), the drone was launched at approximately 150 m from each colony; in order to minimize disturbance to birds, the drone reached the vertical point of the colony through a lawn-mower

flight pattern, flying 70 m above ground level (AGL) and was slowly lowered (1.5 m/sec) to an altitude of 30 m, where nest attendance was assessed, checking whether incubating birds were present.

Then, the drone was slowly driven to an altitude of 3 m AGL, which allows clutches, eggs and chicks to be clearly detected upon post-processing (Fig. 1 and Fig. 2) and it slowly flew over the colony at a speed of 1.5 km/h. During each drone flight, a researcher observed the colony from afar to exclude possible predation of unattended clutches and/or chicks.

In the post-processing phase, individual nests were assigned a number and counts of clutches, eggs per clutch, hatchlings and older chicks were performed by two observers using the recorded videos on a personal computer using the free software GIMP for image processing (release 2.10; <https://www.gimp.org>). Nests were ascribed to one of the following categories: 1) successful, if a) a recently hatched chick was found in the nest or nearby, b) date of egg disappearance matched expected hatching date and no sign of predation was found, or 2) unsuccessful, when a) unattended, b) flooded, c)



Fig. 1 - Nest distribution in a colony of Gull-billed Terns in the Lagoon of Venice in 2018. / Distribuzione dei nidi in una colonia di sterne zampanere nella Laguna di Venezia nel 2018.

predated, or d) disappeared, when egg disappearance was prior to expected hatching date according to Grussu *et al.* (2019).

Habitat choice was investigated superimposing a grid of 1 x 1-m quadrates on the drone imagery of the colony sites using the free software QGIS (release 3.12.1; www.qgis.org), stitching images together with ICE (Microsoft's Image Composite Editor, release 2.0; <https://www.microsoft.com>). We characterized each quadrate for the presence-absence and number of nests and for the following biotic and abiotic parameters: 1) % of the quadrate covered by vegetation, bare mud, water surface both inside the islets and surrounding the islets; 2) % cover by the dominant plant species; 3) height of ground above the water level, visually estimated in two categories (<30 cm and >30 cm) according to field observations made in the days before egg laying, since water level inside the fish farms may change abruptly during a breeding season; 4) location, classified as "central" (the quadrate was separated from the water edge by at least another quadrate) or "peripheral" (the quadrate was at the water edge).

Nest site selection was characterized using QGIS and images, recording: 1) substrate type (mud, vegetation, bivalve shells, etc.); 2) elevation above water level (AWL), visually dichotomized in low (<30 cm) and high (>30 cm). The high location could result either from placing nest on bare ground in areas with elevation >30 cm or by building nest on vegetation taller than 30 cm; 3) presence of vegetation circling the nest for the whole perimeter; 4) distance from the closest body of water, either inside or outside the colony site; 5) distance from the nearest neighbor nest.

The amount of disturbance during each flight was estimated from: 1) the mean duration of permanence of the drone over the colony; 2) the time spent away from nests by incubating birds, until the last breeding bird went back to the nest; 3) the distance walked/swum by chicks.

Categorical data are presented as numbers (percent) and continuous data as means + 1 SD. Variables not normally distributed (Kolmogorov-Smirnov test; $P < 0.001$) were square-root or arc-sin-square-root transformed as necessary to meet assumptions of normality for parametric tests. All tests were two-tailed, and $P < 0.05$ was considered significant. Difference in count data (elevation above water level and location of nests) were tested by means of a χ^2 test. Differences in mean number of fledged young per nest between sites were analysed by means of paired *t*-tests (Sokal & Rohlf, 1981).

We investigated the relationships of the biotic and abiotic variables of marsh islands with GBT presence-absence by means of logistic regression (Sokal & Rohlf, 1981). We conducted correlation analyses (Spearman's test) to reduce collinearity and the number of variables used in multivariate analyses (Green, 1993); 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. We compared survival functions using Cox proportional hazards model, a semiparametric method (Cox, 1972); analyses were performed using SPSS software for Mac, release 20.0 (SPSS, Inc., Chicago, IL).

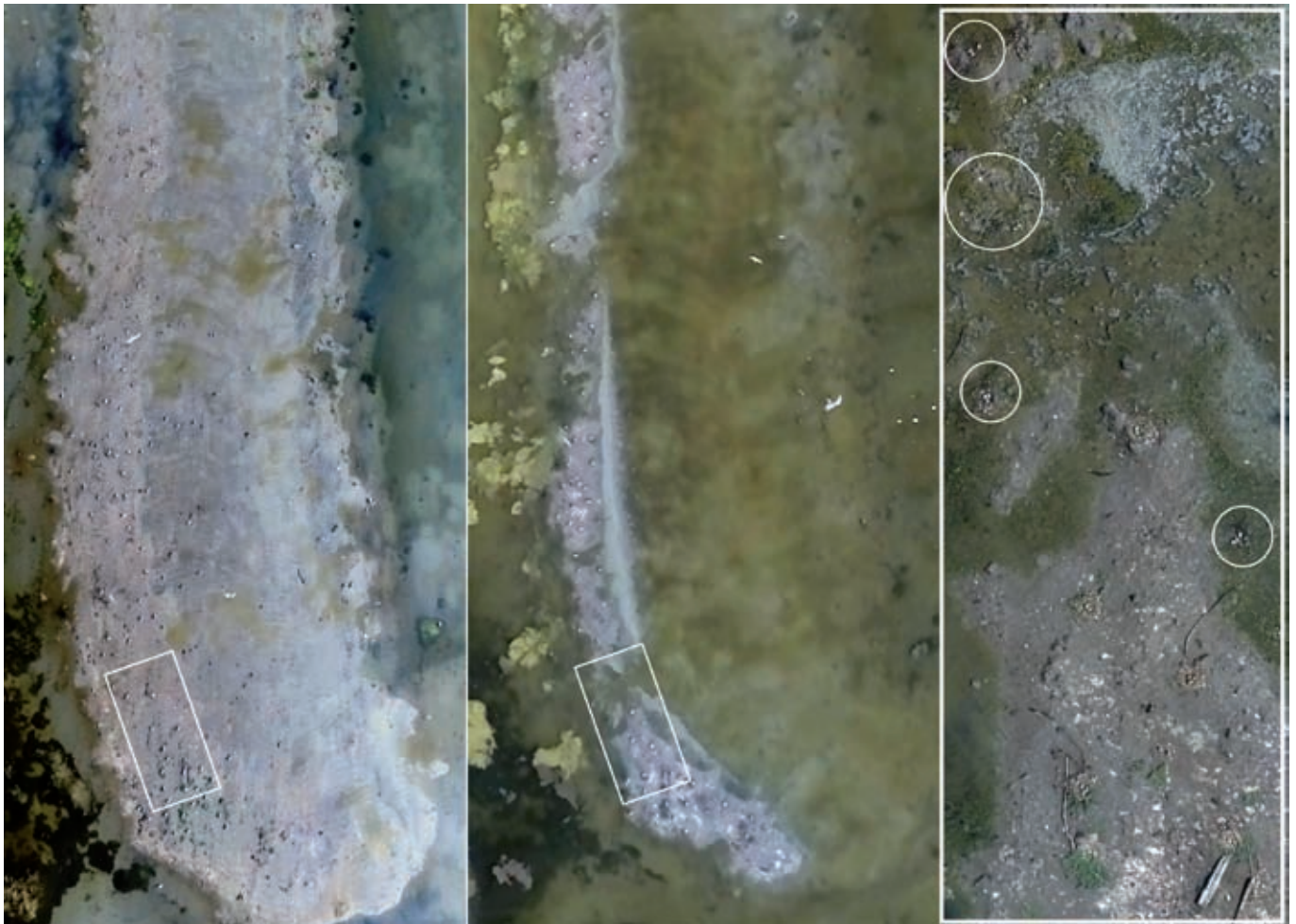


Fig. 2 - Left panel: baseline nest distribution in a colony of Gull-billed Terns in the Po Delta in 2018. Central panel: nest distribution after flooding. Right panel: magnification of a plot with nests (white box) after flooding. White circles: flooded nests. / Pannello di sinistra: distribuzione dei nidi in una colonia di sterne zampenere nel Delta del Po nel 2018. Pannello centrale: distribuzione dei nidi dopo l'allagamento. Riquadro destro: ingrandimento della precedente (riquadro bianco). Cerchi bianchi: nidi allagati.

RESULTS

Habitat selection

Habitat use differed from a random pattern, as apparent by the distribution of nests on drone imagery (Fig. 1 and Fig. 2). Compared with availability, GBT positively selected quadrates higher above the water level, with a higher vegetation cover, which lay farther from the water edge, contain less water, and more frequently located in the center of the island (Tab. 1). Both elevation above the water level and vegetation cover entered the stepwise binary logistic regression for GBT presence prediction (Tab. 2). A ROC curve (not illustrated) was traced to estimate the predictive power of the model ($AUC \pm SE = 0.826 \pm 0.024$; $CI = 0.779-0.873$).

Breeding success

One hundred and forty-seven out of 178 clutches (for overall 464 eggs; 2.61 ± 0.58 ; range 1-4) hatched 383 chicks (82.5%; 2.15 ± 1.09 chicks per nest), with large differences between the two colonies. Hatching success ranged from 95.0% in the Venice colony (2.54 ± 0.66

hatched chicks per nest) to 69.1% in the Po colony (1.80 ± 1.28 hatched chicks per nest: t -test = -5.2; $P < 0.001$). Overall, from 28 nests (15.7%) did not hatch any chick and 17 more nests had a partial loss of one or two eggs, thus overall 80 eggs (17.5%) were lost (Tab. 3).

The most common cause of egg loss was flooding (97%). Flooded nests were easily classified by drone surveys, since they appeared heavily damaged and eggs were very frequently washed away from the cups (Fig. 2). As an aside, we mention that among 52 flooded nests, in the 19 which were circled for at least 270° by vegetation higher than the cup, only 13 (22%) had eggs washed away in comparison with 24% of the remainder ($\chi^2 = 22.0$; $P < 0.001$). Eggs retained in flooded nests were then successfully brooded to hatching. No eggs were predated, but three eggs disappeared from a “high” nest safe from flooding. Cox multivariate regression confirmed the superiority of both the elevation above the water level ($HR = 7.869$, $P = 0.005$) and to a lesser extent the distance from the water edge ($HR = 1.014$, $P = 0.001$) as prognostic indexes of egg survival. Fledging success ranged from 0.56 young fledged per pair for clutches in the Po colony to 1.40 in the Venice colony.

Tab. 1 - Drone-derived, imagery-based assessment of nest site selection of Gull-billed Terns nesting in two colonies. Environmental variables were measured at 1-m² quadrats occupied or not by the species. / Valutazione (derivata da droni e basata su immagini) della selezione del sito di nidificazione di sterne zampenere nidificanti in due colonie. Le variabili ambientali sono state misurate su quadrati di 1 m² occupati o meno dalla specie.

^a *t* test carried out on the variable square root or arc-sin square root transformed. / ^a *t* test effettuato su dati normalizzati mediante radice quadrata variabile o radice quadrata arco-sin trasformata.

^b Difference tested by means of a χ^2 test on the count data. / ^b Differenza verificata mediante test χ^2 .

Parameter	All	Occupied	Non occupied	P
Venice colony (N = 76)	N = 76	N = 45	N = 21	
Vegetation cover (%)	58±30	71±25	30±20	<0.001
Mud (%) ^a	11±13	11±14	13±11	0.368
External water (%) ^a	30±27	18±20	57±21	<0.001
Internal water (%) ^a	2±11	3±13	0±0	0.272
Ground elevation above water level (n/%)				0.011
- <30 cm	6	1/17	5/83	
- >30 cm	60	44/73	16/27	
Location (n/%)				0.041
- peripheral	8	8/100	0/0	
- central	58	37/64	21/36	
Po colony (N = 816)	N = 816	N = 83	N = 733	
Vegetation cover (%) ^a	0.3±2.5	1.7±6.0	0.1±1.6	<0.001
Mud (%) ^a	89±27	99±3	88±28	<0.001
External water (%) ^a	3.6±14.4	0.4±3.3	4.0±15.1	0.020
Internal water (%)	7±23	0±0	8±25	0.002
Elevation above water level (n/%)				<0.001
- < 30 cm	690	33/5	657/95	
- >30 cm	126	50/40	76/60	
Location (n/%)				0.025
- peripheral	741	81/11	660/89	
- central	75	2/3	73/97	

Tab. 2 - Nest site selection of Gull-billed Terns nesting in two colonies (pooled data) according to binary logistic regression (89% of correctly reclassified cases). / Selezione del sito di nidificazione di Sterne zampenere nidificanti in due colonie (dati aggregati) in base alla regressione logistica binaria (89% dei casi correttamente riclassificati).

^a Environmental variables were measured at 1-m² quadrats occupied or not by the species. / Le variabili ambientali sono state misurate su quadrati di 1 m² occupati o meno dalla specie.

Variable	Parameter estimate ± SE	df	P
Ground elevation above water level >30cm (yes vs. no)	2.331±0.260	1	<0.001
Vegetation cover (%)	0.050±0.025	1	0.045
Internal water (%) ^a	-0.039±0.028	1	0.169
External water (%) ^a	-0.036±0.032	1	0.267
Mud (%) ^a	-0.002±0.027	1	0.947

Tab. 3 - Breeding success of Gull-billed Terns nesting in two colonies, data pooled together, in relation to habitat selection. Environmental variables were measured on drone-derived imagery at 0.5-m circles around nests. / Successo riproduttivo di sterne zampenere nidificanti in due colonie, dati aggregati, in relazione alla selezione dell'habitat. Le variabili ambientali sono state misurate su immagini derivate da droni su cerchi di 0,5 m attorno ai nidi.

^a *t* test carried out on the variable square root or arc-sin square root transformed. / ^a *t* test effettuato su dati normalizzati mediante radice quadrata o radice quadrata arcoseno trasformata..

^b Difference tested by means of a χ^2 test on the count data. / Differenza verificata mediante test χ^2 .

Parameter	All	Successful nests (N = 148)	Failed nests (N = 30)	<i>P</i>
Distance from the water edge (m) ^a	0.81±0.63	0.75±0.68	1.07±0.35	<0.002
Nearest neighbour distance (m) ^a	1.04±0.50	1.26±0.40	0.58±0.33	0.621
Vegetation cover (%) ^a	52.0±49.2	63±48	6±25	<0.001
Elevation above water level (n/%) ^b				<0.001
<30 cm	113	85/75	28/25	
>30 cm	65	63/97	2/3	

Drone effectiveness and disturbance

In the Po colony, where nests were in a bare area, drone imagery clearly visualized all present clutches, eggs and chicks (Fig. 1 and Fig. 2). In the Venice colony, in vegetated areas early in the season nests were clearly visible, due to low vegetation height and cover; then, the latter rapidly grew, partially hiding some nests (Fig. 1). Anyway, nest attendance could always be ascertained by 30-m AGL drone-derived imagery, which could easily record incubating birds sitting on nests (Fig. 1; Fig. 2). Likewise, while chicks were clearly visible in bare areas, they might easily hide within vegetation in response to low elevation AGL drone intrusions in the colony with high vegetation cover (Fig. 1).

Neither nest desertions, nor clutch/chick predations were observed during drone surveys. Time spent far from nests by alarming birds for 12 surveys was very short (105 ± 67 sec) and roughly coincided with the mean duration of permanence of the drone over the colony, in view of the short flight initiation distances of the species for the drone (12 ± 9 m, N = 12). The distance walked/swum from the colony site by chicks in response to drone intrusion was very short: 0.6 ± 0.8 m, N = 175. The time taken to complete the whole surveys (12 visits) was 23 min for drone inspections of the colonies and 27 min of additional drone flight time, but 126 more min were needed for post-processing work for overall 176 min.

DISCUSSION AND CONCLUSIONS

The use of a drone allowed the study of habitat selection, nest site selection and reproductive success of GBT in two breeding sites where the traditional approach, i.e. researchers reaching the islets by boat and then collecting data in the field, would have been very difficult, causing unavoidable disturbance to the nesting adults. As known from other studies (Fasola & Canova, 1991 and 1992; Barati *et al.*, 2012; Wu *et al.*, 2020) the GBT did select some specific environmental features, preferring habitat

patches which could reduce (due to their position and elevation) the possibility of nests being washed away. Among the possible causes of nests failures, previous studies found predation, flooding and human disturbance (see review in Gochfeld *et al.*, 2017); nevertheless, recent studies made by Windhoffer *et al.* (2017) at barrier islands and Grussu *et al.* (2019) in man-regulated habitats found flooding was the main cause of breeding failure. In the fish farms, rapid increase in the water levels sufficient to flood the islets are generally due to strong rainfalls, as we observed several times during concomitant studies. GBT eggs and/or chicks may be predated by both mammalian and aerial predators (Eyler *et al.*, 1999; Molina & Erwin, 2006; Gochfeld *et al.*, 2017); at our study sites, the possible terrestrial predators, such as the Red Fox *Vulpes vulpes*, were most likely deterred by the very shallow water and soft bottoms surrounding the islets. It has been documented several times that the occurrence of this predator may significantly impact the nesting success of waterbirds (see for a recent review Alessandria & Carpegna, 2019); thus the selection of small islets, quite far from banks and levees and completely surrounded by water, seems to be of primary importance for the settlements of GBT colonies. This evidence should be well acknowledged when planning management actions for the conservation of this species.

On the other hand, possible aerial predators in our area included Yellow-legged Gull, Marsh Harrier *Circus aeruginosus* and Carrion Crow *Corvus corone*, but again we did not observe any event of predation. Elsewhere, aerial predation of GBT clutches due to both diurnal and nocturnal raptors has been documented (Eyler *et al.*, 1999; Windhoffer *et al.*, 2017).

Overall, the hatching success at our two study sites, due to both the absence of predation and the limited impact of flooding events, was high (82.5%), similar or higher than values reported by other authors (Eyler *et al.*, 1999; Barati *et al.*, 2012). Fledging success was different between our two study sites (0.56 vs. 1.40 young/pair); and in addition considering the different hatching success

(69.1% vs. 95%), it is clear the Venice lagoon colony was superior to the Po Delta colony, in terms of productivity. We can only speculate about the possible causes, such as a better food availability in the surrounding of the colony sites and the different age of the breeding adults. On the other hand, an underestimation could not be ruled out due to a possible displacement of chicks towards dikes and islets, which were abundant in the surroundings of the Po colony.

Despite the above-mentioned strengths of our study, we declare some limitations, which are inherent to studies investigating waterbirds by drone imagery. First, we lack a comparison to ground data as a control of our results (Chabot *et al.*, 2014), so that further comparative studies are needed to assess the accuracy and precision of the drone approach. A second limitation resides in a possible underestimation of fledging success, since fledglings could have hidden within the surrounding vegetation before they were detected by drone in the Venice colony (Grussu *et al.*, 2019). Though this is improbable, due to the high figure of fledging success found in this colony and the limited available space, underestimation could be a matter of concern in large, highly vegetated sites. Anyway, higher altitude flights (>5 m AGL) could solve the problem avoiding chick hiding in response to the approaching drone (Brisson-Curadeau *et al.*, 2017). A final limitation concerns the inclusion of small, single-species colonies in our study. The possibility to broaden drone use for habitat selection and breeding success assessment in large, multi-specific seabird colonies, where expertise is strongly required for the differential diagnosis of clutches of different species, needs further confirmation studies.

Our results indicate that drone flights may be successfully used to count nests of GBT and to estimate the bird's reproductive success. If the use of drones to census nesting seabirds is already well established (Hodgson & Koh, 2016; Hodgson *et al.*, 2016; Brisson-Curadeau *et al.*, 2017; Barr *et al.*, 2018; Rush *et al.*, 2018; Valle & Scarton, 2019a and 2019b), far less is known about the possibility of using them for estimation of reproductive success. As far as we know, only four studies have used drones to collect data on reproductive success in waterbirds: Brisson-Curadeau *et al.* (2017) for two gull species, Sardà-Palomera *et al.* (2017) for the Black-headed Gull, Pöysä *et al.* (2018) for three duck species and Scarton & Valle (2020) for Pied Avocet.

The findings of our study indicate that drone flights caused very little disturbance to breeding adults and chicks, as it appears from the short times in which adults abandoned their clutches, the absence of predations in the same occasions and the short distances made by chicks walking or swimming away. We would like to underline that we are not claiming drone-derived imagery can replace the traditional ground counts to assess habitat selection and productivity of seabirds. Drone surveys requires an integrated approach, including on-ground supportive data to be interpreted in an unbiased manner (Callaghan *et al.*, 2018). Nevertheless, a drone-based approach is a useful tool for the assessment of habitat selection

and breeding success of Gull-billed Terns, nesting in small, single-species colonies and may represent an optimal alternative method for field researchers at low-accessibility sites.

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