Moving to Venice and settling there: a synthesis on the biology of Sandwich Tern (*Thalasseus sandvicensis*) in the largest Mediterranean wetland during the 1995-2023 years

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Abstract - In 1995, the first colony of *Thalasseus sandvicensis* settled in a saltmarsh islet in the Lagoon of Venice, NE Italy. The number of nesting pairs rose from 202 (1995) pairs to 3503 (2023), with the arrival of immigrants peaking in 2014 (+887 pairs) and 2023 (+1884). From 1995 to 2023, the number of breeding pairs showed a moderate increase ($p<0.01$), with a yearly rate of +5.7%. Two kinds of colony sites were used: i) salt marsh islets, where birds nested mostly on windrows. These sites were usually in well-secluded area, with low levels of human disturbance; ii) man-made sites such as dredge islands, with nests placed on the bare ground. These man-made sites, in one case located at about 200 m from the town of Venice, were used only since 2014 and now support a large fraction of the breeding population. Overall, 73 colonies were found (361±423 pairs, range: 5-2762; median: 203). Each year there were one to six colonies; 21 colony sites were used at least once. On average, a site was used for 3.5±5.4 years (range 1-25), but the first site was used 25 years out of 29. The turnover rate was overall 41.4%. Over the study period, the biggest cause of clutch loss was flooding during extreme high tides, which are becoming more and more frequent and responsible for more than 90% of losses until 2022. In 2023, an H5N1 avian influenza outbreak annihilated the productivity of the whole nesting season. Clutch size was 1.7±0.5 (n=1338) without differences between saltmarsh and dredge islands: 1.64±0.5 vs 1.81±0.45 eggs per clutch. At the colonies, the association between *T. sandvicensis* and *Larus ridibundus* was strong and moderate with *Sterna hirundo*; instead, a negative and moderate correlation was found between *T. sandvicensis* and *Sternula albifrons*. The persistence of the largest Italian population appears threatened by several factors, among which the multiple effects of climate change are the most dangerous.

Keyword: climate change, coloniality, dredge islands, Laridae, population trend, saltmarshes, Sterninae.

Riassunto - Trasferirsi e stabilirsi a Venezia: una sintesi della biologia del beccapesci (*Thalasseus sandvicensis*) nella più vasta laguna del Mediterraneo durante gli anni 1995-2023.

In laguna di Venezia (NE Italia) la prima colonia di beccapesci si è insediata nel 1995. Negli anni successivi la popolazione è diventata la più numerosa d'Italia e ha mostrato due arrivi massicci di immigrati nel 2014 e nel 2023: nel periodo 1995-2023 ha mostrato un trend di moderato aumento ($p<0,01$), con un tasso annuo del +5,7%. Per nidificare sono stati utilizzati due tipi di siti: i) barene naturali, dove gli uccelli nidificavano principalmente su cumuli di materiale spiaggiato. Questi siti erano di solito in aree lagunari poco frequentate dall'uomo; ii) barene artificiali (isolotti artificiali intertidali), con nidi posti sul terreno nudo. Questi siti, in un caso a circa 200 m dalla città di Venezia, sono stati utilizzati solo dal 2014 e ora ospitano una rilevante frazione della popolazione nidificante. Complessivamente sono state censite 73 colonie (361±423 coppie, range: 5-2762; mediana: 203). Ogni anno c'erano da una a sei colonie; nel complesso sono stati utilizzati almeno una vota 21 siti. In media un sito è stato utilizzato per 3,5 ± 5,4 anni (media±1 d.s: range 1-25), ma il primo sito ad essere occupato è stato utilizzato 25 anni su 29. Il tasso di turnover è stato complessivamente del 41,4%. La principale causa di insuccesso riproduttivo è stata la sommersione durante le alte maree estreme, che stanno diventando sempre più frequenti anche in primavera-estate e che sono responsabili di oltre il 90% delle perdite fino al 2022. Nel 2023, un'epidemia di influenza aviaria H5N1 ha azzerato la produttività dell'intera stagione. La dimensione della covata è stata di 1,7±0,5 (n=1338) senza differenze tra barene e isole artificiali: 1,64±0,5 contro 1,81±0,45. Nelle colonie, l'associazione tra il beccapesci e il Gabbiano comune *Larus ridibundus* è stata forte mentre moderata quella con la Sterna comune *Sterna hirundo*; invece, è stata osservata una correlazione negativa moderata tra il beccapesci e il fraticello *Sternula albifrons.* La persistenza nella laguna aperta di Venezia della popolazione di beccapesci appare minacciata da diversi fattori, tra i quali i molteplici effetti del cambiamento climatico sono i più pericolosi.

Parole chiave: andamento di popolazione**,** barene artificiali, cambiamento climatico, Laridae, nidificazione coloniale, Sterninae, trend di popolazione.

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INTRODUCTION

Colonisation of new breeding sites by seabirds is a common feature of their behaviour, allowing them to respond to environmental changes such as shortage of prey, unfavourable weather conditions, habitat degradation, predation by terrestrial mammals, or the effects of humane disturbance, both direct and indirect (Doxa *et al*., 2013; Francesiaz *et al*., 2017; Payo-Payo *et al*., 2017; Mitchell *et al*., 2020). This is particularly true for several species of Larids, in particular those that often use ephemeral sites, such as barrier islands, saltmarshes or gravel islets in riverbeds (Emslie *et al*., 2009; Sanz-Aguilar *et al*., 2014; Martinović *et al*., 2019). Although most colonial seabirds exhibit high levels of site fidelity (Bried

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& Jouventin, 2002), in some species, such as the Little Tern *Sternula albifrons* or the Slender-billed Gull *Larus genei*, it may be close to zero from one year to the next one, meaning that no colonies used in the previous are occupied the following one (Renken & Smith, 1995; Doxa *et al*., 2013).

Nevertheless, according to some authors (Kildaw *et al*., 2005; Pyk *et al*., 2013; Munilla *et al*., 2016; Payo-Payo *et al*., 2017) the colonisation of new breeding sites has been rarely described in detail, even if several examples in the recent literature do exist (Oro & Ruxton, 2001; Garthe & Flore, 2007; Herrmann *et al*., 2008; van Bemmelen *et al*., 2022). Describing the settlement of a new population of top predators such as Larids and following its trend for long periods, in the order of several tens of years, may give useful insights into particular ecological aspects, such as the population growth rate, the reproductive output, the association with other species nesting in the same site, the colony- and nesting site selection, which are all of particular interest for specialists and wetland managers as well. More importantly, these long-standing monitoring are not affected by the short-time fluctuations which are well known for several Larids, and that can cause misinterpretation of the life history of the species in a particular site.

The Sandwich Tern *Thalasseus sandvicensis* has a worldwide distribution of 325,000-430,000 individuals, with population trend considered as "fluctuating", over a large nesting area that spans from the Americas to Eurasia (BirdLife International, 2019). In the latter, the species is found from Turkmenistan in the East to the Iberian Peninsula in the West, including the Mediterranean and the Black Sea. In Europe, west of the Urals, its population size has been recently estimated to be 80,200-160,000 breeding pairs with a fluctuating trend; the wintering population size is 3200-10,000 individuals, showing an increasing trend (Burfield *et al*., 2023).

Ten to fifteen thousand pairs were estimated for the Mediterranean Region in 2013-2018, scattered in the coastal wetlands of southern France (9347-9657 pairs), Spain (3731), and Greece (400-800 pairs: EIONET, 2023). Nevertheless, as pointed out by Stienen (2020), this species shows a highly dynamic distribution, with gains and losses throughout its European breeding range. In Italy, the most recent estimates indicate over 1500 pairs in 2014-2015 (Brichetti & Fracasso, 2018) and 2000-2500 pairs for recent years, mostly breeding in the Lagoon of Venice (Stival, 2022). This large wetland complex was colonized by nesting Sandwich Terns in 1995; before that year, only wandering birds were observed (Scarton & Valle, 2015).

The aim of this paper is to review, using our unpublished data collected over the last thirty years and additional published information, what is known about the population trend, breeding biology and diet of the species in the Lagoon of Venice during the 1995-2023 years. Moreover, given the paucity of data regarding the wintering of this species in north Italy (Zenatello *et al*., 2014), using the available data we present an analysis of mid-winter counts, in the framework of the International Waterbirds Census made in the Lagoon of Venice over the 1993-2020 years.

MATERIALS AND METHODS

The Venice Lagoon is the largest (55,000 ha) coastal Lagoon around the Mediterranean, located along the Adriatic Sea, with its geographic centre at 45°26' N, 12°19' E (Fig. 1). Two barrier islands and one peninsula, each about 10 km long, separate the Lagoon from the Adriatic Sea. A large part of the Lagoon consists of an open water body of about 40,000 ha, with peripheral, private-owned fish farms for an additional 10,000 ha along the borders. Salt marshes cover an area of about 3800 hectares and are regularly flooded during mean high tides, while extreme high tides can cover salt marshes with at least 40-50 cm of water; dominant plant species include *Sarcocornia fruticosa, Salicornia veneta, Limonium narbonense*, *Halimione portulacoides* and *Puccinellia palustris*. Since 1985 about 130 dredge islands, i.e., artificial low-elevation islets made with the controlled use of dredged sediments (Scarton *et al.*, 2013; Scarton & Montanari, 2015), have been built in the Lagoon, with a total area of about 1300 ha (range: 2-38 ha). These dredge islands are used by several nesting waterbirds, with totals that can exceed 3000 pairs each year (Scarton & Valle, 2021). The mean depth of the Lagoon is 1.1 m and the tidal range during spring tides is about 1 m, with a mean of 0.6 m; nevertheless, extreme tides can reach 1.5 m above sea level (Venice local datum), the highest value in the whole Mediterranean due to the combined effects of high tides, storm surge and the seiche phenomenon (Medvedev *et al*., 2020; Šepić, *et al*., 2022). Recent studies show the relative sea-level rise is the major driver of the increase in the frequency of floods observed in the Lagoon of Venice over the last century (Ferrarin *et al*., 2022). Extremes high tides used to occur in late autumn, but over the last two decades they have been observed in spring as well, with disastrous effects on the reproductive success of waders and seabirds nesting at saltmarshes and, to a lesser extent, dredge islands (Valle & Scarton, 2022; Valle & Scarton, 2023a).

The Lagoon of Venice hosts important populations of Larids, both at national and Mediterranean level (Scarton, 2017; Valle & Scarton, 2023b). Apart from the Sandwich Tern, seven species nested so far: Black-headed Gull *Larus ridibundus*, Mediterranean Gull *Larus melanocephalus*, Yellow-legged Gull *Larus michahellis*, Slender-billed Gull *Larus genei*, Gull-billed Tern *Gelochelidon nilotica*, Common Tern *Sterna hirundo*, Little Tern *Sternula albifrons*. Moreover, one single individual of Lesser Crested tern *Sterna bengalensis* mated with a Sandwich Tern in 1999 (Scarton *et al*., 2000). Colonies of Larids are often mixed with other Charadriiformes, such as Eurasian Oystercatcher *Haematopus ostralegus*, Common Redshank *Tringa totanus*, Pied Avocet *Recurvirostra avosetta,* Black-winged Stilt *Himantopus himantopus*. Predators of eggs, chicks or adults include rats *Rattus* spp., Marsh Harrier *Circus aeruginosus*, Montagu's Harrier *Circus pygargus*, and Peregrine Falcon *Falco peregrinus* (Valle & Scarton, 1999).

Three different kinds of colony sites were used by Sandwich Tern (Fig. 2): i) natural sites, i.e., salt marsh islets. Here, the breeding adults build their nests mostly on mats of debris, usually windrow, i.e., bands of drifted vegetation such as reed *Phragmites australis* stems, large desiccated green algae *Ulva* sp., or leaves of seagrasses such as *Zostera marina* and *Cymodocea nodosa*, laying

on the top of salt marsh vegetation; this results in the nests being well above (>20 cm) the saltmarsh ground; ii) artificial sites, mostly dredge islands, where nests are placed both on the bare, silty ground and to a lesser extent on heaps of shell fragments; iii) only occasionally large heaps of bricks, remains of old buildings collapsed many years ago and now completely surrounded by the Lagoon, were used.

In 1989, we begun a comprehensive survey of all seabirds' colonies occurring in the open basin (i.e., excluding only the fish farms) of the Lagoon of Venice, which went on without interruption until 2018; in 2019-2023, only colonies of Sandwich Tern were monitored, due to lack of funding. During the whole study period, a few nesting events of Sandwich Tern occurred in a couple of fish farms; data regarding fish farm colonies were not used in the following analysis.

Each year the whole open Lagoon was searched by boat; in 2014-2018 surveys made from an airplane were also done, to locate colonies. Since 2017 a drone was also used to survey the colonies (Valle & Scarton, 2021). In the field, two observers visited each colony at least twice during the peak months of the breeding season, i.e., May-July. Surveys took place between 9:00 and 14:00 hours, avoiding days with unusually high tides, strong winds and rains. All apparently active nests, i.e., containing eggs and/or chicks, were counted, with only the peak value of nests considered for each colony in any given year.

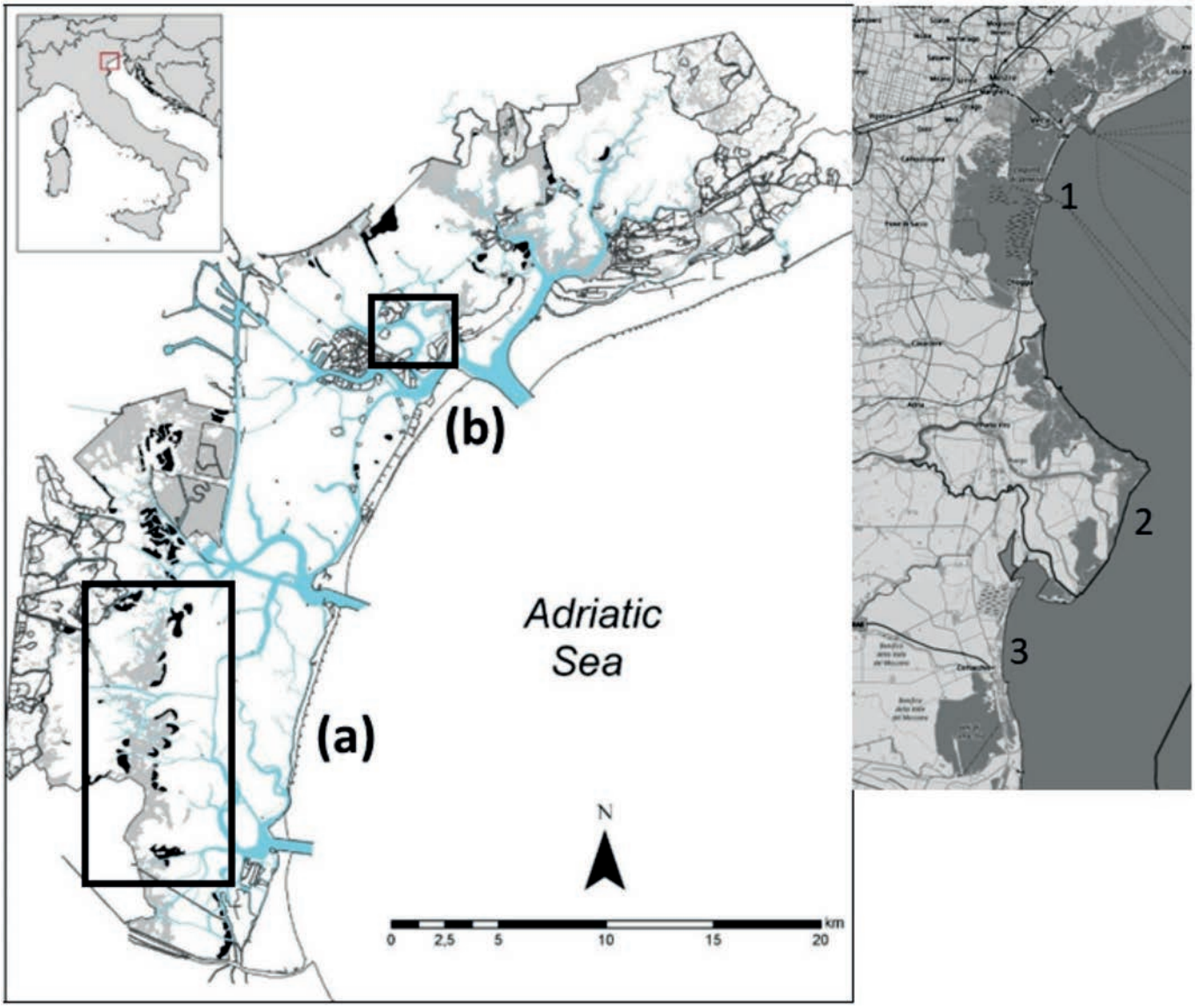

Fig. 1. – The Lagoon of Venice, with saltmarshes (in grey) and dredge islands (in black). The large rectangle (a) encompasses the area where Sandwich Tern colonies settled from 1995 till 2023, the smallest (b) the area used only since 2014. Location of colonies is not shown for conservation reasons. In the inset, the position of the Lagoon of Venice (1), the northern Po Delta (2) and the southern Po Delta (3), encompassing Comacchio and Valle Bertuzzi wetlands, is shown. / La Laguna di Venezia, con le barene naturali (in grigio) e le barene artificiali (in nero). Il rettangolo grande (a) comprende l'area in cui si sono insediate le colonie di sterne dal 1995 al 2023, quello più piccolo (b) l'area utilizzata solo dal 2014. La posizione delle colonie non è indicata per motivi di conservazione. Nell'inserto è mostrata la posizione della Laguna di Venezia (1), del Delta del Po settentrionale (2) e del Delta del Po meridionale (3), che comprende le zone umide di Comacchio e Valle Bertuzzi.

The number of Sandwich Tern breeding pairs was assumed to be the same as the number of active nests, an assumption that may not always be valid (Frederick *et al*., 2006). The most likely source of error in estimating the size of the breeding population is nevertheless through birds nesting in one colony, being unsuccessful then moving to renest in another. Despite this behaviour has been reported as unusual by Fijn & van Bemmelen (2023) for Sandwich Terns breeding in northern Europe, we did observe it several times. To reduce this kind of error, all the colonies occurring in the Lagoon in a given year were surveyed whenever possible within two-week periods. Then, the highest number of pairs among those estimated in any two-week period was considered as the total population for that year. Colony location was originally plotted on a 1:10,000 scale map, or in more recent years with the use of a portable GPS. In this paper a "colony site" is considered a spatially well-defined place (a salt marsh islet, a dredge island) used at least once by at least two breeding pairs. The reproductive success was estimated at selected sites as the number of fledglings per breeding attempt, in accordance with methodologies validated in previous work (Scarton & Valle, 1998; Valle & Scarton, 2021).

Regarding the diet, in June 2018 before young hatched several faecal samples of adult Sandwich Terns were collected around the nest at two colonies and sent to W. Courtens (Research Institute for Nature and Forest - INBO, Belgium) for content analysis, made in accordance with Courtens *et al*. (2017). In the same year, videos were taken at one colony to assess prey given to chicks (Valle *et al*., 2023). Information on areas used by feeding adults come from Scarton (2008) and subsequent unpublished observations made by the authors of this paper.

For the statistical analyses, parametric and non-parametric tests were used, according to data normality; differences between medians were tested with the use of Mann-Whitney and Kruskal-Wallis tests. PAST 4.08 and STATISTICA 7.1 software were used. To analyse the population trends for the 1995-2023 years, we used TRIM (Trends and Indices for Monitoring data) v. 3.5, a free software package used to determine species' population trends (Pannekoek & Van Strien, 2005). Using suggestions given by Vořišek *et al*. (2008), as we were dealing with complete counts, we used a Time Effects Model, with overdispersion set to "off" and serial correlation to "on".

Colony turnover was expressed as a percentage ranging between 0% (no new sites used from one year to the following) and 100% (all sites of the second year were new: Buckley & Buckley, 2000). Colony sites were grouped according to their origin and coded as "natural sites" (saltmarsh islets) and "artificial sites" (dredge islands and ruins of buildings). We evaluated the degree of possible association between Sandwich Terns and other breeding seabirds only in 1995-2018 (no data in 2019-2023 for the other species) using the following coefficient (Goutner, 1990):

$$\text{Phi} = \frac{ad - bc}{\sqrt{[(a+b)(c+d)(a+c)(b+d)]}}$$

where a = species x and y are both present in a colony; b = species x absent, species y present; c = species x present, species y absent; d = both species absent. 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. Based on the observed Cramer's V values, the association was considered very weak (<0.1), weak (0.1-0.19), moderate (0.20-0.29), strong (>0.30).

Finally, mid-winter data come from the results of 1993 – 2020 IWC counts annually presented in reports publicly available through the web site of Associazione Faunisti Veneti (www.faunistiveneti.it: ASFAVE, 2020).

Fig. 2 – The two commonest nest substrates in the Lagoon of Venice: left) windrow, at natural saltmarshes: right) silty-sandy bare soil, at dredge islands. / I due substrati di nidificazione più comuni nella Laguna di Venezia: a sinistra) cumuli di materiale spiaggiato, sulle barene naturali; a destra) il suolo nudo e limoso, presso le barene artificiali.

RESULTS

Population establishment and growth over the years 1995-2023

Between 1989 and 1994, during the colony surveys made in the Lagoon, only a few non-breeding adults of Sandwich Tern were observed in May-June; the species was never reported nesting in the years before, although the occurrence of adults fishing at the sea inlets was known since the beginning of the last century (Ninni, 1938).

On 9 June 1995, we discovered a colony with 202 Sandwich Tern nests on a saltmarsh islet, located within the largest colony of gulls and terns found in that year, totalling 1337 pairs (Scarton *et al.*, 1995; Scarton & Valle, 1998). The Sandwich Terns' nests were clumped in a small area of about 60 m^2 of windrow. The mean clutch size was 1.67 (s.d. = ±0.47, n=200); in each of two nests there was a chick of a few days, thus the laying period could be estimated between 10 and 15 May. From the end of June and the beginning of July, 113 chicks were ringed (M. Basso and G. Cherubini, pers. comm.). During these ringing sessions, it was noticed that several adults had rings placed at colonies located in the Comacchio wetland (Emilia - Romagna region, Fig. 1; Accipiter, 2012), about 80 km from the Venice Lagoon colony. The colony discovered in 1995 settled in a very secluded place, a 1.45 ha saltmarsh islet surrounded by extensive tidal flats and located about four km far from the closest navigable channel. In 1996, there were two clearly separated groups of nesting adults in the same saltmarsh islet of 1995: a first group of 217 pairs settled in early May, whereas a second group of 168 pairs began to nest at the end of that month.

Since 1995, the population went through three phases (Fig. 3): from 1995 to 2013, there was a "moderate increase", with a yearly rate of +3.5%; from 2014 to 2018, the trend was classified as "uncertain"; then, in 2019-2023 there was a strong increase, with a 44.5% yearly rate. Overall, during the 1995-2023 years the species rose from 202 till 3503 pairs, showing a trend of moderate increase ($p<0.01$), with a yearly rate of +5.7%.

Colony sites characteristics, turn over and location

During 1995-2023, 73 colonies of Sandwich Tern were found, hosting a mean of 361±423 pairs (range: 5-2762; median: 203). Each year there were one to six colonies; the first colony site which was occupied in 1995 hosted the largest, or the only one, colony of the Lagoon in 17 years out of 29. There were at least two colonies in 20 years out of 29; nevertheless, the population was highly concentrated, since at least 50% of adults nested in just one colony in 24 years.

The annual median size of colonies did not change across the 29 years (Kruskal-Wallis: h=6.29, p=0.09). Colonies located at artificial sites (n=14) did not differ in size from those at saltmarsh sites (n=59; Mann-Whitney test on medians, Z=0.21, U=397.5, p=0.82).

In the whole study period, twenty-one colony sites were used: 12 saltmarsh islets and 9 artificial sites, of which 8 were dredge islands and 1 consisted of ruins of an old building. On average a site was used for 3.5±5.4 years (range 1-25), but the frequency distribution was highly skewed: one site, the first where Sandwich Tern settled, was used 25 years out of 29, being unused for just one year over the first 23. At this site, the colony rose from 202 till 571 pairs during the first five years, when it was the only one in the whole Lagoon. Another site was used for seven years and the re-

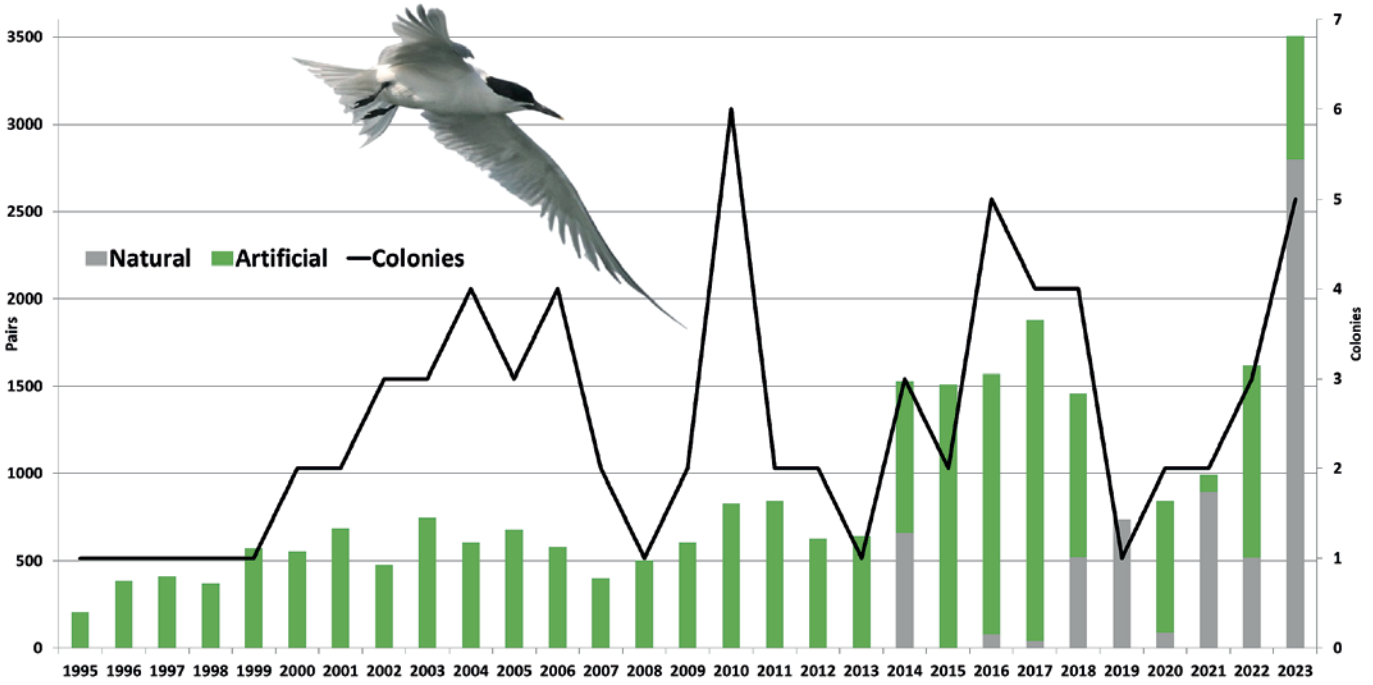

Fig. 3 – Number of Sandwich Tern nesting pairs in the Lagoon of Venice, at artificial and natural sites (bars). Number of colonies is also shown (line). / Numero di coppie di beccapesci nidificanti nella Laguna di Venezia, in siti artificiali e naturali (barre). È indicato anche il numero di colonie (linea).

maining 19 sites for less than five years, often (n=11) for just one year. Turnover rate was on average 41.4% (over 28 years, 1995 not included), with a 0 value (i.e., no change between two consecutive years) in eight years (Fig. 4).

From 1995 to 2013, only saltmarsh islets were used, despite the occurrence of several tens of dredge islands, some of them apparently suitable to nest, having bare, silty-sandy mounds. Only in 2014 the Sandwich Tern begun using artificial sites; since then, the fraction of the whole population using them in a given year was highly variable, from 0 to 100%. The fraction of the population nesting at artificial sites showed a mean increase of 16.1% in the 2014-2023 period, but without a significant trend, probably due to large variations across the years (Fig. 3).

Between 1995 and 2013 colonies were always located in the southern Lagoon (Fig. 1), this area has a low level of humane disturbance, with hundreds of saltmarsh islets, tens of dredge islands and with a dense network of very shallow channels, used only by local fishermen. These colony sites were located at 4.6-10 km from the open sea, where most of the foraging activity of the breeding birds took place (see later). Only from 2014 onwards, three additional sites, two dredge islands and one saltmarsh islets, were used north of Venice (Fig. 1); all these colony sites were close to large channels, heavily used by public and private boats and, in one case, located at less than 200 m from the Venice town buildings (Fig. 5). These colony sites were also closer to the open sea than the colonies of the southern Lagoon, being at a distance between three and four km.

Association with other gull and tern species

Sandwich Terns bred mostly in mixed colonies with other species of gulls and terns, i.e., the Black-headed Gull, the Mediterranean Gull, the Common Tern, and the Little Tern. Only isolated pairs of Yellow-legged Gulls were very rarely observed in the colonies, and thus they will not be considered here.

Of the 73 colonies of Sandwich Tern, only three (4.1%) were monospecific; 20 (27.4%) had two species, 33 (45.2%) three species, 16 (21.9%) had four species, and just one (1.4%) hosted all the five species.

The commonest species nesting with Sandwich Tern was the Common Tern (in 65 colonies out of 73, 89%), followed by Black-headed Gull (44 colonies, 60.36%), Little Tern (17 colonies, 23.3%) and Mediterranean Gull (12 colonies, 16.4%). Colony size of Sandwich Tern differed according to the number of other co-breeder species, colonies with three other species being the largest, with differences at the threshold of significance (Kruskal-Wallis, Chi^2:8.79, d.f.=4, p=0.06).

A positive and significant correlation was observed between Sandwich Tern and Black Headed Gull colony size (Spearman test: r_s=0.36, p=0.016). It must be stressed that at saltmarshes the two species shared the same site in 44 out of 59 colonies, whereas this never happened at artificial sites. This was due because the man-made sites lacked the dense network of tidal creeks and ponds surrounded by dense vegetation, which makes the preferred nesting site of the Black-headed Gull. Colony size of Sandwich Tern showed a non-significant negative correlation with those of Common Tern and also Little Tern (p>0.05 always), while too little data were available for Mediterranean Gull colonies. Nevertheless, it may be added that in six cases out of seven the Mediterranean Gull shared the same colony site with those of Sandwich Tern.

Between 1995 and 2018, 385 colonies with one or more species of gulls and terns were found. The association between Sandwich Tern and the Black Headed Gull was strong (Cramer V=0.54, Chi^2=109.7, p<0.001), and moderate with

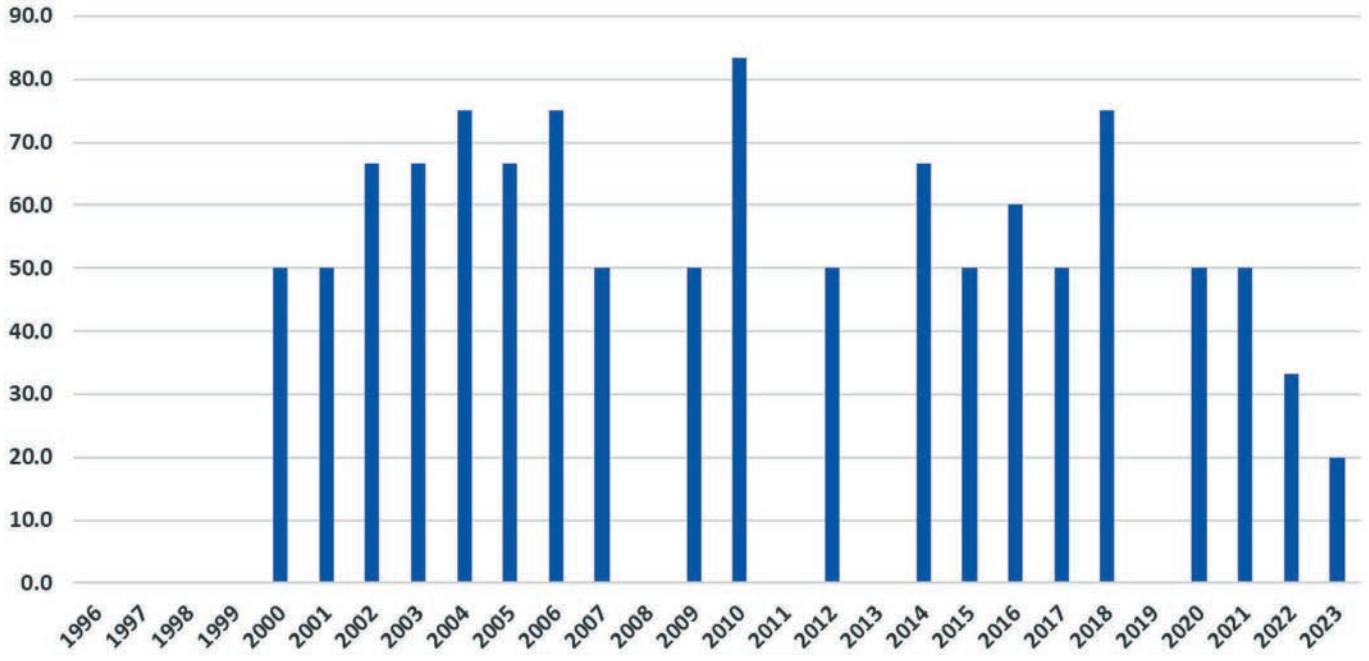

Fig. 4 – Turnover % rate (0 = no change of colony sites from previous year, 100 = complete change) observed in the lagoon of Venice. / Tasso di turnover % (0 = nessun cambiamento dei siti delle colonie rispetto all'anno precedente, 100 = cambiamento completo) osservato nella laguna di Venezia.

Common Tern (Cramer V=0.24, Chi2=21.29, p<0.01); instead, a negative and moderate correlation was found between Sandwich Tern and Little Tern (Cramer V=-0.22, Chi^2=18.41, p<0.001).

Nest site and reproductive success

Nest location differed remarkably between saltmarsh islets and artificial sites: in the former ones, nests were almost always placed on the top of stranded material (windrow; Fig. 2), while occasionally heaps of shell fragments were also used. The windrow is stranded by high tides during the late winter-spring storms and give birds a substrate for making the nests slightly higher than the ground, affording at least partial protection from flooding due to the high tides in the following spring. At dredge islands, which have higher elevation above sea level than the saltmarsh islets, nests were placed directly on the sandy or silty ground, both bare or covered with a thin layer of shell fragments and marine debris (Fig. 2).

Clutch size was 1.7±0.5 (n=1338) without differences between saltmarsh and dredge islands: 1.64±0.5 vs 1.81±0.45 eggs per clutch (Mann-Whitney U-test, p=0.270).

Similarly, hatching success did not differ between the two habitats, in years free from tidal flooding as in 2014, when respectively 649 and 659 nests in natural and artificial marsh islands hatched: 1.40±0.75 vs 1.52±0.72 eggs per clutch (Mann-Whitney U-test, p=0.266), for an overall value of 1.46±0.74 (83%). When tidal flooding occurred, productivity was seriously affected, sometimes with catastrophic effects. In 2020, a colony of 700 nests located on a large shell pile in a saltmarsh was annihilated by an extremely high tide (about 1 m), whereas in 2022 no chick hatched from all 1301 clutches on a saltmarsh islet flooded by a 0.86 m tide. The same level was not enough to wash away any of the 150 clutches laid in a dredge island, which was subsequently used by a renesting colony of more than 800 pairs.

Over the study period, the most important cause of clutch loss was flooding during extreme high tides, responsible for more than 90% of losses until 2022. In 2023, an H5N1 avian influenza outbreak annihilated the productivity of the whole nesting season. Predation was instead low, due to the absence of terrestrial predators in the Lagoon saltmarshes, except for the islets closest to the mainland, which were rarely used by Norwegian Rats *Rattus norvegicus* with negligible effect. The harriers prey regularly in colonies of the southern Lagoon, but avian predators are absent in the area laying north of Venice, where predation is limited to the modest but constantly observed toll taken by Oystercatcher, though this phenomenon was observed mostly on abandoned eggs. The average productivity was

Fig. 5 – Colony of Sandwich Tern on a dredge island. In the background the buildings of Venice. / Colonia di beccapesci su una barena artificiale. Sullo sfondo i palazzi di Venezia.

0.56+0.11 young per breeding attempt (range = 0.41-0.69, n=2046) and very homogeneous during the study period: 0.5 fledglings per pair in 1995-96 in comparison to 0.6 in 2018-19. As previously mentioned for clutches, no predation was observed for chicks, which were lost mostly due to starvation. As an aside, we mention that no case of kleptoparasites were observed in our colonies, where only a few Black-headed Gull pairs occur, with a ratio Sandwich Tern/Black-headed Gull of 10 to 30:1.

Feeding area and food

Detailed observations about the distribution of adults Sandwich Terns over Lagoon and nearshore waters were done only in 2001-2003, using boat transects made up to five km from the coastline (Scarton, 2008). Observations of Sandwich Terns were concentrated around the colonies and in the open sea, while sightings were very rare in the Lagoon area between the two areas. Some adults were seen carrying fish at more than 15 km from the colonies, suggesting the feeding area could extend well beyond this distance. Beside this, occasional observations made by the authors in the following years indicate the species may also exploit the three sea inlets, some shallows north of Venice and sometimes the mouths of rivers flowing into the Lagoon.

The diet of Sandwich tern in the lagoon of Venice is only scanty known. For what concerns breeding adults, the analysis of the otoliths occurring in the food pellets collected in 2018 showed that the main items were two size-classes of European pilchard *Sardina pilchardus* (7.5-12.5 cm and 17.5-20.0 cm, respectively); also, anchovies *Engraulis encrasicolus* of 14.5-17.5 cm were consumed.

Wintering occurrence

Fig. 6 presents the results of the IWC census made in the 1993-2020 years (ASFAVE, 2020); these data refer to the whole Lagoon, including fish farms and birds seen from the barrier islands, thus reasonably at less than one km offshore. Until 2009 about 10 birds were observed each year; between 2010-2020, the mean rose to 27, with a maximum of 50 birds in 2014; the trend from 1993-2020 years is of moderate increase ($p<0.05$) with a rate of +6.1% per year. Despite this, in 2018 (the only recent year for which wintering data for the whole Italy are available: Zenatello *et al*., 2018), Sandwich Tern counted in the Lagoon of Venice still represented a mere 1% of the national total.

Considering the total number of birds counted in 1993-2020 (n=392) during the IWC counts, 52% were observed in the open Lagoon, 45% along the littoral strip and the remaining 3% inside fish farms. There is a positive correlation among the number of wintering birds and those nesting in the previous year (n=25; Spearman test: r_s 0.46, p=0.019), suggesting a few individuals may remain all year round in the Lagoon of Venice.

DISCUSSION AND CONCLUSIONS

During the period 1995-2023, we monitored the settlement and growth of a population of Sandwich Tern, which became in a few years the largest among those occurring in Italy and one of the largest in the whole Mediterranean.

In Italy, the Sandwich Tern until 1994 used to nest only in the large wetland complex of Valli di Comacchio (southern Po Delta); from here a group of birds moved in 1995 to the Lagoon of Venice, probably following a deterioration of the

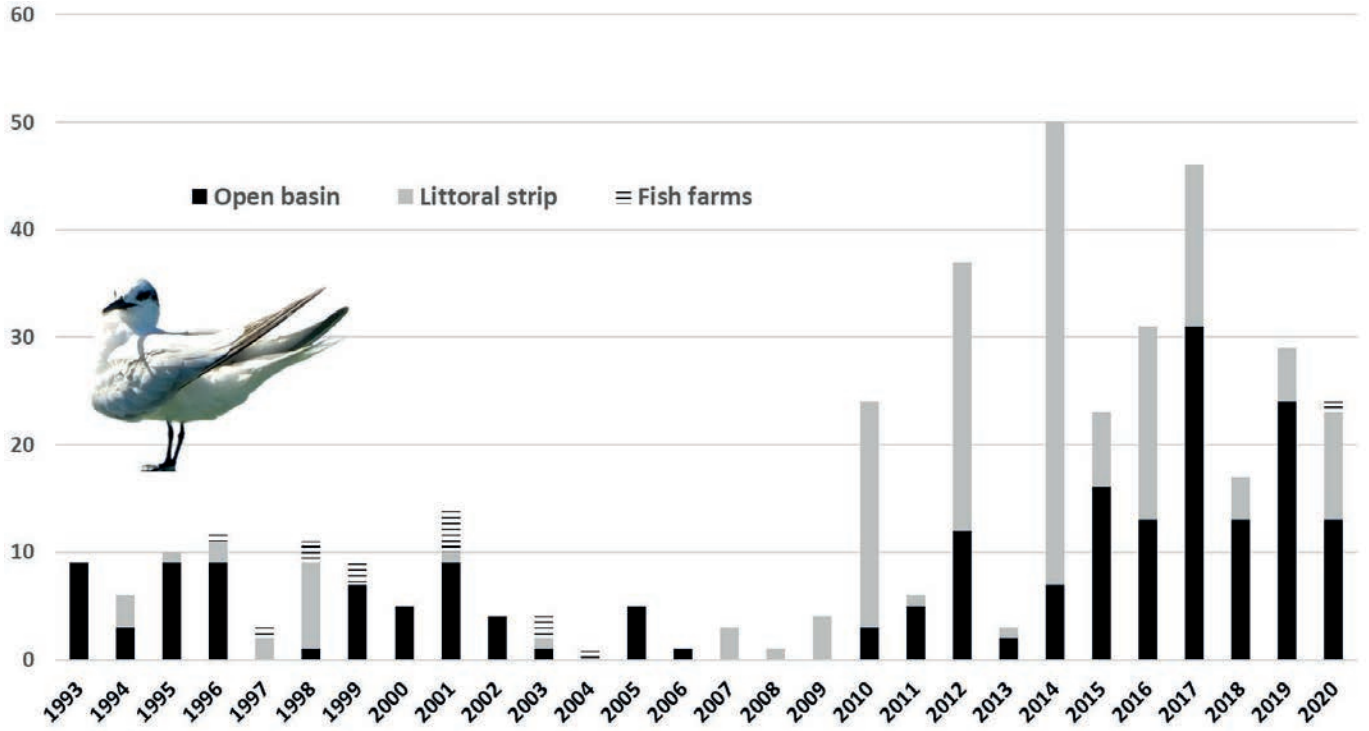

Fig. 6 – Numbers of Sandwich Terns counted in the Lagoon of Venice during 1993 – 2020 mid-January IWC counts. Source of data: Associazione Faunisti Veneti (2020). / Numero di beccapesci censiti nella Laguna di Venezia durante i conteggi IWC di metà gennaio 1993-2020. Fonte dei dati: Associazione Faunisti Veneti (2020).

breeding sites formerly used (Volponi, 2014). Thereafter, the nesting population of the southern Po delta fluctuated widely, with a new site named Valle Bertuzzi colonized in 1998 and used regularly in the following years (Foschi, 2009; Volponi, 2014). The whole southern Po Delta hosted 170-285 pairs in the 2004-2006 years (Foschi, 2009), with pairs sharing the two sites of Valli di Comacchio and Valli Bertuzzi. In the following years, the Valli di Comacchio site became more and more marginal, with just one pair nesting in 2017 (Volponi, 2018). It has been suggested that the lagoon of Venice and the two wetlands of the southern Po Delta probably shared the same birds that moved across these sites (Foschi, 2009; Volponi, 2014). A new site, the northern Po Delta (Veneto region) was colonized for the first time in 2005 (Verza, pers. com.); after a lack of nesting records, the species nested here irregularly between 2018 and 2023, with a maximum of 893 pairs (Valle & Verza, 2020; Verza *et al*., 2023; Verza *et al.*, 2024). The settlement in the northern Po Delta was reasonably due to adults coming from the Venice Lagoon since it took place when here the population showed a numerical decrease (Valle *et al*., 2022). Outside the Veneto and Emilia-Romagna regions, nesting of Sandwich Tern in Italy has always been extremely scarce: in Sicily, nesting was confirmed in the province of Syracuse in 2006 (Brichetti & Fracasso, 2018), while in Apulia, nesting was irregular, with a few pairs at the Margherita di Savoia saltpans (Stival, 2022).

Use of new sites by groups of birds moving across several wetlands in following years is well known for the Sandwich Tern, which according to several authors (Veen, 1977; Díes & Díes, 2004; Liechty *et al*., 2017) shows a high "group tenacity" sensu McNicholl (1975). While the first settlers came from the Comacchio wetlands, subsequent rings readings attested that adults coming from Scotland, Denmark, Netherlands, and Spain were occurring in the Venetian colonies (Accipiter, 2012; Sighele et al., 2015), as well as birds born in the Black Sea and Sea of Azov colonies (Spina & Volponi, 2008).

After the first settlement, in the lagoon of Venice in 2014, a massive new immigration event occurred, with an additional 800-900 pairs nesting not only at natural sites but also for the first time at artificial sites (Scarton *et al.*, 2018). Both the use of artificial sites and the closeness of colonies to a town, the largest being located to just 200 m from the buildings of Venice (Fig. 5) were never observed before and may suggest the new breeders could come from a wetland where they were already accustomed to these locations: Sandwich Terns are known to nest elsewhere on jetties and into harbours or other man-disturbed places (Stienen *et al*., 2005). A third, massive immigration event occurred in 2023, with about 2000 additional pairs nesting in one single colony. In this case, it may possible the bird came from colonies of NW Europe, which in 2022 were swept away by the avian influenza (HPAI virus: Knief *et al*., 2024). In that year, colonies in the Lagoon of Venice were not affected at all, while in 2023 they were heavily struck (Valle *et al*., 2024). Data about the origins of these immigrants are not available, thus both these hypotheses cannot be confirmed at the moment.

In the Lagoon of Venice, the Sandwich Tern become in a few years the second most abundant seabird species, after the Yellow-legged Gull; its settlement and growth were possible due to the existence of suitable colony sites (saltmarsh islets in the first years, then artificial sites) and good availability of prey. Sandwich Tern in the Lagoon of Venice seems to prefer foraging in the open sea instead of in the more internal waters, as observed at other wetlands (Fasola & Bogliani, 1990; Perrow *et al*., 2010; Cotin *et al*., 2011; Díes & Díes, 2017; Fijn *et al*., 2017).

Concerning the diet, the few data obtained so far confirm the species forages primarily on highly nutritive preys such as Clupeidae and Engraulidae, as observed at other Mediterranean wetlands such as Comacchio (Fasola *et al*., 1989) and Albufera de Valencia (Spain: Díes & Díes, 2005). Moreover, Valle *et al*. (2023) recently studied 373 prey items brought to chicks, 291 (78%) of which were identified. They belonged to five fish species: European anchovies accounted for 92.4% of the total, whereas sand smelts *Atherina boyeri*, European pilchards, mullets *Mugil* sp., and garfishes *Belone belone* accounted for 4.5%, 1.7%, 1.0%, and 0.3%% respectively.

It must be added that in their study about the occurrence of rare elements in fledglings of Sandwich Tern in Venice Lagoon, Picone *et al*. (2022) found that among 25 fish items regurgitated by chicks, the three more represented species were European sprats *Sprattus sprattus,*, European pilchards, and European anchovies. These authors found heavy contents of rare earth elements in fledgling feathers of Sandwich Tern chicks and also contents of neocotinoids pesticides (Distefano *et al*., 2022a; 2022b) showing concentrations among the highest reported in the literature for birds' feathers, reaching the birds through their main preys, which also resulted with high level of this contaminants. This poses a new threat to the reproductive success of Sandwich Terns in the Lagoon of Venice, which was unknown so far.

The breeding parameters observed in the Lagoon are comparable to that reported in other European breeding sites of Sandwich Terns. In particular, the mean number of fledged young per pair was 0.55 in England, 0.64-0.66 in the Netherlands (Stienen *et al*., 2001), 0.2-0.5 in southern France (Schwartz *et al*., 2023).

Many studies found that Sandwich Tern shows a low degree of colony site fidelity, a behaviour which is related to the use of typical ephemeral nesting habitats (Scarton & Valle, 2005; Liechty *et al*., 2017; van Bemmelen *et al.*, 2022) and found also in other Larids, such as the Little Tern, the Mediterranean Gull, or the Slender-billed Gull. While it is out of doubt that saltmarshes or dredge islands are truly ephemeral habitats, our long-term data gathered in the Lagoon of Venice does not conform to the studies quoted above. Indeed, most of the population clumped each year in very few, apparently suitable sites, used for several years in a row. The first colony site, a saltmarsh islet, was used almost continuously over 29 years, showing a remarkable level of site fidelity. Moreover, sites used for just one-year hosted colonies on average much smaller (190 pairs) than the average of the whole study period (360 pairs).

From one side, this finding may have important impacts from a management point of view, showing that simple measures – such as vegetation cutting at dredge islands, to prevent encroaching - directed each year at a few, traditional sites may favour the settlement of most of the nesting population in a given year. From the other side, these practices can attract adults to nest at sites which are becoming more and more unsuitable, due to their frequent submersions by the high tides (see later). This can result in 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 (Greggor *et al*. 2019; Valle & Scarton, 2023b); thus, a careful, site-specific approach must be adopted for the management of man-made sites.

In the Lagoon if Venice, the frequency of tides higher than 80 cm (conventionally defined as "acqua alta" i.e., high water) has been rapidly increasing over the last 20 years, due to several effects of climate change, such as sea level rise and increased storminess (Ferrarin *et al*., 2022; Baldan *et al*., 2023). Nowadays, the occurrence of high tides in periods when they were once very rare, such as late spring, is already having a heavy impact on seabirds nesting in the Lagoon, due to the frequent submersion of colonies of several seabirds and waders (Valle & Scarton, 2023b). In particular, at natural marshes the occurrence of windrow is of paramount importance for the occurrence of Sandwich Tern colonies; seldomly saltmarsh islets without this material were used, and here Sandwich Terns nested on heaps of shell fragments (Valle & Scarton, 2022), which also gave an advantage in terms of elevation gain. In late autumn-winter, the large seagrass meadows existing in the southern Lagoon of Venice (Curiel *et al*., 2020) shade a large amount of leaves, and part of this material become stranded over the saltmarsh vegetation. Apart from flooding the colonies, another less obvious effect of frequent and longer flooding times of saltmarsh in late winter – early spring, before the Sandwich Terns come to nest, could result in a lesser quantity of wracked material on the surface, as we observed in the last years at several sites. The occurrence of large patches of wracked material is needed by Sandwich Terns to nest and it is possible it may act as a cue to judge the suitability of new breeding sites, never used in the past.

These two factors – shortage of wracked material on saltmarsh islet and poor reproductive success on those used - probably prompted the Sandwich Terns to choose alternatives, i.e., the artificial sites.

Sandwich Tern may rapidly use man-made sites, as observed in Belgium (Everaert & Stienen, 2007), Netherlands (van Bemmelen *et al*., 2021), France (Schwartz *et al*., 2023) and USA (McGinnis & Eslie, 2001; Jodice *et al*., 2007; Emslie *et al*., 2009). Artificial sites in the Lagoon of Venice are higher than natural saltmarsh islets and thus less frequently flooded; some of them have bare areas; moreover, those chosen by Sandwich Tern are much closer to the sea than the natural sites once used, thus significantly shortening the length of feeding bouts. These three factors combined may thus explain the progressive use of such artificial sites. Nevertheless, the artificial sites used by Sandwich Terns and other seabirds must be properly managed, since the encroach of the vegetation reduces the suitable, open, and bare surfaces.

Since October 2020 large mobile gates, the so-called MO.S.E. (MOdulo Sperimentale Elettromeccanico), have been in operation at the three Lagoon inlets. When the tide reaches a certain threshold, usually above 1 m asl, they are lifted, effectively separating the Lagoon basin from the sea; this may happen in any season of the year (Mel *et al*., 2021). No one so far has tried to elucidate the possible effects of these operations and the resulting reduction of high tides duration and frequency on the large seabird community, which each spring-summer nest on saltmarsh and dredge islands, where flooding is always the primary cause of nesting failure (Scarton *et al.*, 2018).

The settlement of colonies inside fish farms, where water level is strictly regulated by man, is likely another option the seabirds have to avoid flooding of the clutches. Other seabirds made the same choice over the last decade, such as the Black Headed Gull and the Mediterranean Gull, whose largest colonies nowadays are found only inside fish farms (pers. obs.). While now only a minor fraction of the Sandwich Tern population nest inside fish farms, it is likely this will become more important in the near future.

Sandwich Tern in the Lagoon of Venice almost always shared the colony site with other species, as observed elsewhere (Díes & Díes, 2005; Emslie *et al*., 2009). The association found with the Black-headed Gull is also known, and it has been explained with the protection given by the gull against the predators, despite the kleptoparasitism made by the gull (Díes and Díes, 2005; Stienen *et al*. 2001). Nevertheless, at our colonies the numbers of Black-headed gull pairs ranged between 2 and 90, and to those of Sandwich Tern between 5 and 1504, thus it seems unlikely that the two factors may explain the observed association between the two species.

Despite being important for the breeding population, the Lagoon of Venice according to the literature never hosted large numbers of wintering Sandwich Terns. Fasola (1984) did not report any wintering birds in its study, while in the 1988-1989 winter Cherubini (1989) counted between 70 and 90 birds at a single roost. Bon & Scarton (2012) report only 4 to 35 five birds were observed each year during the IWC counts during 1993-2012. Zenatello *et al*. (2014) wrote that only modest numbers of Sandwich Tern winter in northern Italy, with the Lagoon of Venice ranking 40th among about one hundred Italian wintering sites.

In conclusion, the present review highlighted several aspects of the settlement and growth in a new environment of a Sandwich Tern population, which in about a decade became one of the largest in the whole Mediterranean. The persistence of this population in the lagoon of Venice is nowadays threatened by several factors, among which the multiple effects of climate change are likely the most dangerous. Simple but effective management actions at a few colony sites, so far completely lacking, are urgently needed to counteract these effects.

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