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ARTICLE

Long Term Decline of a Common Tern (*Sterna hirundo)* Population Nesting in Salt Marshes in Venice Lagoon, Italy

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Abstract Each year between 1989 and 2008, I monitored Common Tern colonies in the lagoon of Venice (Italy). This population nests only on salt marsh islets, which are subjected to flooding during high tides. The number of breeding pairs decreased significantly from 832 to 109, with an average rate of decrease of −10.1%. Overall, 188 colonies were found, ranging from two to 583 pairs; median colony size was 57 pairs, and it decreased significantly. The mean turnover rate was high at 41.5%, and it ranged each year between 7.7% and 60%. The observed trends could be attributed to the increase in mean sea level that occurred over the last 20 years (0.5 cm/yr). In the May–June period, the number of days with high tides leading to a complete flooding of the breeding site increased. Between 1989 and 1998 there was on average 4.4 days with floodings. This increased to 8.4 days between 1999 and 2008. Therefore, sea level rise could be a major contributor to declining Common Tern populations in the lagoon of Venice.

Keywords Colonies · Monitoring · Seabirds · Sea level rise · Sternidae

Introduction

The Common Tern (*Sterna hirundo*) is a colonial seabird with a wide breeding range that includes most of Europe and Asia, with a few sites along the western coast of Africa. In the Americas the species breeds mostly in eastern and central North America (Nisbet 2002). In Europe recent estimates indicate a large population, with more than 270,000 pairs, stable during the period 1970–1999 (Birdlife International 2004). Despite this stable trend at the European level, there have been marked national fluctuations in the populations; some populations increasing, others stable or even decreasing. The Italian population is estimated between 4,000 and 6,000 pairs, with a trend reported to be decreasing over the years 1990–2000 (Birdlife International 2004). More recently, an assessment of Italian breeding bird species lists the Common Tern as having an “inadequate” conservation status (LIPU 2009) related to a combination of indicators, such as range, population trend, and condition of the habitat.

The lagoon of Venice (NE Italy) is a traditional breeding place for this species, hosting up to 15% of the whole Italian breeding population at the beginning of this century (Scarton et al. 2005). The Venice lagoon population is unique because Common Terns nest only in salt marshes, there being no records of use of more typical breeding sites such as sand beaches or dunes during the last 150 years. Old accounts by ornithologists dating back to the second half of the 19th century mentioned the nesting of the species only on salt marshes (Arrigoni degli Oddi 1894; Ninni 1882). Until 1981, literature on breeding sites was extremely scarce and anecdotal: Ninni (1938) and Tolotti (1970) wrote that the species was breeding on salt marshes or inside fish farms, never mentioning sandy beaches. The same authors described another species, the Little Tern (*Sternula albifrons*), as breeding along the sandy islands of the Venice lagoon littoral, so it is unlikely that nesting of Common Tern at the same sites was overlooked. Despite the lack of detailed information, it is reasonable to conclude on the basis of the available literature that the Common Tern has never used beaches or dunes as a nesting place.

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Detailed data are available only from the last decades of the 20th century. Between 1981 and 1983, the first surveys were done over the whole lagoon of Venice (Fasola 1986), and Common Tern colonies were found only on salt marshes. After a break, surveys started again in 1989 and continued until the present (Scarton et al. 1994; Guzzon et al. 2001; Scarton et al. 2005), with not a single colony found at sandy islands.

The breeding biology of Common Tern nesting on salt marshes is less well understood compared with that of terns nesting at sandy or gravel sites, although, for USA coastal sites a few works are cited by Buckley and Buckley (2000). The same authors cite just one work by Greenhalgh (1971) for European sites, and another work of the same author (Greenhalgh 1971) deals with British salt marshes. For the Po Delta, located about 60 km south of the Venice lagoon, detailed data reported by Fasola (1993) and Fasola and Canova (1996) refer only to colonies occurring at fish farms, where the water level is strictly regulated.

For Common Tern breeding along the coasts, salt marshes were once regarded as sub-optimal breeding sites compared to beaches and dunes, due to the higher risk of losing chicks and eggs from flooding (see Buckley and Buckley 2000). More recently, reproductive success and colony turnover rate between saltmarsh and beach nesting populations were shown not to differ significantly (Burger and Lesser 1979; Safina et al. 1989; Buckley and Buckley 2000). For a discussion of possible advantages of nesting at salt marshes, such as minimal interspecific competition, abundance of food around breeding sites, and reduced mammalian predation, see Burger (1985) and Greenberg et al. (2006).

As stated above, nesting at salt marshes may expose the birds to several risks, the most important of which is flooding due to storms and/or high tides (Reinert 2006). Given the general concern over expected global sea level rise, with an estimated increase of 0.18–0.58 m by the end of this century (IPCC 2007), it is important to evaluate whether local populations of saltmarsh nesting birds are already responding to this threat. Here I present data which indicate that sea level rise over the last 20 years may have affected nesting of Common Tern at Venice Lagoon.

Study Site

The Venice Lagoon is a large (550 km^2), shallow coastal lagoon, located on the north-western coast of the Adriatic Sea, with its centre at about 45°26'N, 12°19'E (Fig. 1). Two barrier islands, each about 10 km long, separate the lagoon from the sea; water is exchanged through three large inlets. Most of the lagoon consists of an open water body (about 400 km^2) that is partially vegetated by macroalgae (*Ulva* sp., *Chaetomorpha* sp., *Enteromorpha* sp.) and seagrasses (*Zostera marina*, *Nanozostera noltii,* and *Cymodocea nodosa*). The mean depth of the lagoon is 1.1 m and the tidal range during spring tides is about 1.0 m, with a mean tidal range of 0.6 m, one of the highest observed in the Mediterranean basin (Ferla et al. 2007).

In the lagoon there are also extensive intertidal salt marshes that flood regularly during high tides (mean elevation above sea level of only 0.20–0.30 m). Hundreds of islets covered by salt marsh vegetation occur in the south-western and northern corners of the lagoon. Dominant plant species include *Limonium narbonense*, *Salicornia veneta*, *Sarcocornia fruticosa*, *Halimione portulacoides*, *Puccinellia palustris*, *Spartina maritima*, and *Juncus maritimus*. Common Tern colonies are often mixed with other Charadriiformes, especially Little Terns, Black-headed Gulls (*Chroicocephalus ridibundus*), Sandwich Terns (*Sterna sandvicensis*), and Redshanks (*Tringa totanus*). Predators of eggs, chicks, or adults include rats *Rattus* spp., but only at sites close to the mainland, and Marsh Harrier *Circus aeruginosus*, Montagu's Harrier *Circus pygargus*, and Peregrine Falcon *Falco peregrinus* (Valle and Scarton 1999).

On salt marshes, Common Terns build their nests mostly on mats of marsh debris, usually windrows of dead plants (such as reed *Phragmites australis* stems, large green algae, or leaves of seagrasses), laying on the top of live salt marsh vegetation, resulting in the nests being well above (>20 cm) the saltmarsh surface. Of secondary importance are other nesting places, such as small mounds of shell fragments deposited along the edge of the salt marshes, large plastic or wood debris stranded over vegetation, or blinds constructed for waterfowl hunters.

Since 1985, about 80 dredge islands have been built in the open lagoon, ranging in size from 0.4 to 57.4 ha, with a mean surface of 11.2 ha and a total area (in 2008) of about 900 ha. Each dredge island consists of a containment cell formed using piles of woody material along the exterior. These areas are then filled with sediment from the regular dredging of lagoon channels (Cecconi 2005). These dredge islands are heavily used by waterbirds as resting, feeding, and nesting sites (Scarton 2005; 2008). About 10,000 ha along the western part of the lagoon are diked in privately owned reserves for fishing and waterfowl hunting.

Methods

Each year between 1989 and 2008, the whole open lagoon, with the exception of diked reserves, was searched for colonies by boat. Each colony was visited by two observers (the author plus a colleague) at least twice, but most were visited three times during the breeding season (May–July). This occurred between 9:00 and 14:00 hours, avoiding days

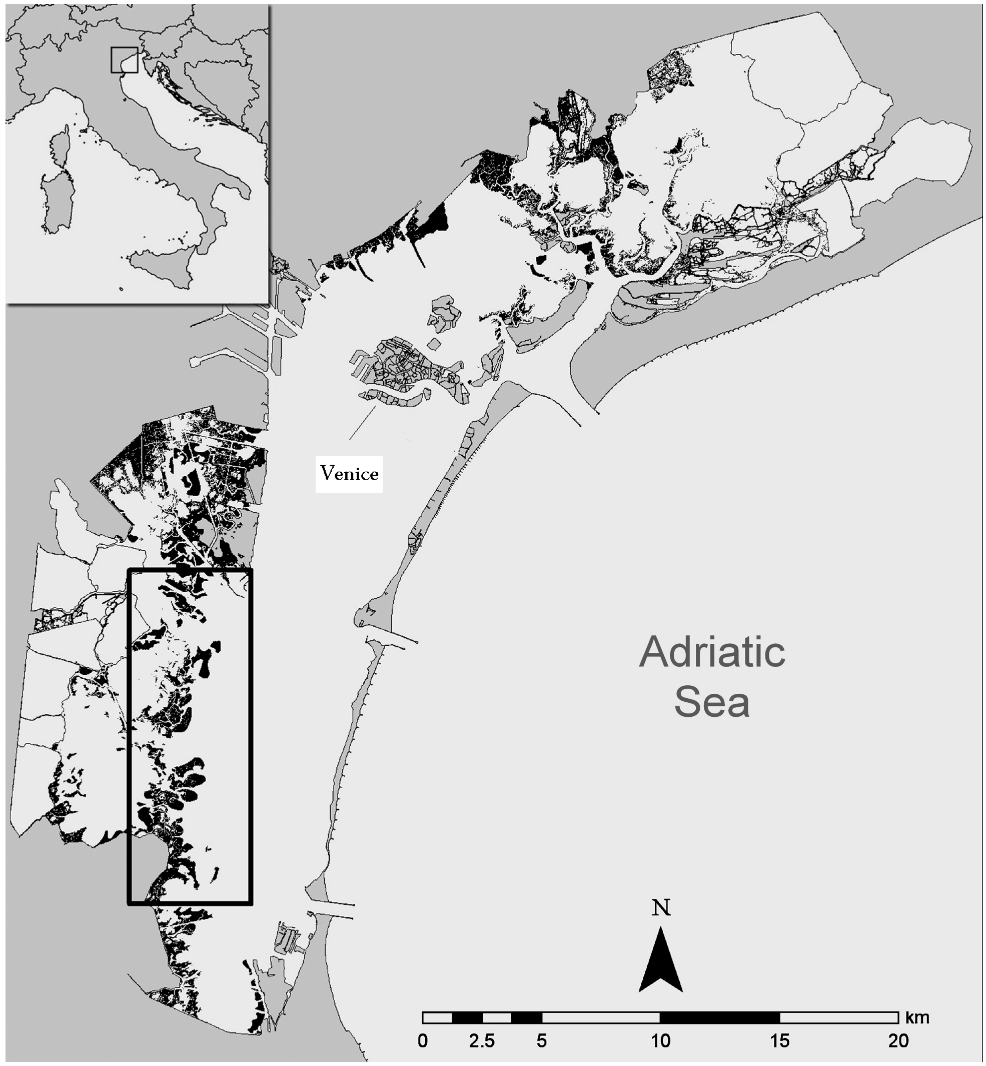

Fig. 1 The lagoon of Venice, with land in grey and salt marshes in black. The rectangle highlights the area where most of the colonies were found

with unusually high tides or strong winds. All apparently occupied nests (sensu Steinkamp et al. 2003) were counted, with only the peak value of nests considered for each colony. The number of breeding pairs was assumed to be the same as the number of occupied nests, an assumption that may not always be valid (see Frederick et al. 2006). Most of the colonies in my study area had fewer than 100 pairs, thus error due to detection probability was probably minimal (Steinkamp et al. 2003).

To avoid errors in estimating the number of breeding pairs due to the same birds nesting at different breeding sites in the same season, which can occur following abandonment, all the colonies occurring in the lagoon in a given year were surveyed 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, and in more recent years with the use of a portable GPS. Most colonies were clumped in the southern basin, in an area of about 60 km^2 (Fig. 1); only a few colonies were found in the northern basin. In this paper a "breeding site" is considered a spatially well defined place (salt marsh islet, dredge island, etc.) used at least once by a "colony" (i.e., a group of breeding individuals which associate together; Coulson 2002); single pairs were not considered colonies.

Colony turnover was expressed, as in Buckley and Buckley (2000), 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). Mean annual population change (λ) was calculated as: $\lambda=(N_{t+1}/N_t)^{1/T}$, where N_t is the local colony size at time t, N_{t+1} is the locale estimated colony size at time $t+1$, and T the number of years between t and $t+1$ (Oro et al. 2004). I arbitrarily divided breeding sites among "regular", used by colonies for at least 10 years, even if non-consecutive, and "occasional", used from one to nine years.

For analyses, non-parametric tests were used because counts of breeding pairs were not normally distributed. Trends in breeding numbers against years were analyzed using the Spearman-Rank correlation test. Differences between medians (for colony size) were tested with the use of Mann-Whitney U-tests. I downloaded tidal level measurements (referenced to a local Ordnance Datum) for the years 1989–2008 for a tide gauge station located in the town of Venice (Comune di Venezia 2009). Rates of sea level rise were determined by linear regression of the cumulative sea level increase (i.e., time$_t$-time$_o$) against year. Exceptionally high tides are conventionally defined in Venice as those exceeding 0.80 m above the OD, which is about 23 cm lower than the present sea level (Zanchettin et al. 2007). Expressed in this reference system, the mean elevation of a salt marsh becomes about 0.50 m above sea level, so I assumed that tides exceeding 0.80 m were sufficient to flood all the breeding sites.

Results

During the 20 years of study, the Common Tern breeding numbers ranged between a maximum of 1391 pairs (in 1995) and a minimum of 109 pairs (in 2008; Fig. 2), a significant negative trend (r_s=−0.72; t=−4.48; P<0.01). Fluctuations between −76% and +81% between two consecutive years were observed and the mean variation between any two consecutive years, in absolute value, was 31.1%. Two phases were observed over the 20 year period: 1) from 1989 to 1995, there was no significant change (r_s=0.28; t=0.66; P> 0.05) and 2) from 1996 onwards, the trend became negative (r_s=−0.68; t=−3.04; P<0.01). Over the whole period, the number of breeding pairs decreased at a rate of −10.1% per year and between 1996 and 2008 the decrease was −15.3%.

Over the study period, I found 188 colonies located on 58 breeding sites. The mean size of a colony was 84 ± (1 SE) 6.7 pairs, with a median of 57 pairs. The majority (70.8%) of colonies had <100 pairs, 27.1% were in the range of 101–300 pairs, and 2.1% had >300 pairs. Median colony size decreased significantly over the 20 years (r_s= −0.64; t= −3.55; P<0.01). Among the 58 sites used at least once, 51 (87.9%) were salt marshes, five (8.6%) were hunting blinds, and two (3.4%) were dredge islands. Barrier islands were never used.

Turnover rate averaged 41.5% over the 20 years, and ranged from 7.7% to 60%. Over the entire 20 year span, turnover rate did not vary significantly (Fig. 2; r_s=0.34; t= 1.46; P>0.05), but from 1991 to 1992 onwards, the trend became positive (r_s=0.62; t=3.06; P<0.01). Each year some of the colony sites used by breeding terns had been used the year before as well, whereas other sites were not (but they could have been used two or more years before). I calculated the percentage of pairs that occurred each year in colony sites already occupied the previous year (for the years 1990–2008, since 1989 is the first year of study) and this value ranged between 13.8% (2008) and 90.8% (2001), with a mean of 68.1%. (S.E.=4.36%). This percentage apparently decreased from 1989 to 2008 (N=19; r_s=−0.27; t=−1.156) but the trend was not statistically significant (P>0.05); nevertheless, if we consider only the 2000–2008 years, the decrease becomes significant (N=8; r_s=−0.90; t=−5.2; P<0.01).

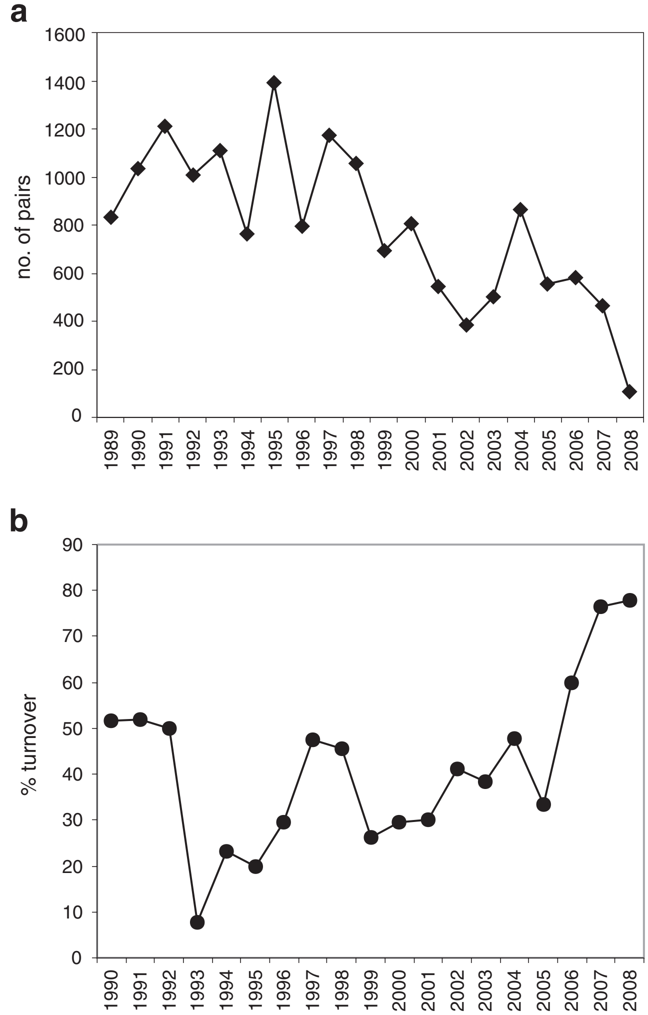

Fig. 2 Number of nests (**a**) counted each year at the Venice lagoon salt marsh colonies and (**b**) turnover rate (%) from 1989/90 until 2007/2008

The number of breeding sites used each year ranged from three to 17, with no detectable temporal trend (r_s= −0.175, t=−0.75, P>0.05). The 58 sites were used on average for 3.2 years, with a minimum of once and a maximum of 17 of 20 years. Overall, 77.6% of the sites were occupied for 1–3 years, 13.8% for 4–9 years, and 8.6% for ≥10 years. Among the 188 colonies surveyed, those occurring at regular sites (used for ≥10 years: N=68; median=100 pairs) were larger than those occurring at occasional sites (used for 1–9 years: N=120; median=40; U=2360.5, Z=4.79, P<0.01). Most (101, 53.7%) colonies were monospecific, whereas the remaining 87 (46.3%) also supported other species of nesting birds.

One possible reason for the observed pattern could be due to the local rise of sea level, which leads to more and more frequent and longer flooding events of the salt marshes. Between 1989 and 2008 the mean sea level in the lagoon of Venice increased considerably, from 0.17 m to 0.28 m, with an estimated mean increase of 0.5 cm/year (Fig. 3). Considering sea level data only for the May–June period, where one may expect the effects on Common Tern colonies are their worst due to the occurrence of eggs and/or chicks, the increase was even higher. Both trends are statistically highly significant (r_s=0.78 and 0.75; t=5.37 and 4.81, P<0.01 in both cases). The number of days with tide levels exceeding 0.80 m in May–June, the peak period for the reproduction, also increased considerably and significantly (r_s=0.51; t=2.55; P<0.05). Between 1989 and 1998 there were on average 4.4 days, and between 1999 and 2008 there were 8.4 days when the tides were above 0.80 m.

Discussion

A twenty-year long (1989–2008) monitoring of breeding Common Tern shows two different trends. Between 1989 and 1996 breeding numbers were stable, with only irregular fluctuations, whereas in the following years breeding numbers decreased significantly. The number of breeding sites used each year and colony size also decreased. Common Terns used salt marshes almost exclusively for nesting, with the use of other sites (such as dredge islands or hunting blinds) being negligible. The lack of use of dredge islands does not match what has been observed elsewhere, particularly in the USA, where dredge islands are an important habitat for terns (Common Terns, Sandwich Terns, Gull-billed Terns (*Gelochelidon nilotica*)

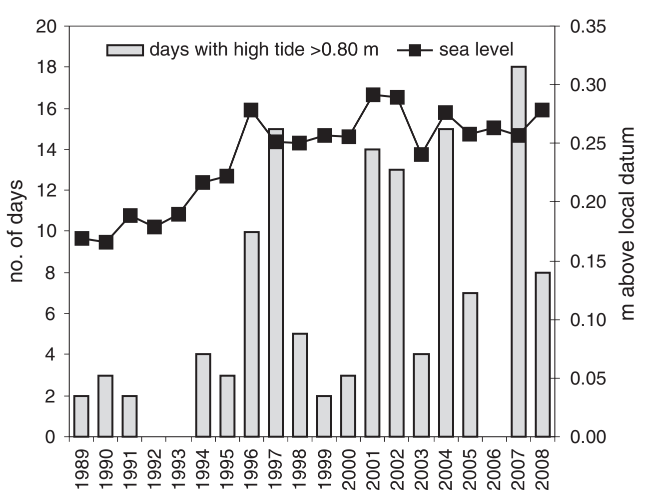

Fig. 3 Mean sea level in Venice (line) and number of days with tides exceeding 0.80 m above sea level in the May–June months (bars)

and Royal Terns (*Sterna maxima*): Erwin et al. 1981; Erwin et al. 2003; Golder et al. 2008).

Breeding parameters such as mean colony size and turnover rate of a purely salt marsh nesting population such as the one nesting in Venice lagoon are almost absent from the literature. Based on the data presented by Burger and Lesser (1979) and Buckley and Buckley (2000), I calculated that their mean colony sizes were 81 pairs and 158 pairs, respectively. Erwin et al. (1981) found that Common Tern colonies nesting in salt marshes had a mean size of between 71 and 100 pairs. The mean size of 84 pairs I found compares well with those results.

According to Burger and Lesser (1979) small size of salt marsh colonies is adaptive to a highly unpredictable habitat, and it was thought to be useful to minimize loss for the whole breeding population when single colonies were lost to due to storms or high tides. The observed decrease in median colony size over my period of study is the possible response of Common Tern to an increasing risk (i.e., very low reproductive success) of breeding in large colonies, likely from sea level rise.

Nevertheless, it is known that smaller colonies are less attractive for colonial breeders compared to large colonies, which are often considered to be of higher quality (Coulson 2002; Martinez-Abrain et al. 2004; Dittmann et al. 2005). According to Dittmann et al. (2005) willingness to desert a site the next breeding season is higher in smaller colonies, and this could lead to the risk of extinction of local populations, as might be happening in the Venice lagoon. Turnover rate at my study area was on average 41.5%, and this is similar to the value observed by Buckley and Buckley (2000) over five years. Alternatively, Erwin et al. (1981) found values ranging between 20% and 44%, over a period of two years. The turnover rate in the Venice lagoon increased significantly from 1992 to 2008. When considering the whole study period, the percentage of breeding terns returning in a given year to a site already used in the previous year decreased significantly from 2000 onwards. Most of these findings lead to the conclusion that Common Terns, before moving elsewhere, tried to find new, suitable places to nest, but these became less available each year.

The abandonment of a breeding site may be the result of unpredictable natural process such as flooding or erosion, reduced prey abundance, increased predation, and disturbance, both anthropogenic and natural (Suryan et al. 2004). In a recent study, Ferla et al. (2007) reported that in the lagoon of Venice between 1994 and 2005 the sea level increased 0.4 cm/year, compared to a mean of 0.2 cm/year over the period 1872–2005. The effects of frequent flooding on salt marshes are complex and depend on a number of factors, such as compaction, decomposition, and growth of above- and below-ground halophyte biomass (Day et al. 1999; Erwin et al. 2006). The effects of a higher flooding frequency could be also responsible for the shift of Little Tern breeders from salt marshes (which hosted the bulk of breeders from 1989 till 2000) to dredge islands in the lagoon of Venice from 1998 onwards (see Scarton 2008). However, this did not happen to the Sandwich Tern, which bred in the lagoon of Venice for the first time in 1995 and, since then, has always nested at one to four salt marsh sites, never using dredge islands or other types of sites (Scarton et al. 2005, pers. obs.). Different species responses to flooding could be related to contrasting patterns of breeding site use. According to Safina et al. (1989), Common Terns are better adapted to salt marsh nesting than other terns, but in the lagoon of Venice they are clearly less able to cope with flooding than Sandwich Terns. Sea level projections for the 21st century in the Venice lagoon are highly controversial, due to local forces (such as subsidence), influence of river discharge in the whole Northern Adriatic Sea, and rain and wind patterns (Ferla et al. 2007; Zanchettin et al. 2007). With a sea level increase similar or higher to that observed over the last 20 years, the future for the salt marsh nesting populations looks extremely uncertain.

No previous papers have presented data for this particular nesting habitat for a period of this length. In terms of conservation, or even recovery, of the breeding population only a few options seem plausible regarding breeding sites: 1) protection of traditional salt marsh sites against erosion using stones, sand bags or wooden piles along the edges, 2) increasing the elevation above sea level of some salt marshes using a thin layer spraying (5–10 cm) of sediments, 3) placing vegetation heaps (made of straw, reed stems, seagrass leaves) at selected salt marsh sites before the breeding season starts, in order to provide terns with suitable nesting places, and 4) using floating rafts at selected sites. Perhaps the existing dredge islands, or those that will be made in the coming years, may become suitable sites, and offer safer breeding from future flooding. In 2009, two large colonies of Common terns settled at dredge islands for the first time, which could indicate the beginning of a shift from natural breeding sites to manmade sites.

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