RELATIVE IMPORTANCE OF ISLAND AVAILABILITY AND TERRESTRIAL PREDATION RISK FOR NESTING HABITAT SELECTION OF COLONIAL CHARADRIIFORMES IN SFAX SALINA (TUNISIA)

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RÉSUMÉ. — *Importance relative de la disponibilité en îlots et du risque de prédation terrestre pour la sélection de l'habitat de nidification des Charadriiformes coloniaux dans le salin de Sfax (Tunisie).* — En zone Méditerranéenne, les salins sont de plus en plus considérés comme un habitat particulièrement important pour la nidification des oiseaux d'eau coloniaux. Toutefois, ces salins manquent le plus souvent d'îlots isolés et inaccessibles aux prédateurs terrestres, ce qui est de nature à exposer les colonies d'oiseaux à une importante pression de prédation, diminuant ainsi leur succès reproducteur. L'importance relative de la disponibilité en îlots inaccessibles et de la pression de prédation terrestre comme clefs possibles dans le processus de sélection des sites de nidification par ces oiseaux a été rarement élucidée. Ainsi, l'objectif de ce travail est d'examiner cette question en utilisant des données sur la nidification de cinq espèces de Laro-limicoles (Avocette élégante, Sterne naine, Sterne pierregarin, Sterne hansel et Goéland railleur) dans le salin de Sfax, l'un des plus importants sites de nidification de ces oiseaux sur la rive sud de la Méditerranée. Ces données ont été recueillies grâce à un suivi des colonies de nidification installées sur un total de 101 sites au cours de deux saisons de reproduction successives (2004 et 2005). Parmi ces sites, 19 correspondent à des îlots complètement isolés, soit le nombre total de sites inaccessibles aux prédateurs terrestres du salin. La très grande majorité des effectifs reproducteurs se sont installés sur des sites accessibles (92,6% et 86,3% des 8277 et des 7844 couples recensés en 2004 et 2005 respectivement). Nos résultats montrent aussi que l'occupation des sites accessibles précède généralement celle des sites inaccessibles et que les caractéristiques physiques sélectionnées par les oiseaux pour le choix de ces sites accessibles varient selon les espèces. Globalement, l'ensemble de nos résultats suggère qu'en absence d'un nombre suffisant d'îlots isolés, les digues, parcourues par les prédateurs terrestres, représentent des pièges écologiques pour les oiseaux d'eau coloniaux nichant dans ce salin. Ces résultats sont enfin utilisés pour proposer un mode de création de sites de nidification attractifs pour les oiseaux.

SUMMARY. — Salinas are highly valued habitats for the conservation of ground-nesting colonial waterbirds in the Mediterranean, yet they often lack islets, preferred breeding habitats for these species. In this paper, we evaluated the relative importance of island availability and terrestrial predation risk for nesting habitat selection of five species of colonial Charadriiformes (Avocet, Little Tern, Common Tern, Gull-billed Tern and Slender-billed Gull) in the Sfax Salina (Tunisia), one of the most important breeding areas of these species along the southern Mediterranean coast. We monitored colony settlement pattern, colony size and colony site features used by the birds in 2004 and 2005. In total, 101 sites were occupied during the two years of study. These occupied sites included 19 isolated islets, which represent the total number of available inaccessible islets in the studied salina. 92.6% of the 8277 breeding pairs counted in 2004 and 86.3% of the 7844 breeding pairs counted in 2005 settled on accessible sites. Our results also show that the occupation of accessible sites began before the occupation of isolated ones. We propose that these accessible sites should be considered as ecological traps resulting from the overall lack of isolated sites. Finally, because dikes are an unlimited habitat for nesting, we identify the environmental cues selected by colonial Charadriiformes within this habitat to develop guidelines for the construction of attractive islets.

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The selection of nesting habitat by colonial waterbirds can be viewed as involving a succession of choices at different spatial scales (Burger, 1985). In the first place, the home range, which comprises several habitats, must meet the energetic needs of parents and offspring. Secondly, the colony site must offer a set of physical traits that facilitate social cohesion and protection from predators and weather conditions (Wittenberger & Hunt, 1985). Lastly, individual birds seek microhabitat conditions for nest location to ensure the survival of eggs and chicks (Parsons, 1982; Burger & Gochfeld, 1990). The high densities of breeding colonial waterbirds make the colonies easy to detect visually, acoustically, and olfactorily by terrestrial predators. It explains why isolation is one of the most important criteria determining the choice of colony site (Greer *et al.*, 1988; Clode, 1993; Borboroglu & Yoro, 2004).

Habitat is selected using environmental cues expected to correlate with site quality and future reproductive success. With no constraints and an unlimited choice, individuals should select the best sites, *i.e.* where their fitness is maximized (Fretwell & Lucas, 1970). However, a site may be selected from a limited choice (Partridge, 1978) or be influenced by misleading environmental cues that result in the selection of an ecological trap (Gilroy & Sutherland, 2007). Under such conditions, habitat selection differs from habitat preference and the habitat ultimately selected may not be optimal (Robertson & Hutto, 2006).

Salinas are highly valued habitats for the conservation of colonial waterbirds in the Mediterranean region (Sadoul *et al.*, 1998). However, they are often artificial coastal wetlands in which islets, often the preferred habitat of ground-nesting colonial waterbirds, are lacking. Under such conditions the breeding pairs are likely to be constrained to use sites that are accessible to terrestrial predators, which may increase predation risk against their nests. Even though the construction of artificial islets may seem an effective management response to this constraint, this requires a good understanding of the processes involved in the choice of breeding site by the birds in such habitats. In this paper, we evaluate the extent to which salina habitat offers good quality breeding sites for colonial waterbirds in the Sfax salina (Tunisia), one of the largest breeding areas for gulls, terns and waders in the southern Mediterranean coastal region (Chokri *et al.*, 2008). Observing the presence on the salina of numerous stray dogs (*Canis lupus familiaris*) led us to develop a study evaluating the role of terrestrial predation in site selection by colonial birds.

Our primary objective was to determine the distribution of breeding pair numbers among sites that were accessible or isolated to terrestrial predators. Three hypotheses may be advanced:

1) All birds settle in isolated sites: in that case, the islets may be regarded as a non-limiting resource in the salina and the selected habitat corresponds to the preferred habitat. The construction of artificial islets would therefore be pointless on the assumption that reproductive success of colonies is good.

2) A significant proportion of the breeders concentrates on accessible sites. The other proportion settles on isolated islets, many of them remaining unused. Breeders are thus possibly attracted by environmental cues that trap them in sites with low breeding success expectation. Mimicking these cues on artificial islands may divert breeders from these ecological traps.

3) Isolated islets are fully occupied and only late-arriving breeders settle on accessible sites. Isolated sites are then a limited resource forcing birds to use accessible, suboptimal sites. The construction of artificial islets would therefore be useful.

The preference for isolated sites may vary with the sensitivity of the species to terrestrial predation; the most sensitive species giving priority to the most isolated sites.

In a second step, we identified the environmental characteristics, apart from remoteness, selected by the birds to establish their colonies. These should provide guidance for building or restoration of artificial islets so that they would mimic preferred breeding habitats. For this analysis, we restrained our dataset to the less limiting nesting habitat (*i.e.* the dikes). We then assumed that colony size was positively correlated with the attractiveness of the selected characteristics.

METHODS

STUDY AREA AND SPECIES

The Sfax salina (Tunisia) comprises 1600 ha of sub-urban salt pans located at the northern end of the gulf of Gabes (34° 39'N, 10° 42'E) along the eastern Mediterranean coast. The Sfax salina has been designated as a RAMSAR site since 2007. Seven species of colonial gulls, terns and waders breed in the Sfax salina. They represent a functional unit and frequently form multispecific colonies that reflect selection of the same environmental factors. In 2004 and 2005, we monitored the breeding pair numbers of Avocet *Recurvirostra avosetta*, Little Tern *Sternula albifrons*, Common Tern *Sternula hirundo*, Gull-billed Tern *Gelochelidon nilotica* and Slender-billed Gull *Chroicocephalus genei*. Yellow-legged Gull *Larus michahellis* and Black-winged Stilt *Himantopus himantopus* have not been included in this study because of the small number of colonies in the case of the former and the highly scattered distribution of small colonies for the latter.

DATA COLLECTION

During the 2004 and 2005 breeding seasons, colony sites of the studied species were identified and located on maps prepared using ARCGIS 8.0 software. Clusters of nests in different islets and dikes situated at least 100 m apart were considered as separate colonies. Each year the number of breeding pairs in each colony was checked weekly. The maximum number recorded each year on a given site was considered as the colony size for that species-site combination.

We measured a set of quantitative and qualitative variables reflecting the typology of colony sites. Water depth around the islets was measured weekly by means of graduated rods placed near the islets. However, because the other variables are not likely to vary during the breeding season, they were thus measured once the sites had been abandoned by the colonies in order to avoid disturbance during reproduction. These variables are as follows:

– *Isolation*: The salina is not a remote area and all nesting sites are accessible to avian predators. However, the Yellow-legged Gull, the only aerial predator in the area, is relatively few in numbers (127 pairs) and mainly feeds in the waste dump located only a few metres outside the salina. In the contrary, terrestrial mammalian predators occur constantly in the area. They are primarily stray dogs coming from the nearby city, and occasionally foxes (*Vulpes vulpes*), and cats (*Felis silvestris*). The two factors governing islet accessibility to terrestrial predators are water-depth, *i.e.* the maximum depth that a predator has to cross to reach the islet, and distance from mainland, *i.e.* distance from the nearest dike in the salina (Burger & Lesser, 1978; Goutner, 1997; Hoover, 2006). Because it varied little within a given basin, the average water depth (cm) measured during the breeding season was used for each islet in that basin. The distance to the nearest dike was measured in metres using a double decametre for the smallest ones and with ArcView for the larger ones. For colony sites situated on dikes, the water depth and distance from the dike were zero. Other factors may affect the accessibility of islets considerably. The bottom of some basins is extremely muddy and greatly limits access when the water depth does not allow predators to swim. Similarly, when salinity is over 150 g/l, the bottom of the basins is covered with a thick layer of calcium sulphate, the crystals of which form sharp edges that may deter terrestrial predators. High salinity of the brines may also restrict the access of predators owing to the formation of salt crystals on their fur. Since the isolation of the sites depends on a number of factors, analyses were also performed regarding two site categories: accessible sites include all those on dikes and all islets on which the presence of terrestrial predators was directly observed during the weekly monitoring or was detected by their tracks; isolated sites are islets on which the presence of terrestrial predators was never observed or detected. We are aware that the fact that dog footprints were not recorded on a given site could not necessary mean that dogs have never visited that site and preyed on colonies established there. However, we believe that sites with no recorded dog footprints are likely to be less frequently visited by dogs and their nests suffered lower predation pressures than those where dog footprints were abundant.

– *Distance to the city suburbs edge*: Terrestrial predation reduces breeding numbers in some ground-nesting waterbirds (Cote & Sutherland, 1997; Newton, 1998; Nordström *et al.*, 2003). In the Sfax salina stray dogs, the main terrestrial predators, came from the suburbs area bordering the west side of the salina. We thus predict that the proximity of the suburbs edge to the salina may affect negatively colony size. For each site the distance to the suburbs edge was calculated from a digitalized aerial photograph (1997) using ARCVIEW software.

– *Salinity*: In addition to its potential contribution to the isolation of a colony site, saltpan salinity may affect food supply, in particular invertebrates and fish (Britton & Johnson, 1987; Toumi *et al.*, 2005). As within a particular lagoon salinity is constant throughout the year we used values provided by the Tunisian Salt Company (COTUSAL).

– *Surface area*: The available surface area is a major factor that partly determines the size of waterbird colonies (Ainley *et al.*, 1995). Islets surface area were measured in the field on the basis of maximum length and maximum width and the shape of the islet or using ARCGIS for particularly long or wide islet or those presenting an irregular shape. The surface areas of the colony sites on the dikes were calculated from the total area of the dike between two intersections. No colony was established at the intersection of two or more dikes. Surface areas are expressed in square metres.

– *Vegetation*: Vegetation preferences vary according to the particular needs of each species (Greer *et al.*, 1988). Some species search for protection against extreme heat (Slazman, 1982; With & Webb, 1993; Kim & Monaghan, 2005), predation (Burger & Shisler, 1978; Parsons, 1982; Parsons & Chao, 1983; Burger, 1985; Saliva & Burger, 1989; Good, 2002), parasitism (Miyazaki, 1996) and against intraspecific interferences (Bukacinska & Bukacinski, 1993) whereas others seek bare areas in order to detect predators (Burger & Gochfeld, 1981; Parsons, 1982; Burger & Gochfeld, 1988; Götmark *et al.*, 1995). On each site the percentage of cover was calculated with ARCGIS using the most recent aerial photographs (1997), corrected by direct observation in the field. Vegetation cover ranged from zero (absence of vegetation) to 100% (full coverage).

Several variables (substratum type, vegetation height and floristic composition of the vegetation cover) which varied little between sites were not taken into account in the analyses. Also because the distance to the sea was <1.8 km, it is not a limiting foraging distance for the species we studied (Fasola & Bogliani, 1990). The average elevation of the colony site above water ranges from about 20 cm to one metre. However, water-level in the salina does not vary a lot and all sites remain entirely above water whatever the wind conditions. These two latter variables were therefore also excluded from the analyses.

Finally, the vulnerability of the various species to terrestrial predation was estimated by the time they spend on the colony site during the breeding season. Thus, with incubation periods of 22 and 24 days respectively and precocial chicks that form crèches in one case or that accompany their parents on the feeding grounds in the other (Cramp & Simmons, 1983), Slender-billed Gull and Avocet were regarded as the two least vulnerable species. On the other hand, Common Tern and Gull-billed Tern, with a similar incubation period but necessarily raising their chicks on the colony site for nearly one month, were considered the most predation-sensitive species. The vulnerability of the Little Tern, which displays the same nesting strategy but with shorter incubation and rearing periods and at a frequently lower density, was regarded as intermediate.

DATA ANALYSIS

We used Mann-Whitney U-test to compare environmental variables (water depth, distance to the nearest dike, surface area, vegetation, edge slope, salinity) between accessible and isolated nesting sites. We also used linear multiple regression analyses to explain colony size variation in relation to the typology of colonies located on the dikes (distance to the edge, vegetation cover surface area, and salinity for Avocet). These analyses could not be carried out for the Slender-billed Gull and the Gull-billed Tern owing to the small number of sites occupied during the two years. Because of their great variation, vegetation cover and salinity, were considered as categorical variables, with two classes for the first variable (vegetated *vs* non-vegetated) and three classes for the second one ([40 g/l to 80 g/l], [81-120 g/l] and >120 g/l). Salinity was tested uniquely for Avocet which feeds just near colony site unlike the remaining species that can reach 20 km far from the colony site for feeding (Cramp & Simmons, 1983). Prior to the regression analyses, all continuous variables were checked for normality using Shapiro-Wilk test. When the normality assumption was not met log(x) and log(x+1) transformations were used. In a first step we considered a full model including the interactions between the different explanatory variables, but as these interactions were not significant they were removed and the analyses were rerun. All analyses and tests were carried out using SAS software (SAS, 1998).

RESULTS

DISTRIBUTION OF BREEDING PAIRS IN TERMS OF SITE ACCESSIBILITY

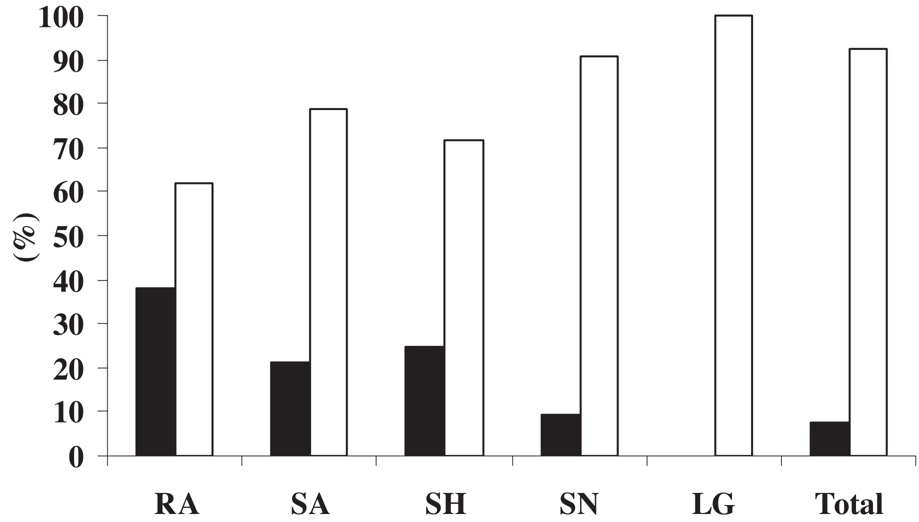
During the first year of the study, we recorded a total of 44 colonies of Avocet (923 pairs), 35 colonies of Little Tern (327 pairs), 43 colonies of Common Tern (712 pairs), 5 colonies of Gull-billed Tern (140 pairs) and 5 colonies of Slender-billed Gull (6175 pairs). During the second year, there were 44 colonies of Avocet (838 pairs), 43 colonies of Little Tern (380 pairs), 48 colonies of Common Tern (730 pairs), 9 colonies of Gull-billed Tern (262 pairs) and 10 colonies of Slender-billed Gull (5634 pairs). These colonies were settled over a total of 101 different sites. Of these sites, 61 were dikes and 40 were islets. Of the latter, only 19 did not show any indices of visit by terrestrial predators. Hence, 82 of the 101 sites were regarded as accessible and 19 as isolated. All except two islets of the salina were occupied: one rocky outcrop islet used as a roost by Yellow-legged Gulls and a very small islet entirely covered by dense vegetation. The accessible islets had lower water levels and were closer to the dikes than isolated islets (Tab. I). The characteristics of accessible islets are consistent with our predator tracks survey.

TABLE I

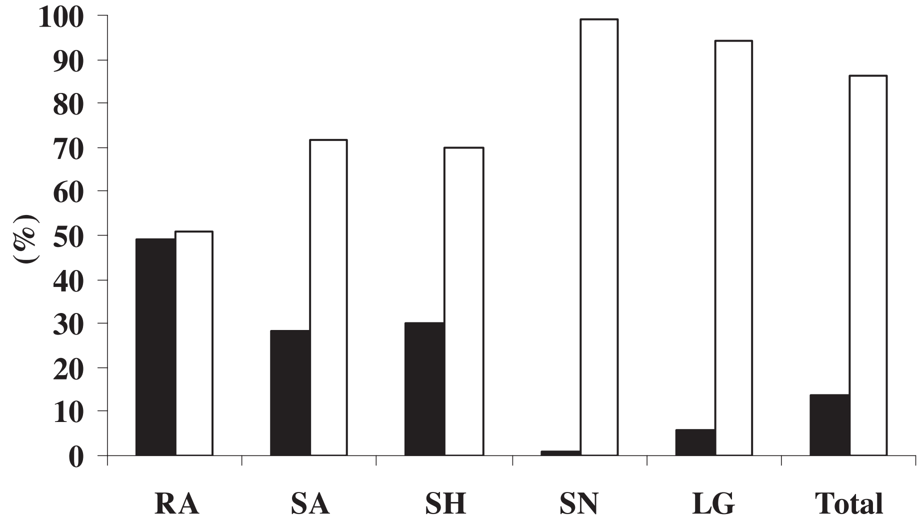
Average distance from the dike and minimum water depth around accessible and isolated islets occupied by colonial Charadriiformes in 2004 and 2005, and results of the Mann-Whitney test

	Isolated islets	Accessible islets	*U*	*Z*	*P*
Number of islets	19	21			
Distance from dike (m)	17.7	9.7	110	-2.42	0.014
Water Depth (cm)	62.1	16.3	41	-4.29	0.000004

For all species, the number of breeding pairs was higher on accessible sites. Among the 8277 and 7846 pairs of colonial waterbirds breeding in 2004 and 2005 in the salina, 92.6% and 86.4% settled on accessible sites respectively for each year of the study. However, the species were distributed differently between accessible and isolated sites (Fig. 1) with Gull-billed



2004



2005

Figure 1. — Frequency distribution (number of pairs,%) of the different species on isolated (grey column) and accessible sites (white column) (RA: Pied Avocet; SA: Little Tern; SH: Common Tern; SN: Gull-billed Tern; LG: Slender-billed Gull).

Terns and Slender-billed Gulls breeding almost exclusively on accessible sites, and over 70% of the Common Terns and Little Terns on accessible sites. Avocets had the most balanced distribution between accessible and isolated sites.

The number of colonies established on accessible sites was, for all species, much higher than the number on isolated sites (Tab. II). In addition, mean colony size of Slender-billed Gulls and Gull-billed Terns was also higher on accessible sites than on isolated ones. Mean colony size did not differ however for Common Terns ($U = 171$, $P = 0.68$ in 2004; $U = 210$, $P = 0.4$ in 2005) and for Little Terns ($U = 91.5$, $P = 0.51$ in 2004; $U = 148$, $P = 0.62$ in 2005). In contrast, colony size was as much as three times higher on isolated versus accessible sites for Avocets ($U = 58.5$, $P = 0.009$ in 2004; $U = 40$, $P = 0.001$ in 2005).

TABLE II

Average colony size ±SE and number of colonies (into brackets) on isolated and on accessible sites in 2004 and in 2005

	2004		2005	
	Isolated sites	Accessible sites	Isolated sites	Accessible sites
Pied Avocet	44 ± 9.6 (8)	16 ± 7 (36)	51 ± 17.5 (8)	12 ± 3 (36)
Little Tern	9 ± 2.3 (8)	10 ± 2.9 (27)	10 ± 3.2 (10)	8 ± 1.8 (33)
Common Tern	15 ± 3.9 (12)	17 ± 4.6 (31)	15 ± 2.6 (15)	15 ± 4.4 (33)
Gull-billed Tern	13 (1)	32 ± 10.4 (4)	1 ± 0 (2)	37 ± 14.1 (7)
Slender-billed Gull	0 (0)	1235 ± 935.7(5)	166 (2)	663 ± 336.5 (8)

Although the salina appears to have a limited number of isolated sites, they are not colonized first during the season. Sites used by Avocets during the first week were isolated (Fig. 2) while from the second week onwards they settled on both types of sites simultaneously. Consequently the occupation of accessible sites did not result from the saturation of isolated ones. For the other species, the situation was even clearer since the accessible sites were the first to be occupied and numbers grew much more rapidly than on isolated sites. The vulnerability of the species to terrestrial predation seems to have little influence on the distribution of bird numbers and the timing of settlement between accessible and isolated sites.

TYPOLOGICAL COMPARISONS BETWEEN ISOLATED AND ACCESSIBLE SITES

The surface area of accessible sites used by all the species, except for Little Tern in 2005, was almost similar to that of the isolated sites (Tab. III). The water surrounding the isolated sites was fresher than around the accessible ones. This indicates that isolated islets were more likely to be located in the first basins of saltpans directly connected to the seawater entrance. The difference, however, was only significant for sites occupied by Avocets and Common Terns (Tab. III). The vegetation cover of isolated sites appeared to be greater, but not significantly so. Lastly, distance to the salina-suburbs edge of isolated sites, except only for Avocet the earliest species, was similar to that of accessible sites (Tab. III).

ENVIRONMENTAL CUES FOR COLONY SITE SELECTION ON DIKES

About one third of the 250 dikes of the salina (the dikes forming the outer boundary of the salina were not counted) were occupied by waterbird colonies in 2004 and 2005. It is thus a reasonable assumption to consider that the dikes, unlike the islets, do not constitute a limited resource and that the birds select the ones they prefer.

Avocet: Some 26 and 25 colonies were established on dikes in 2004 and in 2005 respectively. Multiple regressions analysis suggests that the characteristics of the dikes explained 40% and 51% of colony size variation in 2004 and 2005 respectively (2004: $F_{5,20} = 2.64$, $r^2 =$

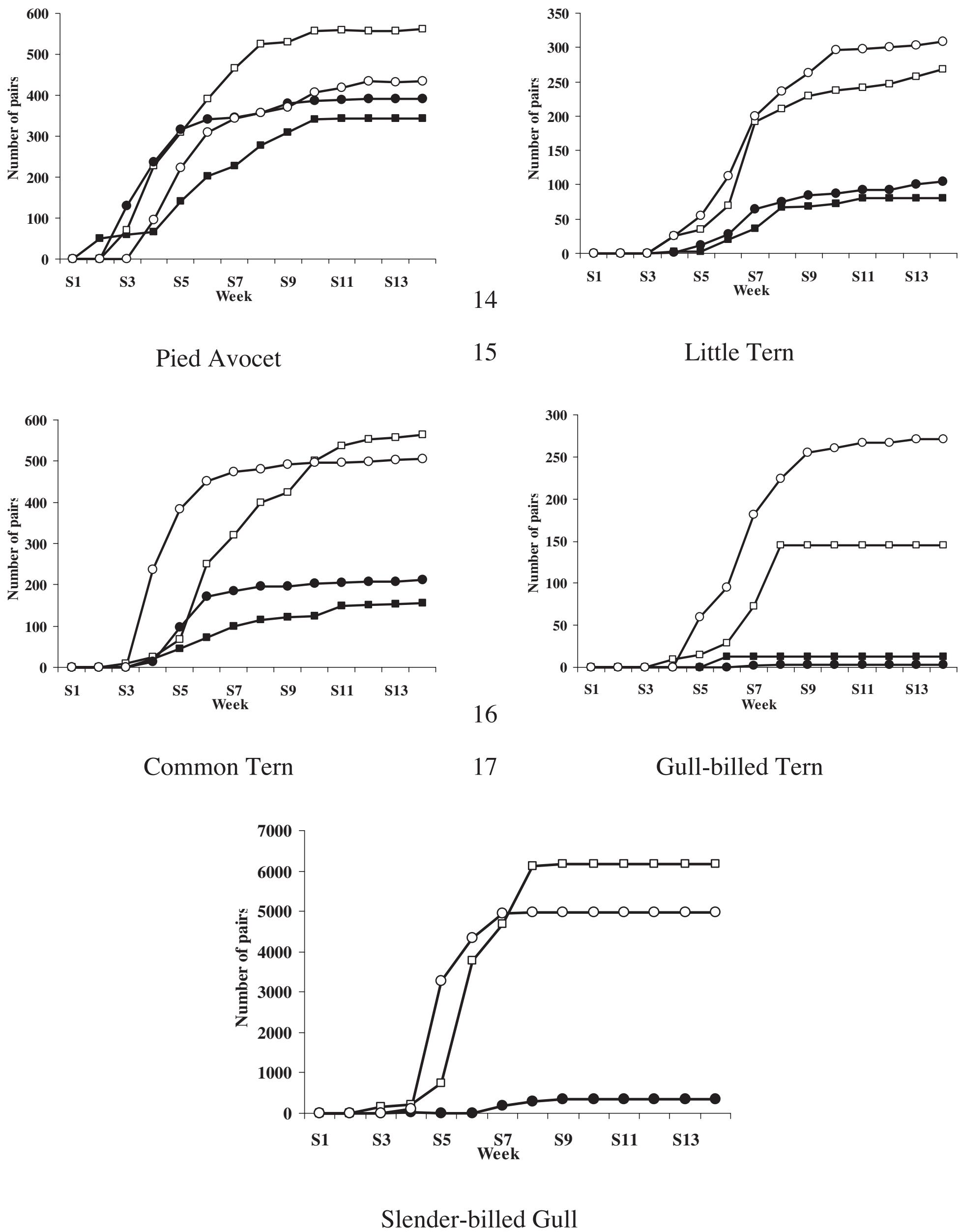


Figure 2. — Sequence over time of cumulative numbers of nesting pairs settled on accessible (open circles and squares) and isolated sites (black circles and squares) in 2004 (squares) and in 2005 (circles).

0.40, $p = 0.05$; 2005: $F_{5,19} = 4.02$, $r^2 = 0.51$, $p = 0.01$). Salinity was the only variable affecting colony size in both years but was significant only in 2004 (Tab. IV). Colony size was medium at 40-80 g/l, large at 80-120 g/l and small when salinity exceeds 120 g/l (Fig. 3).

Little Tern: Twenty three and thirty colonies established on dikes in 2004 and 2005, respectively. Dikes characteristics explained 47% and 54% of colony size variation in 2004 and 2005

TABLE III

Average surface area, slope, vegetation cover and salinity of isolated and accessible sites occupied by each species and Mann-Whitney U-test results in 2004 and in 2005. N = number of sites

	2004			2005		
	Isolated	Accessible	*P*	Isolated	Accessible	*P*
PIED AVOCET	N = 8	N = 36		N = 8	N = 36	
Surface area (m^2)	10122.3	6939	0.77	9799.1	6945	0.54
Distance to edge (m)	1315	585.8	0.03	1052.5	665.1	0.21
Vegetation (%)	34.5	25.6	0.84	25.3	31.7	0.34
Salinity (g/l)	74.2	106.8	0.007	83.5	111.2	0.07
LITTLE TERN	N = 8	N = 27		N = 10	N = 33	
Surface area (m^2)	7247.6	9698.7	0.10	5575.5	8958.1	0.05
Distance to edge (m)	1315	999.4	0.34	997	1078.9	0.16
Vegetation (%)	44.7	25.4	0.26	35.8	35	0.68
Salinity (g/l)	74.2	77.2	0.65	82	85.7	0.98
COMMON TERN	N = 12	N = 31		N = 15	N = 33	
Surface area (m^2)	4760.3	6358.1	0.94	3913.6	3609.2	0.53
Distance to edge (m)	1333.4	1082.6	0.37	1223	973	0.38
Vegetation (%)	41	38.9	0.88	43.6	39.1	1.0
Salinity (g/l)	76.1	157	0.02	80.4	164.7	0.003
GULL-BILLED TERN	N = 1	N = 4		N = 2	N = 7	
Surface area (m^2)	798	2169.2		1449	3718.8	
Distance to edge (m)	1600	1482.2		1600	1197.8	
Vegetation (%)	85	60		82.5	52.1	
Salinity (g/l)	70	179.75		70	201.1	
SLENDER-BILLED GULL	N = 0	N = 5		N = 2	N = 8	
Surface area (m^2)		2140.4		1449	3654.8	
Distance to edge (m)		1555.8		1600	1440.25	
Vegetation (%)		53		82.5	44.2	
Salinity (g/l)		151.8		70	157.5	

respectively (2004: $F_{3,19} = 5.71$, $r^2 = 0.47$, p = 0.006; 2005: $F_{3,26} = 10.39$, $r^2 = 0.54$, p = 0.0001). Colony size increased with dike surface area and distance to edge of salina (Fig. 4 & 5).

Common Tern: Twenty colonies settled on dikes in 2004 and 2005. Dike characteristics explained significantly 79% of colony size variation only in 2005 ($F_{3,16} = 20.07$, $r^2 = 0.79$, p = 0.001). During the latest year all variables affected significantly colony size (Tab. IV). The largest colonies were found on dikes far from the edge (Fig. 6), devoid of vegetation and with high surface area. In 2005, 15 among the 20 colonies occupied dikes with no vegetation.

Gull-billed Tern and Slender-billed Gull: Nine of the 15 Gull-billed Tern colonies and 11 of the 16 Slender-billed Gull colonies were established on dikes. The dikes occupied by these two species were of very similar typology and were relatively small, from 784 to 2771 m^2. A single site that sheltered three pairs of Slender-billed Gull and 11 pairs of Gull-billed Tern had a surface area of 15 314 m^2. For each species, vegetation was only present on two dikes. The high salinity and steep slopes due to the height of the dikes is explained by the fact that most of the birds nested on the salt harvesting area.

TABLE IV

Results of the regression analysis of colony size (log-transformed) of Pied Avocet, Little Tern and common Tern as functions of breeding site area (log-transformed), vegetation cover, distance to the suburbs-edge (log-transformed) and salinity in 2004 and in 2005

	Effect	DF	SS	F-value	*P*
PIED AVOCET	2004 (r^2 = 40.7%, $F_{5,20}$ = 5.20; P = 0.05)				
	Vegetation cover	1	0.104	0.08	0.779
	Surface area	1	0.812	0.63	0.437
	Distance to edge	1	0.057	1.59	0.222
	Salinity	2	7.199	5.56	0.012
	2005 (r^2 = 51.4%, $F_{5,19}$ = 4.02; P = 0.01)				
	Vegetation cover	1	2.429	2.23	0.152
	Surface area	1	3.974	3.64	0.071
	Distance to edge	1	0.616	0.56	0.461
	Salinity	2	6.675	3.06	0.070
LITTLE TERN	2004 (r^2 = 47.4%, $F_{3,19}$ = 5.71; P = 0.006)				
	Vegetation cover	1	0.002	0	0.958
	Surface area	1	6.399	8.46	0.009
	Distance to edge	1	3.992	5.28	0.033
	2005 (r^2 = 54.5%, $F_{3,26}$ = 10.39; P < 0.001)				
	Vegetation cover	1	1.671	3.30	0.081
	Surface area	1	3.017	5.96	0.022
	Distance to edge	1	12.00	15.58	0.0001
COMMON TERN	2004 (r^2 = 27.1%, $F_{3,16}$ = 1.99; P = 0.15)				
	Vegetation cover	1	0.082	0.07	0.800
	Surface area	1	2.168	1.75	0.204
	Distance to edge	1	4.440	3.59	0.076
	2005 (r^2 = 79%, $F_{3,16}$ = 20.07; P < 0.001)				
	Vegetation cover	1	16.756	28.18	<0.0001
	Surface area	1	0.152	0.26	0.022
	Distance to edge	1	18.953	31.87	<0.0001

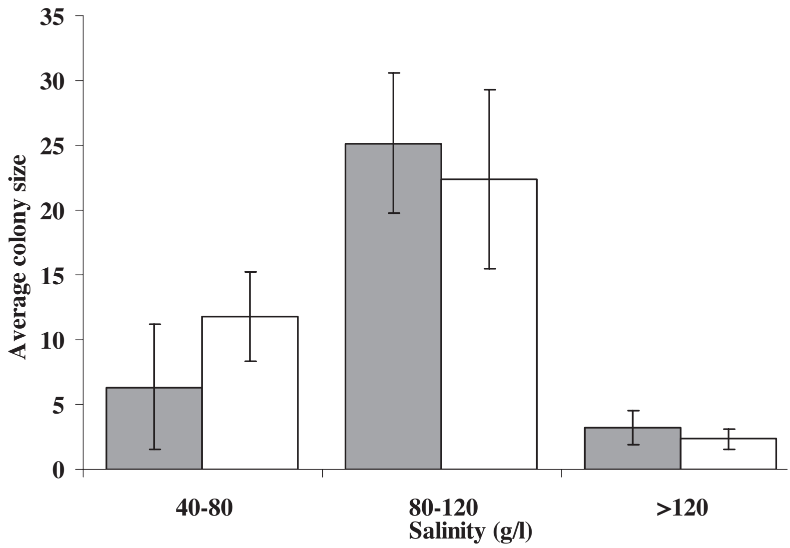


Figure 3. — Variation of Pied Avocet colony size on the dikes in relation to salinity (g/l) in 2004 (grey, $F_{5,20}$ = 2.64, r^2 = 0.40, P = 0.05) and in 2005 (white, $F_{5,19}$ = 4.02, r^2 = 0.52, P = 0.01).

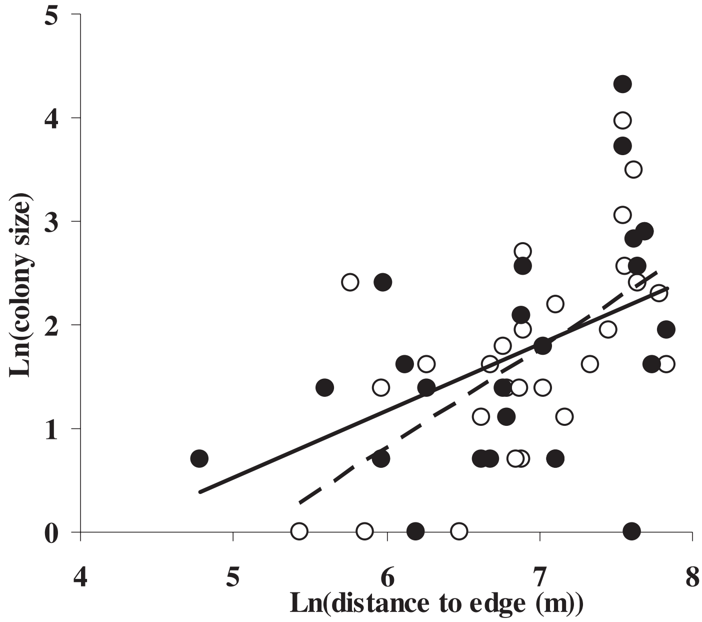


Figure 4. — Variation of Little Tern colony size on the dikes in relation to the distance to the edge in 2004 (filled circles and solid line, $F_{3,19} = 5.71$, $r^2 = 0.47$, $P = 0.006$) and in 2005 (hollow circles and dashed line, $F_{3,26} = 10.39$, $r^2 = 0.54$, $P = 0.0001$).

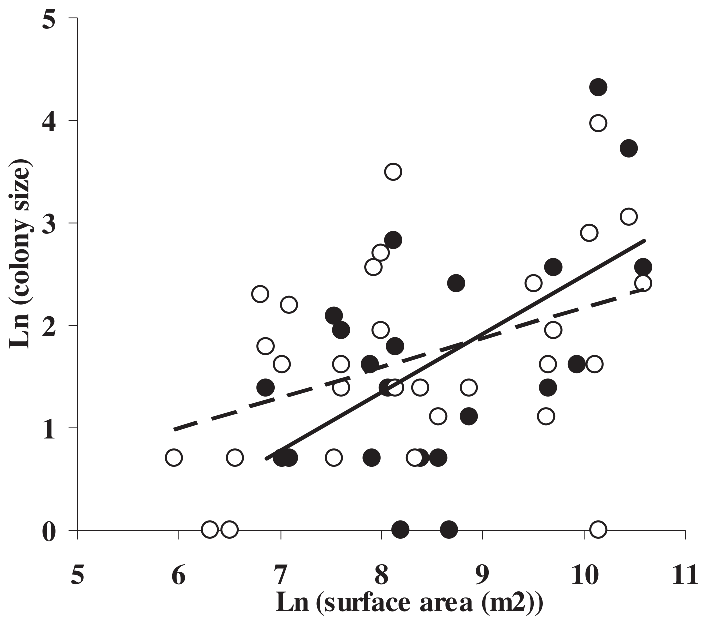


Figure 5. — Variation of Little Tern colony size on the dikes in relation to surface area in 2004 (filled circles and solid line, $F_{3,16} = 1.99$, $r^2 = 0.27$, $P = 0.15$) and in 2005 (hollow circles and dashed line, $F_{3,16} = 20.07$, $r^2 = 0.79$, $P = 0.001$).

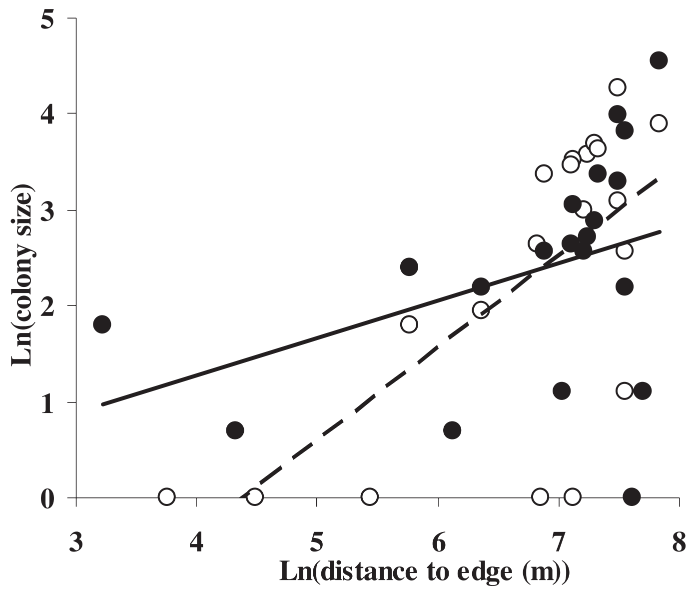


Figure 6. — Variation of Common Tern colony size on the dikes in relation to the distance to the edge in 2004 (filled circles and solid line, $F_{3,16}$ = 1.99, r^2 = 0.27, P = 0.15) and in 2005 (hollow circles and dashed line, $F_{3,16}$ = 20.07, r^2 = 0.79, P = 0.001).

DISCUSSION

Inaccessibility to predators is one of the main criteria for the selection of nesting sites by colonial birds (Wittenberg & Hunt, 1985; Siegel-Causey & Kharitonov, 1990; Brown & Brown, 2001). Thus ground-nesting gulls, terns and waders often seek isolated islets (Burger & Lesser, 1978; Buckley & Buckley, 1982; Burger & Gochfeld, 1981; Fasola & Bogliani, 1984; Goutner, 1990; Valle & Scarton 1999; Borboroglu & Yoro, 2004; Hall & Kress, 2004). The great majority of the available islets of the Sfax salina were occupied by colonies but accounted for only a third of colony of all species and for 67% of the breeding pairs during the two years covered by the study. However, at least 50% of these islets were visited at least once during the breeding season by terrestrial predators. These accessible islets are distinguishable from more isolated sites by water-depth and distance from the nearest dike, decisive factors to permit site remoteness (Hartman & Eastman, 1999; Nordström & Korpimaki, 2004; Hoover, 2006). In the Sfax salina, only 7.4 and 13.6% of the breeding pairs colonized isolated islets in 2004 and 2005 respectively. Our first hypothesis is thus rejected. In the Camargue (delta of the Rhône river in Southern France), Sadoul (1996, 1997) also shows a shortage of isolated sites: the great majority of colonial waterbirds establish their colonies on dikes and consecutively suffer from heavy predation and disturbance and with high rates of breeding failure. In such conditions, the selection of accessible sites cannot be an optimal choice. The presence of numerous dogs wandering in the Sfax salina explains the lower breeding success observed on accessible sites compared to inaccessible ones (Chokri, 2008). Related works carried out in the Sfax salina have also shown that wandering dogs constitute the main cause of breeding failure of the great majority of colonial waterbirds (Chokri & Selimi, 2011a, 2011b). For instance, in Pied Avocet colonies, Chokri & Selmi (2011a) have found that the terrestrial predation accounts for 68% of nest failure on dikes and for 39% of nest failure on isolated islets. Unfortunately, quantitative data on dog activity have not been collected, but some field observations let us believe that dogs were actually more active on accessible sites than on isolated islets. However, we are aware that these observations, as well as the results of this study, do not allow us to accurately determine the relationship between site accessibility and nest predation rate.

According to Robertson and Hutto (2006), behavioural traits such as settlement pattern constitute an accurate way to infer habitat preferences. The timing of colony settlement during the season at Sfax appears independent of the accessibility of sites to terrestrial predators. Although the colonies of the earliest-nesting species, the Avocet, establish earlier and become larger on isolated sites, occupation of the accessible sites begins before saturation of the isolated sites and proceeds faster. The pattern for the other species is even more distinct, with accessible sites occupied early in the season. Similarly, the sensitiveness of the species to terrestrial predation does not affect the timing of colony settlement. The Avocet, which, together with the Slender-billed Gull, spends the shortest time on colony site, and should thus be the least sensitive to terrestrial predation, is the species which concentrated most on isolated sites (earlier colony establishment, larger colony, and higher numbers). In contrast, the great majority of Slender-billed Gulls, like the other species, seemed more sensitive to predation, settled and nested on accessible sites early in the season. Consequently, accessible sites appear equally or more attractive than isolated sites and may be considered at first glance as "ecological traps" instead of sink habitat (hypothesis 2).

However, the concept of ecological trap requires that individuals choose suboptimal habitats while suitable habitats are widely available (Gilroy & Sutherland, 2007). In the Sfax salina, isolated islets are a very limited resource fully occupied by birds. Thus the selection of accessible habitat appears to be constrained by this limitation. Therefore, rather than opposing our two hypotheses, *i.e.* birds first colonize trap habitat and a significant number of good sites remain unused (hypothesis 2) *versus* birds colonize sink habitat after the good sites have been fully occupied (hypothesis 3), we suggest that the concept of ecological trap could apply when good habitats are a very limited resource. In this case, birds broaden their selection criteria to encompass poorer quality habitats.

Finally, the concept of ecological trap requires also that habitat selection is guided by misleading environmental cues of habitat quality (Robertson & Hutto, 2006). In our case, three other factors may affect habitat selection: a territorial behaviour of exclusion on isolated islets, attraction to founding individuals, and a philopatric preference for the birth site. Competition for space and the aggressive behaviour of the first-arrived or dominant birds may induce later arrivals to settle on sites of lesser quality (Sherry & Holmes, 1988). It appears, however, rather unlikely that the Avocet is responsible for actively driving out other species. Firstly, only 8 out of the 20 isolated sites available were colonized by this species during the two years of the study. Secondly, Avocets often joined other gulls, terns and waders to form mixed colonies (Sadoul, 1996) and was never observed to behave aggressively toward other species. The social attraction represented by the first arrivals, founders of the new colony, could lead the majority of birds to settle on sites of lesser quality (Kharitonov & Siegel-Causey, 1988) but cannot explain the choice of the founding individuals. Lastly, philopatry might also lead to an over-representation of birds on accessible sites; however this does not seem to apply to long-lived birds (Kokko & Sutherland, 2001) such as gulls, terns and waders. They show a highly flexible behavior and generally, low site fidelity (Erwin *et al.*, 1998). Therefore the idea that colonial Charadriiformes which first settle on these sites are guided by misleading environmental cues becomes the most likely explanation.

Numerous environmental cues are taken into account by the birds in habitat selection (Cody, 1985). The identification of such cues is only possible when the resource is not limited, *i.e.* when the birds are able to make a choice among multiple possibilities, as in the case of the dikes of the Sfax salina. Identifying dike characteristics also appears relevant to promote the settlement of colonies on attractive sites.

In the first place, the choice of nesting site is governed by the need to find in the surrounding area a sufficient food supply nearby (Burger, 1985). Avocets which feed in the immediate neighbourhood of the colonies (del Hoyo *et al.*, 1996) are constrained by the distance between nesting and foraging areas. The relation between salinity and colony size for this species is inferred from the food availability near the colony site. Salinity, which ranges from about 40 g/l to > 300 g/l in salinas, is the main factor governing the structure of the invertebrate communities (Britton & Johnson, 1987; Toumi *et al.*, 2005). Although the invertebrate richness also declines up to a salinity of 70 g/l, owing to the precipitation of carbonates, it remains relatively stable up to 120-150 g/l, the threshold at which calcium sulphates precipitate (Toumi *et al.*, 2005). Here the biomass appears to be higher, undoubtedly owing to the absence of aquatic invertebrate predators (Britton & Johnson, 1987). At this salinity, Avocets finds their preferred prey, brine shrimp and brine flies, in abundance and establish their largest colonies. The Sfax salina appears as a wetland 15 km long along the sea coast and 1.8 km wide. Then, according to Fasola & Bogliani (1990), no matter where the colonies are located the salina does not seem large enough to limit access to the feeding areas of the other species feeding in the salina or at sea. Lastly, Gull-billed Terns prefer to feed outside the salina, on insects and even small vertebrates in terrestrial habitats (del Hoyo *et al.*, 1996).

Colony size seems to increase with the distance to the city suburbs edge, which suggests that the breeding pairs avoid settling on dikes frequented by wandering dogs. It reinforces the hypothesis that terrestrial predation reduces breeding numbers in some ground-nesting waterbirds (Cote & Sutherland, 1997; Newton, 1998; Nordström *et al.*, 2003). In Sfax salina, Stray dogs, were often observed predating on bird eggs and chicks. Therefore the installation of breeding pairs far from the suburbs edges possibly reduces predation risk (Chokri & Selmi 2011b).

By means of a simple model, Siegel-Causey & Kharitonov (1990) showed that a loose colony settled on a large surface area accessible to predators such as canids suffers lower nest predation. In the Least Tern *Sterna antillarum*, nest predation decreases as the colonies become larger (Brunton, 1999). Among the species studied, Little Terns generally breed at very low density (Goutner & Kattoulas, 1984; Goutner, 1990). It is therefore not surprising that the colony size of Little Terns increases with the surface area of the nesting site in the Sfax salina. Large and loosely structured colonies settled on dikes (sometimes extending over several hundred meters), would thus reduce the probability of nest detection by terrestrial predators. This is confirmed by the fact that colony size of Little Tern is not different between accessible and isolated sites despite a significantly smaller surface area of the latter. Conversely, the other species appeared unable to adjust their density in keeping with predation pressures as the surface area of the dikes had no effect on colony size.

Vegetation is another key factor of the nesting habitat selection of colonial waterbirds. Little Tern displays a preference for bare areas (Fasola & Bogliani, 1984; Goutner, 1990) but the other species prefer vegetation cover which provides eggs and chicks protection against heat and predation by birds (Møller, 1975; Isenmann, 1976; Burger & Gochfeld, 1991). Only one species, however, the Common Tern, avoids vegetation in Sfax salina and the size of its colonies decreases with an increase in vegetation cover on the dikes. This may be explained by the presence of terrestrial predators on dikes and the need to ensure an open field of vision to optimize predator detection (Parsons, 1982; Parsons & Chao, 1983; Spear & Anderson, 1989; Burger & Gochfeld, 1990). This preference for bare areas would seem stronger when avian predators do not exert heavy pressure on colonies, such as it is observed in the Sfax salina where Yellow-legged Gull rarely predates on colonies.

Habitat improvement could reduce the impact of maladaptive habitat selection on population maintenance (Gilroy & Sutherland, 2007). The construction of artificial islets would appear to be a suitable conservation action for limiting the use of dikes as the main nesting sites of colonial Charadriiformes in the Sfax salina and thus increasing their reproductive success. Our results suggest that these islets should be far from the city suburbs edge, isolated to predators (depth of water > 60 cm, distance from dike > 20 m) and present a sparse pioneer stage of vegetation in order to satisfy the majority of the species. They should also present features preferred by the target species. The establishment of Avocets would be facilitated by such islets in basins of medium salinity (70 – 150 g/l) whereas the Little Tern would be more attracted to large islets located in the first basins with salinity up to 70 g/l. It is likely that the other species would be satisfied with these managements but special attention should be paid to the Slender-billed Gull, present in the largest numbers (carrying capacity of the artificial islets) and to the Gull-billed Tern, whose feeding grounds outside the salina are not yet known.

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