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ORIGINAL PAPER

Use of dredge islands by a declining European shorebird, the Kentish Plover *Charadrius alexandrinus*

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Abstract Colonization of newly created habitats is a challenge for waterbird populations in a changing world. Knowing which habitat characteristics are required by waterbird populations is a research challenge for rational management of the new ecosystems and their aquatic bird populations. Since 1989 intertidal dredge islands have been built in the lagoon of Venice using sediments coming from regular dredging of lagoon channels and inlets. Kentish Plover, a species declining in Europe, readily uses these new sites as soon as they become available. Between 2005 and 2007, 75 dredge islands were surveyed each year and the number of breeding pairs of Kentish Plover estimated. Each year about one-third of available dredge islands was used by Kentish Plover. Between 34 (in 2005) and 131 (in 2007) breeding pairs were found, and possible differences in vegetation and morphological characteristics between occupied and unoccupied sites were investigated. Only age, mean elevation above sea level and extension of bare ground were statistically different; Kentish Plover preferred younger sites, with higher elevation and with larger areas of bare ground. The largest groups of breeding pairs, up to thirty pairs, were found on islands which also supported colonies of Little Terns. In the study period dredged islands supported about 60 % of the total breeding population of the lagoon of Venice and 4–6 % of the estimated Italian population. Along coastal sites where human pressure on beaches is particularly heavy, man made habitats such as dredge islands may become a valuable alternative breeding site for this and other species of conservation concern. Management works aimed at promoting the occurrence of this species at selected dredge islands have been made in the lagoon of Venice.

Keywords Artificial habitats · Coastal site management · Salt marshes · Venice lagoon

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Introduction

Beneficial use of dredged material at coastal sites includes the creation of tidal flats or salt marshes, with the aim of restoring previous areas, creating new substrate for halophytic vegetation and providing new feeding and nesting sites for birds, in particular waterbirds (Parnell et al. 1988; Zedler 2000; Streever 2000; Yozzo et al. 2004). Artificial islands created with the controlled disposal of sediments dredged from sea inlets, channels and lagoons have often been named as "dredge islands", and several studies have been published about bird use of these. The large majority of the studies found in scientific literature deals with sites in the USA (Soots 1975; Melvin and Webb 1998; Mallach and Leberg 1999; Delaney et al. 2000; Shafer and Streever 2000; Perry et al. 2001; Erwin et al. 2001; Erwin et al. 2003; Neckles et al. 2002; Darnell and Smith 2004; Golder et al. 2008), whereas we have found very few data for European sites (ABP Southampton 1998; Atkinson et al. 2001; de Jonge and de Jong 2002; Bakker and Piersma 2006; Gallego Fernández and García 2007) where these large scale works are far less common (Atkinson 2003).

The nominate form of the Kentish Plover *Charadrius alexandrinus* breeds mostly along coastal beaches, shorelines and saline lakes from western Europe and northwest Africa to central Asia (Delany et al. 2009). Formerly treated as conspecific with *C. alexandrinus*, the Snowy Plover *C. nivosus* lives in North America and it is now separated on the basis of differences in male calls, morphology, and mitochondrial and nuclear DNA (Page et al. 2009). The population breeding in the European range was recently estimated at about 10,500–16,500 pairs (BirdLife International 2004), whereas a more recent estimate for the same area gave a total of 13,000–16,000 pairs (Delany et al. 2009).

The species has declined moderately across most of its European range, especially in North–West and Central Europe, Spain and Italy. For these reasons it was given the status of "declining" by BirdLife International (2004) and it is classified as level "3" Species of European Concern (SPEC) with negative population trends confirmed or suspected for most of European countries. The population decline has been attributed mainly to human activities, in particular disturbance and/or destruction of breeding sites and increase in predators that take advantage of the human activities, such as Black-billed Magpies *Pica pica* and gulls *Larus* spp. (Montalvo and Figuerola 2006; Delany et al. 2009).

It was recently estimated that 1,400–2,000 pairs occur in Italy (Brichetti and Fracasso 2004), mostly located in the north-eastern and southern coasts; a recent synthesis of the conservation status of birds in Italy by the Italian League for Bird Protection (LIPU 2009) classified the Kentish Plover as having a "poor" status of conservation.

It was estimated in 2002 that between 103 and 160 pairs of Kentish Plovers occurred along the northern Adriatic Italian coasts, about 200 km in length, mostly in the lagoon of Venice (Scarton et al. 2005). Here the breeding pairs used to settle along the lagoon littoral strip, which is made by two peninsulas and two barrier islands between the mouth of Piave river in the north and that of the Brenta river in the south. In 1998 a nine-km long beach was created along one of the two barrier islands. The Kentish Plover readily nested in these new littoral habitats, reaching a total of 51 pairs in 2001 but decreased to a mere 20 pairs in 2008 (Scarton et al. 2007 and pers. obs.).

Nesting habitats of Kentish Plover have been extensively studied throughout its breeding range (Kosztolányi et al. 2006; Fraga and Amat 1996; Kosztolányi et al. 2009; Page et al. 2009; Lott and Fischer 2011; Hanane 2011). Detailed studies about nest site selection in southern European coastal sites have been made by Valle and Scarton (1999) and Norte and Ramos (2004). The results were remarkably similar, with the species preferring bare, sandy habitats, with vegetation coverage very scarce if not absent at all. The occurrence of shell fragments in the sand was selected by nesting pairs, probably to help in camouflaging the eggs and to facilitate draining of the nest substrate after rains. Apart from natural habitats, such as coastal beaches, saline lakes and river bars, the species nests also in man made habitats such as dredge islands, salinas (Page et al. 2009) and even at parking lots, building yards and road sides (Stienen et al. 2005; Montalvo and Figuerola 2006; author personal observations). Despite detailed comparisons between natural habitats and dredge islands have not been made in our study area, some morphological characteristics of dredge islands we studied (such as occurrence of large bare, sandy surfaces; occurrence of shallow ponds or tidal flats inside the dredge islands or in the close proximity) make them suitable for nesting and feeding by Kentish Plover. Feeding has been studied by several authors (Piersma 1996; Kuwae 2007; Castro et al. 2009): the Kentish Plover looks for invertebrates, such as small insects, crustaceans and Anellida, mostly along the shoreline or in tidal flats, in this last case when they are exposed due to low tides. Both diurnal and nocturnal feeding behaviors have been documented.

In the Lagoon of Venice the area of salt marshes has fallen from about 12,000 ha to less than 4,000 ha between 1900 and the present, due to reclamation, erosion, natural and man-induced subsidence (Cecconi 2005; Tiezzi et al. 2010). A large dredging program undertaken for the Italian Ministry of Public Works has been under way since 1984 to maintain channel depths for purposes of navigation and to increase tidal flushing in the inner lagoon. The resulting dredged material has been used to build artificial salt marshes (hereafter called dredge islands) and tidal flats. In 2009 eighty dredge islands occurred, for an extension of about 900 ha and a total volume of sediments used in excess of 10 million cubic meters.

The occurrence and nesting of the Kentish Plover at dredge islands of the Venice lagoon had been known for about a decade (Scarton and Valle 1999; Scarton 2005), but monitoring of the breeding sites, commissioned by the Venice Water Authority Ministry of Infrastructures and Public Works—Consorzio Venezia Nuova, began only in 2005–2007.

The aims of this paper are therefore: (1) to document the importance of dredge islands to a particular shorebird species, the Kentish Plover; (2) to evaluate the influence of geomorphologic and vegetation site characteristics on use of these man made habitats by breeding pairs; (3) to identify the effect of management actions that had been already undertaken and the likely effect of expected future actions at the dredge islands on breeding success of Kentish Plovers.

Materials and methods

Study area

The Venice Lagoon is a large (550 km^2) shallow coastal lagoon, the largest along the Mediterranean coast, and it is 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 (Lido and Pellestrina, See Fig. 1) each one about ten km long, separate the lagoon from the sea; water is thus exchanged through three large inlets. Most of the lagoon consists of an open water body (about 400 km^2) which is partially vegetated by macroalgae (*Ulva* sp., *Chaetomorpha* sp. and *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 m, with a mean tidal range of 0.6 m, one of the highest observed in the whole Mediterranean (Cecconi 2005). In the lagoon there are extensive intertidal salt marshes, regularly flooded during high tides since they have a mean elevation of only 0.20–0.30 m above mean sea level; hundreds of these islets are common in both the south-western and northern corners of the lagoon. Dominant plant species include *Limonium narbonense* (=*L. serotinum*), *Salicornia veneta*, *Sarcocornia fruticosa* (=*Arthrocnemum fruticosum*), *Halimione portulacoides*, *Puccinellia palustris*, *Spartina maritima* and *Juncus maritimus*. About 10,000 ha along the western part of the lagoon are occupied by 22 fish farms, used mainly for fishing and waterfowl hunting. These are privately owned estates, completely surrounded by dikes and the water level inside them is strictly regulated by the owners. Breeding pair counts for the fish farms, where access is limited, are extremely scarce and indicate the occurrence of a few pairs of Kentish Plover (pers.obs.).

The lagoon of Venice is of particular importance for waterbirds, both as a wintering site (the most important in Italy, with more than 200,000 birds counted in mid-January censuses; Scarton and Bon 2009) and as a breeding site. Among breeding species, 90 % of the Italian populations of Common Redshank *Tringa totanus* and 50–70 % of Sandwich Tern *Sterna sandvicensis* are regularly found here. For other species, e.g. Common Tern *Sterna hirundo*, Little Tern *Sterna albifrons*, Eurasian Oystercatcher *Haematopus ostralegus*, Pied Avocet *Recurvirostra avosetta* and Black-winged Stilt *Himantopus himantopus* the area hosts between 5 and 40 % of the national totals (Scarton and Valle 1998; Scarton 2010). Due to its importance for birds, the whole lagoon of Venice has been recognised since 2007 as a Special Protection Area, according to the 147/2009 Birds Directive of the European Union.

Between 1985 and 2009, about 80 dredge islands were built in the lagoon, ranging in size from 0.4 to 57.4 ha, with a mean surface of 10.5 ha and a total area (in 2009, the last year for which data were available) of almost 900 ha. Dredge islands were built primarily as an innovative and efficient way to reuse dredged sediments, formerly discharged at sea. Each dredge island consists of a containment cell formed using wooden poles along the exterior. These areas of shallow waters are then filled with sediments coming from the regular dredging of lagoon channels or

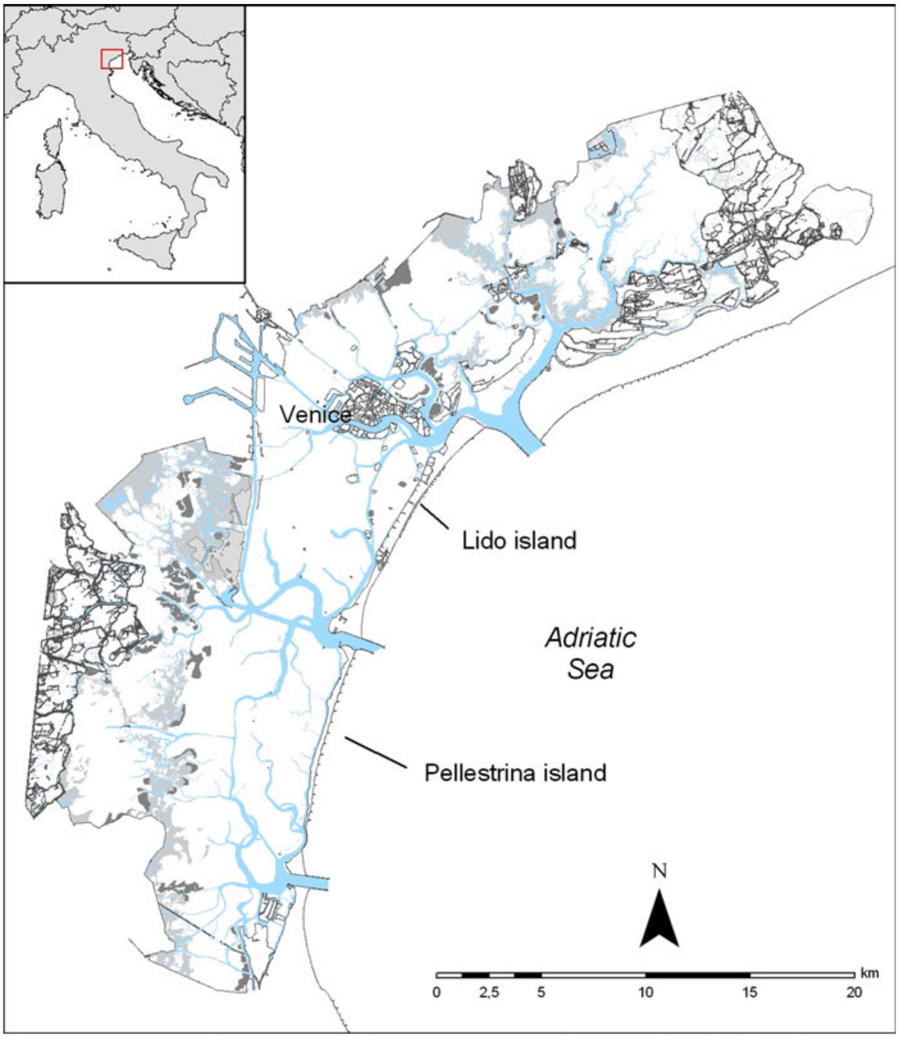

Fig. 1 Lagoon of Venice, with saltmarshes in *light grey* and dredge islands in *dark grey*

inlets (Cecconi 2005; D'Alpaos et al. 2007). Sediments may be silty, sandy or more often a mixture of both. Sediments discharged into dredge islands are thus confined by: (1) a row of posts, between 30 and 40 cm in diameter, with a sheet of geotextile along the inner side in order to reduce sediment release into the lagoon water; (2) two or three rows of gabions, filled with stones, laying one above the other, and with geotextile in the inner side. The upper row of gabions lays at about 10–20 cm above the mean water level. The two techniques may be used, along the perimeter of a single dredge island, alone or in combination. At some dredge islands posts or gabions were removed along selected sectors, in order to promote tidal creek formation.

After sediment compaction, these dredge island reach a mean elevation above sea level between 0.5 and 1 m. For this reason, the area flooded by normal high tides is variable, ranging from most of the site surface for the lowest dredge islands to less than 30 % for the highest. Despite the very low elevation, topography of dredge islands is not completely flat; small mounds, never higher than one meter and depressions occur, producing an array of micro habitats. Soil composition and elevation above sea level of dredge islands drive the processes of vegetation colonisation and succession. Over the years, remarkable modifications occur to the vegetation cover and structure of dredge islands. From almost a bare surface, with the occurrence of just a few annual species mostly of the genus *Salicornia*, several stages lead to an almost continuous coverage of halophilous (*Sarcocornia fruticosa*), *Aster tripolium*, *Limonium narbonense*, *Puccinellia palustris*) or, less commonly, ruderal and nitrophilous species (*Elymus* sp., *Oenothera* sp. and *Atriplex* sp.). Bushes or small trees (*Tamarix gallica* and *Populus alba*) are extremely rare, occurring only at a few sites which have the higher elevation.

The 75 dredge islands considered in this study ranged in size from 0.09 to 51.37 ha, had a mean surface of 11.3 ± 10.7 ha (mean ± 1 SD) and a total area (in 2007) of 846 ha. Most of the sites (59 %) were smaller than 10 ha, whereas only five sites (7 %) were larger than 30 ha. In 2007 the mean age of the sites (i.e., time elapsed from the end of construction work or, for some sites, from disposal of fresh sediments over most or all the existing area) was 8.2 ± 5.1 years, ranging from 1 to 19 years. Human disturbance at most of the sites was very low or absent, only a few sites were irregularly used by fishermen or occasional visitors.

Data collection

Field data were gathered during spring and summer in the years 2005–2007. In 2005, 55 sites were monitored and these increased to 75 by 2007 as a result of the construction of new dredge islands. Among geomorphologic characteristics calculated for each island using recent aerial or satellite pictures and GIS software were area, perimeter and the area of tidal flats (within a radius of 1 km).

Vegetation mapping at a scale 1:2,000 was carried out for 65 dredge islands in the years 2005–2006; field work was carried out between June and October, with the aid of aerial photos taken in the same years. Digitization took place using ArcGis 9.3 (ESRI, Redlands, CA, USA); vegetation was classified according to the dominant species, since at many islands a classical phytosociological approach was not feasible due to the heterogeneity of vegetation structure and composition. We used the following classes: (1) *Salicornia* sp. dominated area: this indicates depressions frequently inundated and covered with annual species belonging to the genus *Salicornia*, i.e. *Salicornia veneta* and *S. patula*, (2) *Sarcocornia* dominated area: areas with slightly higher elevation, covered mostly with dense stands of *Sarcocornia fruticosa*, (3) other halophytes: dredge island surfaces covered mostly with other typical halophytes of the Venice lagoon such as *Puccinellia palustris*, *Halimione portulacoides* and *Limonium narbonense*; (4) other non halophytes: usually the highest areas, covered mostly with ruderal species (genus *Elytrigia*, *Aster*, *Oenothera* etc.).

Other typologies of soil cover were: (1) intertidal pond + creek surface, (2) bare surface, (3) bare, marginal surfaces exposed only during low tides and originated from erosion processes occurring along the inner side of the containment perimeter. Discriminating in the field between the two last categories was not easy, and a subjective approach had to be followed.

For the remaining ten islands, soil coverage categories were estimated only with the use of aerial or satellite pictures taken in 2007. Tidal flat extension, i.e. the area of shallow bottoms with elevation between +0.05 and −0.30 m around each site in a radius of 1 km, was estimated with the aid of detailed digital bathymetric maps made by the Venice Water Authority. Elevation of dredge islands above sea level was obtained by topographic maps or field levelling transects made in the framework of other projects.

Counts of Kentish Plover pairs were made annually at each island between April and July, when the occurrence of breeding pairs is the highest in our study area (pers. obs.); each island was visited every year three times. Two observers reached the dredge islands by boat and walked slowly through the whole area, with binoculars or a telescope, looking for incubating or displaying adults and searching for nests. Field visits usually lasted about 30 min (1 h at the largest islands), in order to avoid excessive disturbance to breeding pairs, and took place between 09.00 a.m. and 02.00 p.m., always in good meteorological conditions. Both "probable" and "confirmed" nesting pairs were considered in this study, definitions follow Hagemeijer and Blair (1997). Kentish Plover has a peculiar and well known breeding biology; one parent, more frequently the female, often deserts the brood and re-nests with a new mate (Székely et al. 2008; Kosztolányi et al. 2009). As it is likely that at least at the largest sites some birds were missed and since our breeding adults were not individually marked, number of pairs must be considered an estimate of those actually present.

Common and scientific nomenclature follow the BirdLife International checklist of the birds of the world (BirdLife International 2011).

Data analysis

In order to analyse relationships between morphological and vegetation characteristics of dredge islands and occurrence of Kentish Plover, we selected those sites that were occupied for at least 1 year. Differences between medians of occupied and unoccupied islands were tested with Mann–Whitney *U* test, since variables were not normally distributed. Accuracy of the distribution obtained was estimated with the area under the curve (AUC) index, based on the receiver operating characteristic (ROC; Fielding and Bell 1997). This index may vary between 0.5 (random assignments) and 1 (accurate predictions) and represents the probability that the method used correctly predicts the observed presences and absences. Spearman rank correlation was used to measure the degree of association between number of pairs of Kentish Plover and Little Tern breeding at the same island.

Since several species of seabirds and shorebirds nested at the same islands, we evaluated the degree of possible association between Kentish Plover and other species using the following coefficient (Fasola and Canova 1992; Goutner 1997):

$$\mathrm{Phi} = \mathrm{ad} - \mathrm{bc}/[(a+b)(c+d)(a+c)(b+d)]^{1/2},$$

where a is the species x and y are both present in a colony; b is the species x absent, species y present; c is the species x present, species y absent; d is the 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.

Results

Breeding pair occurrence, distribution and associations with other Charadriiformes

A total of 34 breeding pairs were recorded in 2005, 71 in 2006 and 131 in 2007. Each year, about one-third of available islands were used by Kentish Plover. Considering only islands used by Kentish Plover, there was a mean of 1.79, 2.84 and 5.24 pairs/island in the three successive years.

The high value of 2007 is related to the occurrence of two groups (or "colonies") of nesting pairs, each one with more than 20 pairs. Only nine islands used in 2005 by Kentish Plover were occupied in both the following 2 years, but it should be noted that the number of islands increased considerably in 2006. About 64 % of the islands used that year were occupied also in 2007.

Density of Kentish Plover pairs, considering the whole area of dredge islands available in any given year, is reported in Table 1. Density at each island ranged between 0 and 576 pairs/10 ha, with the last value observed at a very small island, only 0.1 ha in size. Excluding three sites where bare ground surface was considered to be absent because it was covered by heaps of shells too small to be mapped, a minimum amount of 500 m^2 of bare ground was needed to host at least one pair of Kentish Plover.

Besides Kentish Plover, other 12 waterbird species were nesting; among these, number of other Charadriiformes are shown in Table 2. In six cases numbers of breeding pairs were >1 % of the estimated Italian total. The most abundant species was the Yellow-legged Gull (802 ± 252 pairs per year), followed by Little Tern (235 ± 133 pairs) and Common Redshank (113 ± 21 pairs). The degree of association between Kentish Plover and seven other species (those in Table 2 apart from Northern Lapwing and Common Tern, too scarce for meaningful analysis) are shown in Table 3. The highest values were found between Kentish Plover and Little Ringed Plover (0.32) or Little Tern (0.22); the lowest value, close to zero and thus indicating lack of association, referred to the Yellow-legged Gull. Coefficients of association were significant in four cases out of seven.

Kentish Plover occurrence and morphological or vegetation characteristics

Vegetation and morphological characteristics of the 75 dredge islands are reported in Table 4. On average, dredge islands were covered with vegetation for 54.5 % of their area, whereas bare ground made an additional 31.6 %; the remaining 13.9 % was made of ponds + creeks and marginal eroded areas. Considering only the vegetation, the highest coverage was due to *Salicornia* spp. (29 % of the total extension of the islands), with *Sarcocornia fruticosa* and other halophytes making an additional 16.6 %. A potential feeding habitat, consisting of tidal flats surrounding the dredge islands, had on average an area of 51 ha.

Vegetation succession at our dredge islands begins with annual species, such as those of the genus

Table 1 Number of breeding pairs and pair density of Kentish Plover observed at dredge islands in the lagoon of Venice

	Year 2005	Year 2006	Year 2007
Islands (and area, in ha) monitored	55 (556)	74 (809)	75 (846)
No. of islands occupied by Kentish Plover (% of available sites)	19 (35 %)	25 (34 %)	25 (34 %)
No. of estimated Kentish Plover pairs	34	71	131
Overall density, whole area (no. of pairs/10 ha)[a]	0.61	0.87	1.54
Overall density, only bare ground considered (no. of pairs/10 ha)	7.55	6.28	6.75
Density at each islands (occupied and unoccupied sites): min–max (no. of pairs/10 ha)	0–576	0–115	0–230
Density at each islands (occupied and unoccupied sites): mean (±1 SD)	14.84 (±80.5)	3.16 (±13.8)	5.04 (±27.0)

[a] Total area of dredge islands in that year/no. of pairs

Table 2 Other shorebirds and seabirds nesting in dredge islands of the Venice lagoon

	2005	2006	2007	Estimated % of the Italian population
Haematopus ostralegus	31	39	40	30
Himantopus himantopus	96	69	62	2
Recurvirostra avosetta	39	45	35	2
Vanellus vanellus	0	2	5	<0.1
Charadrius dubius	8	3	18	<1
Tringa totanus	94	136	110	7
Larus michahellis	553	1,057	796	2
Sterna albifrons	115	213	379	9
Sterna hirundo	8	10	0	<0.1
Total no. of pairs	995	1,694	1,607	

Table 3 Coefficients of association of Kentish Plover with other seven nesting species (3 years pooled, $N = 204$ dredge islands); significant values marked in *bold*

	Phi	Fisher exact *P*
Haematopus ostralegus	0.16	**0.03**
Himantopus himantopus	0.14	**0.04**
Recurvirostra avosetta	0.04	0.62
Charadrius dubius	0.32	**<0.001**
Tringa totanus	0.08	0.29
Larus michahellis	0.01	0.87
Sterna albifrons	0.22	**0.01**

Salicornia and less commonly *Puccinellia palustris*; in the first stage, i.e. 2 years after the end of sediment deposit, bare ground makes on average up the 55 % of the dredge island area (Fig. 2). In the following years the sites began to be covered with halophytes, biannual or perennial, up to about 70 % of the total surface. At the oldest sites (more than 15 years; $N = 6$) there was a decrease of % area covered with vegetation, mostly due to large erosion surfaces observed at two of these dredge islands.

Results of comparisons between islands occupied by Kentish Plover (in at least one of the 3 years) and unoccupied islands indicate that three variables showed significant differences (Mann–Whitney *U* test; Table 4), including age, elevation and surface of bare ground. Islands used by Kentish Plover were therefore younger, higher and with larger bare surface than unoccupied islands. Nevertheless we did not find a clear relationship of breeding pair density with % of bare ground surface; despite it was always positive in the 3 years, significance threshold was reached only twice and this was due to the occurrence of two dredge islands with very high density. A negative correlation of breeding pair density with vegetation cover was also observed in all the 3 years, but only once it was statistically significant.

Values of other variables that we expected to be important in explaining the use of islands by Kentish

Table 4 Morphological and vegetation characteristics for 75 dredge islands in the lagoon of Venice and comparisons between dredge islands occupied and unoccupied by Kentish Plover

	Age (years)	Mean elevation a.s.l. (m)	Perimeter (m)	Total area (ha)	Area of creeks + ponds (ha)	Marginal eroded surfaces (ha)	Bare ground (ha)	*Salicornia* dominated area (ha)	*Sarcocornia* dominated area (ha)	Other halophytes (ha)	Other non halophytes (ha)	Total area with vegetation (ha)	External intertidal areas (ha)[a]
Mean ± SD ($N = 75$)	6.3 ± 4.97	0.41 ± 0.17	1722.1 ± 1110.8	11.29 ± 10.73	0.99 ± 1.64	0.61 ± 1.23	3.57 ± 6.47	3.30 ± 4.18	1.21 ± 2.65	0.67 ± 1.51	0.83 ± 1.98	6.01 ± 7.11	51.01 ± 31.19
Median	4.0	0.37	1468.8	8.70	0.37	0.00	1.40	1.77	0.31	0.01	0.07	3.98	48.72
Occupied ($N = 39$)													
Mean ± SD	4.3 ± 3.3	0.47 ± 0.19	1811.2 ± 1040.8	13.3 ± 12.6	1.3 ± 1.9	0.4 ± 0.7	5.7 ± 8.3	2.7 ± 3.5	1.1 ± 3.2	0.7 ± 1.4	1.2 ± 2.4	5.7 ± 6.9	51.4 ± 31.6
Unoccupied ($N = 36$)													
Mean ± SD	8.5 ± 5.5	0.34 ± 0.12	1625.7 ± 1189.2	9.1 ± 7.8	0.6 ± 1.1	0.9 ± 1.6	1.3 ± 1.8	3.9 ± 4.8	1.3 ± 1.9	0.6 ± 1.7	0.5 ± 1.3	6.4 ± 7.4	50.6 ± 31.1
M–W *U* test: *Z*, *P*	**−3.6, $P < 0.001$**	**3.06, $P < 0.01$**	1.31, $P > 0.05$	1.28, $P > 0.05$	1.46, $P > 0.05$	**3.52,** $P > 0.05$	3.52, $P < 0.001$	−0.81, $P > 0.05$	−1.70, $P > 0.05$	0.86, $P > 0.05$	1.87, $P > 0.05$	−0.77, $P > 0.05$	0.02, $P > 0.05$

Data are the number of sites (*N*) and mean ± SD of untransformed variables. Significant *P* are marked in *bold*

[a] Within 1 km from the perimeter

Plover, such as extension of tidal creeks + ponds or extension of tidal flats in the surroundings (which are often used as feeding sites: See Kuwae 2007; Castro et al. 2009), were not significantly different between occupied and unoccupied islands. The ROC analysis showed that the highest values of AUC relate to percentage of bare ground (0.75), mean elevation above sea level (0.71), and perimeter (0.61; Fig. 3).

The number of breeding pairs at occupied islands did not correlate with the total island area in 2007 ($N = 19$, $r_s = 0.14$, $P > 0.05$), whereas only a weak, non-significant positive correlation was found in 2006 ($N = 25$; $r_s = 0.34$, $0.05 < P < 0.10$); in 2005 a similar, but negative, non significant correlation was observed ($N = 25$; $r_s = -0.42$, $0.05 < P < 0.10$).

On the other hand, considering only islands where both Kentish Plover and Little Tern occurred a significant positive correlation between pair numbers was found ($N = 12$, $r_s = 0.75$, $P < 0.01$; Fig. 4).

Discussion

As far as we know, this is the first time such a large number of dredge islands are studied in Europe to assess their value for a species of conservation concern. Beside Kentish Plover other waterbirds, including other rare or endangered species, regularly used the study sites both for nesting and for feeding, as we have been observed in the last 10 years (See for instance Scarton 2005; Scarton et al. 2011). As already observed for other artificial sites, such as salinas, wetland treatment plants and rice fields (Takekawa et al. 2001; Sebastián-González et al. 2010) our study confirm that dredge islands as well may have high value in improving and/or maintaining biodiversity at local or regional levels.

Moreover, given their slightly higher elevation above sea level compared to that of naturally formed salt marshes, dredge islands of our study area are less prone to flooding by high tides; this could explain why they became more and more attractive for other salt marsh nesting species, e.g. Little Tern and Common Tern (Scarton 2008; Scarton 2010).

We recognize that the success of a salt marsh creation project, like many other nature environmental management projects, may not be judged only by the number of breeding birds, as pointed out by Stienen et al. (2005). Other indicators such as for instance

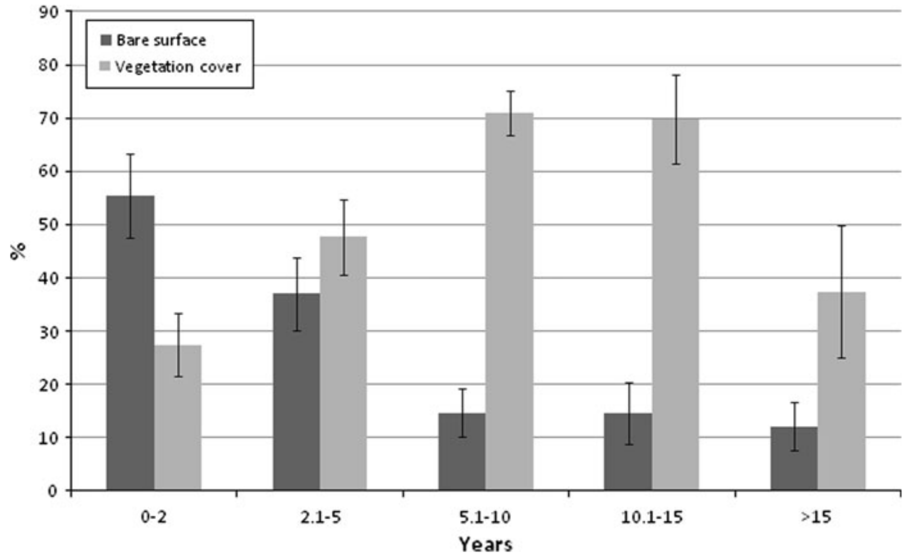

Fig. 2 Mean (±SE) extension of bare ground and vegetation coverage (in % of the total dredge island area) at 75 dredge islands, grouped by age

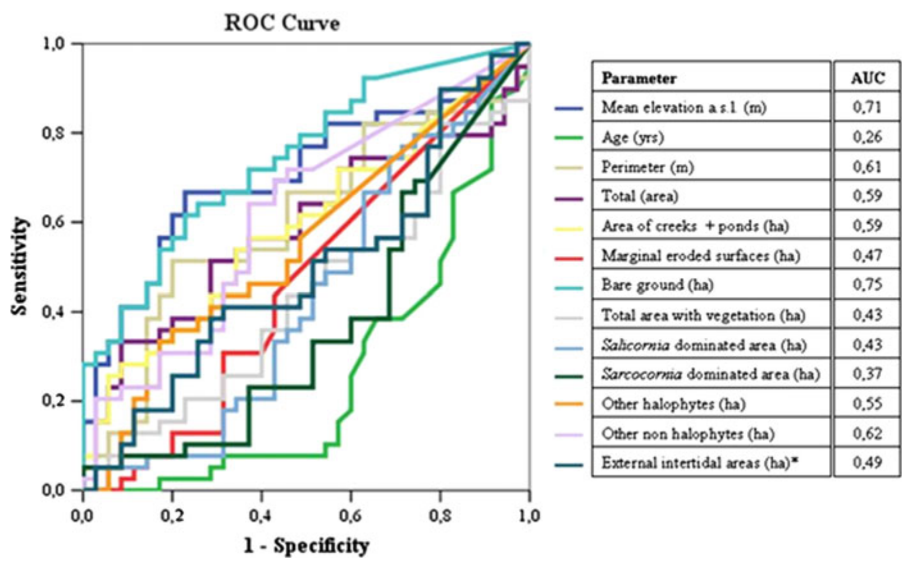

Fig. 3 Receiving operator characteristics curves for the selected environmental variables

reproductive performance or fidelity to nesting sites shown by adults should be used. Despite the lack of such detailed studies at our sites, we deem that the nesting population at our dredge islands is now well consolidated; new surveys made in more recent years (2008–2011) showed that between 30 and 71 pairs nested each year (pers. obs., unpubl.).

With an average of 79 Kentish Plover pairs found over the 3 years of monitoring, dredge islands supported about 60 % of the population estimated for the whole lagoon of Venice in that period. Using the same terminology adopted by Soots (1975), we may therefore considered this species as “heavily dependent” on dredge islands during its breeding season.

These 79 pairs represent a rough 4–6 % of the total given for the whole Italy by BirdLife International (2004). Despite the obvious uncertainties in comparing estimates from different sources and different years, those percentages show the relevant importance that dredge islands have nowadays reached for Kentish Plover. Since these islands are little or not disturbed at all by man, they are suitable for several species breeding along a coastal area where, as it happens along the north Adriatic coasts, human pressure is

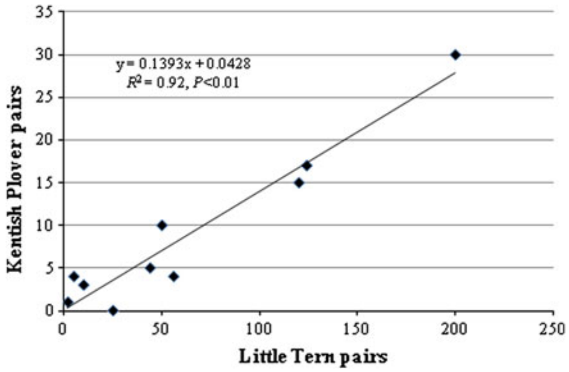

Fig. 4 Numbers of Kentish Plover and Little Tern pairs at dredge islands where both species present. *Each dot* represents a dredge island; data of 2005–2007 pooled together

extremely high for most of the year, especially in late spring and summer. It is worth considering that in the former most suitable breeding sites of the Venice lagoon, i.e. the littoral strip, number of breeding pairs declined from 174 pairs in 1992 to just 30 pairs in 2010 (Biondi and Pietrelli 2011). It is likely several pairs shifted from sand bars to dredge islands, which could explain the increase in the number of Kentish Plovers we observed.

Dredge islands in the first 3–4 years since their construction had most of their area completely bare and were more likely to host breeding pairs than older sites, which were usually mostly covered with thick, halophilous vegetation. Vegetation succession starts with a few annual species and, in less than a decade, ends with a dense coverage due mostly to halophytes, that persists in the following years without evident changes. Regular submersion of dredge islands by high tides prevents spreading of shrubs or trees, which are very uncommon even in the oldest sites (up to 18 years old). Vegetation succession at dredge islands was studied in details by (Soots 1975); unlike ours, their study sites became covered with shrubs and trees, forming in the end shrub forests or young maritime forests.

Density of Kentish Plover pairs was positively related with % of bare surface in 2 years out of three; at the opposite, density of breeding pairs decreased with higher vegetation cover, though in most years not significantly. This is likely due to the fact that in older islands nesting of Kentish Plover may still occur with a few pairs, but is restricted only to the few patches of bare ground that may persist for many years. In any given year most of the pairs were found at young dredge islands, i.e. those that had less than 8–9 years.

This has important site management implications, since indicates that ageing of islands leads to a loss of attractiveness for the Kentish Plover. The occurrence of Kentish Plover showed a clear association with that of other seabirds or shorebirds, Little Ringed Plover *Charadrius dubius* and Little Tern in particular. The latter is also regarded in Europe as species of environmental concern (SPEC 3; BirdLife International 2004); management works (such as island creation or nesting site protection) targeted at this species are likely to favour Kentish Plover as well. On the other side, Kentish Plover showed a complete lack of association with Yellow-legged Gull, a species which may predate eggs and chicks of many shorebirds (Sadoul et al. 1996; Oro and Martínez-Abrain 2007).

As soon as the importance of the dredge islands for birds, and waterbirds in particular, was recognized, several management actions were carried out at selected dredge islands of the Venice lagoon in order to maintain or improve their value for birds. If dredge islands have a mean elevation comparable to that of natural surrounding saltmarshes they become invariably covered with halophilous vegetation in less than 10 years, with only small patches left bare. This natural process has several positive effects, such has the occurrence of halophilous habitats of high conservation value (meaning those included in the Annex I of the 92/43/CEE Habitats Directive), a better integration of dredge islands in the peculiar lagoon landscape, and the reproduction of birds that prefer densely vegetated area (such as Common Redshank and Common Shelduck *Tadorna tadorna*: Hale 1982; van de Kam et al. 2004). On the other hand, this process leaves less and less space available for those species that prefer sandy islands, with large bare areas, not only Kentish Plover (as shown above) but also Little Tern, Eurasian Oystercatcher and Little Ringed Plover. Due to the large number of dredge islands built so far in the Venice lagoon, some of the management works carried out in the last 10 years had the effects of increasing the occurrence of these species and may be replicated at other similar man made islands in different coastal sites. These management works fell within one or more of the following categories:

- Disposal of fresh, sandy sediments over part, or all, of the surface of existing islands. This had the immediate effects of attracting both Kentish

Plover and other nesting species as well, such as Little Tern, Pied Avocet, Little Ringed Plover, Eurasian Oystercatcher. At several islands we observed Kentish Plover pairs, alone or in groups, nesting at short distance (<100 m) from machineries used to deposit sediments still in use, indicating a good tolerance to some forms of indirect and predictable forms of disturbance. Personal field observations made after the end of these works showed that the most attractive islands, in terms of number of Kentish Plover breeding pairs, were those covered with sands rich in shell fragments. These fragments helped in camouflaging eggs and improved water drainage of the nest site. Managing dredge island habitats, in particular their vegetation coverage, appears of pivotal importance in keeping high the number of breeding pairs;

- Shell fragments spreading and creation of small mounds of shells. The first occurrence of small heap creation with shells was carried out in the Venice lagoon in the late nineties (Scarton et al. 1995); at those places nests of Kentish Plover, Common Redshank and Mallard *Anas platyrhynchos* were found after a few months. For the near future, other works of this kind are planned in cooperation with other Public Institutions and local associations of professional fishermen;
- Island reshaping, lowering their elevation above sea level if considered too high. At five dredge islands between 1998 and 2005 most of their area was reshaped, lowering existing mounds and creating small depressions. Field observations showed that several species, including Kentish Plover, used these dredge islands to nest;
- Creation of new intertidal creeks and ponds. Despite the effect of these management works in mimicking the network of creeks and ponds that are commonly observed at salt marshes and so improving habitat diversity inside the dredge islands (D'Alpaos et al. 2007), it was also thought to have had positive effect on Kentish Plover as well, since it feeds along the edge of tidal ponds. Results of the monitoring held in 2005–2007 nevertheless did not highlight the area of intertidal water bodies, both naturally and artificially formed, as significant for island selection (Table 4), and the reasons for this are still unclear.

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