Use of artificial intertidal sites by birds in a Mediterranean lagoon and their importance for wintering and migrating waders

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Abstract Man-made habitats provide suitable nesting, resting and feeding habitats for many birds at coastal sites. Despite intensive study outside Europe, very few data are available to date on the bird communities that exploit artificial intertidal sites along the European coasts. Between July 2009 and December 2010, 32 ornithological surveys were performed at six artificial intertidal sites in the lagoon of Venice (Italy). Overall, 101 species (with 23,399 birds) were observed, about a third of those occurring in the lagoon of Venice; 58 of these species were of conservation concern. Ten species comprised about 80 % of the total; bird abundance was the highest during the post-breeding migration and wintering period. Multivariate analysis identified similarity among sites, seasons and observed behaviours. Dredge islands were mostly used by waders as foraging sites, when surrounding tidal flats were still flooded. In winter the six dredged islands supported about 2 % of the dunlins *Calidris alpina* occurring in the whole lagoon of Venice and about 10 % of the grey plovers *Pluvialis squatarola*. Since the study sites comprised just the 6 % of the total dredge island area available in 2009–2010, the results indicate as large fractions of these shorebird populations might exploit the dredge island habitats for foraging. Among the newly created habitats, intertidal ponds and inner tidal flats were the most heavily used by birds, followed by dykes and mounds with ruderal vegetation. Maintenance of the habitat mosaic is a need for a conservation- based management of the dredge islands.

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Introduction

Artificial islands created by the controlled disposal of sediments dredged from sea inlets, channels and lagoons have often been termed "dredge islands", and many studies have been published concerning their use by birds. Almost all studies in the scientific literature deal with sites in the USA (Soots and Parnell 1975; Soots and Landin 1978; Melvin and Webb 1998; Delaney et al. 2000; Shafer and Streever 2000; Zedler 2000; Erwin et al. 2001; Perry et al. 2001; Neckles et al. 2002; Erwin et al. 2003; Darnell and Smith 2004; Yozzo et al. 2004; Guilfoyle et al. 2007; Spear et al. 2007; Golder et al. 2008; Emslie et al. 2009). However, very few studies exist for European countries, where these particular types of man-made sites are far less common and of very small size (ABP Southampton 1998; Atkinson et al. 2001; de Jonge and de Jong 2002; Atkinson 2003; Bakker and Piersma 2006; Gallego Fernández and García 2007). Data reported in the previously quoted literature indicate that birds rapidly colonise dredge islands, and that nesting populations at these sites might reach levels of regional or national importance (e.g. supporting >1 % of the local population or national population), at least for some species.

It is already well known that man-made wetlands such as salt ponds, water-treatment plants, agricultural ponds, fish-farms and gravel pits might become suitable and alternative sites to natural ones, especially as feeding sites or roosts, enhancing the survival of overwintering birds (Davidson and Evans 1986; Warnock et al. 2002; Santoul et al. 2004; Sebastián-González et al. 2010; Mander et al. 2007). In the

Lagoon of Venice (NE Italy), the total area of salt marshes has fallen from approximately 12,000 ha to less than 4000 ha between 1900 and the present day, due to reclamation, erosion, natural and human-induced subsidence (Cecconi 2005; Day et al. 2011). A large dredging program undertaken for the Italian Ministry of Public Works has been underway since 1984 to maintain channel depths for the purposes of navigation and to increase tidal flushing in the inner lagoon (Scarton 2005). The resulting dredged material has been used to build artificial salt marshes (hereafter called dredge islands); in 2013, about 120 dredge islands were present, over a total area of about 1200 ha and using a total volume of sediment in excess of 13,000,000 cubic meters.

From July 2009 until December 2010, regular bird surveys were carried out at six dredge islands in the Venice Lagoon. As far as we know, this is the first study in Europe that explores bird occurrence and habitat use on intertidal artificial islands. The aims of this paper were:

- to analyse bird occurrence throughout the yearly cycle;
- to analyse the use of the different habitats available at dredge islands;
- to suggest criteria for the optimum management of existing sites and the planning of new ones.

Study area

The Venice Lagoon is a large (550 km^2) shallow coastal lagoon, located along the Adriatic Sea, 45°26′N, 12°19′E. Two barrier islands, each about 10 km long, separate the lagoon from the sea. Most of the lagoon consists of an open water body (about 400 km^2), with peripheral fish farms for about an additional 10,000 ha along the borders. The mean depth of the lagoon is 1.1 m (all the elevations refer to the Venice local datum) 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 (Ferrarin et al. 2013). The highest tides are observed in November, and the lowest tides in February. Salt marshes cover an area of about 3800 ha and are regularly flooded during high tides; tidal flats encompass an area of additional 5000 ha. The climate is temperate, with a mean annual temperature of 14.5 °C; the lowest mean values occur in January (4.1 °C) and the maximum in July (25.2 °C; Ferrarin et al. 2013). Rainfall is around 800 mm per year, with the peak in March and the minimum in May.

In the period 2006–2010 the lagoon of Venice supported about 350,000 waterbirds in mid-January; because of this it is the most important wintering site in Italy and likely the most important one around the Mediterranean (Bon and Scarton 2012). As a breeding site, the lagoon hosts significant fractions (i.e., >1 % of the Italian populations) of several waterbirds, such as Little Tern *Sternula albifrons*, Sandwich Tern *Sterna sandvicensis*, Redshank *Tringa totanus*, Oystercatcher *Haematopus ostralegus* and Kentish Plover *Charadrius alexandrinus* (Hale et al. 2005; Scarton et al. 2013a). Due to its importance for birds, the whole Venice Lagoon has been recognized since 2007 as a Special Protection Area, according to the European Union Birds Directive 2009/147/EC.

Dredge islands built in the lagoon of Venice so far consist of a containment cell formed using wooden piles along the exterior. These areas of shallow water are then filled with sediments originating from the regular dredging of lagoon channels or inlets. Sediments discharged into dredge islands are thus confined by a row of posts, with a sheet of geotextile along the inner side, or by two or three rows of gabions, filled with stones. At some dredge islands, posts or gabions were removed along selected sectors, to promote tidal creek formation. After sediment compaction, these islands reach a mean elevation above sea level of between 0.5 and 1.2 m; for this reason, the area flooded by mean high tides is variable, ranging from about 50 % to almost 100 % (Scarton 2005). Despite their very low elevation, the topography of dredge islands is not completely flat; small mounds and depressions coexist, producing an array of microhabitats. Soil composition and elevation above sea level of dredge islands drive the processes of vegetation colonization and succession. Throughout 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 phases lead to an almost continuous coverage of halophytes, mostly *Sarcocornia* (=*Arthrocnemum*) *fruticosa*, *Aster tripolium*, *Limonium narbonense*, *Puccinellia palustris* or, less commonly, ruderal and halo-nitrophilous species (genus *Suaeda*, *Elymus*, *Oenothera*, *Atriplex*). Bushes or small trees (*Tamarix gallica* and *Populus alba*) are extremely rare, occurring only at a few sites that have higher elevations. Shallow tidal ponds and tidal creeks, both naturally formed and man-made, have a different extent and complexity at each site.

Materials and methods

Surveys were carried out at six dredge islands (Fig. 1). They ranged in size from 6.86 to 14.59 ha, had a mean area of 10.82 ha (1 SD = ±3.06 ha), a total combined area of 64.9 ha and an age of 8–16 years (Table 1). The distance of the dredge islands from the mainland ranged between 250 m and 3.3 km. The six dredge islands were visited between July 2009 and December 2010, twice-monthly between August to April and monthly between May and July. Each island was thus visited 32 times during the survey; all the islands were visited on the same day. Visits took place between 7:00 and
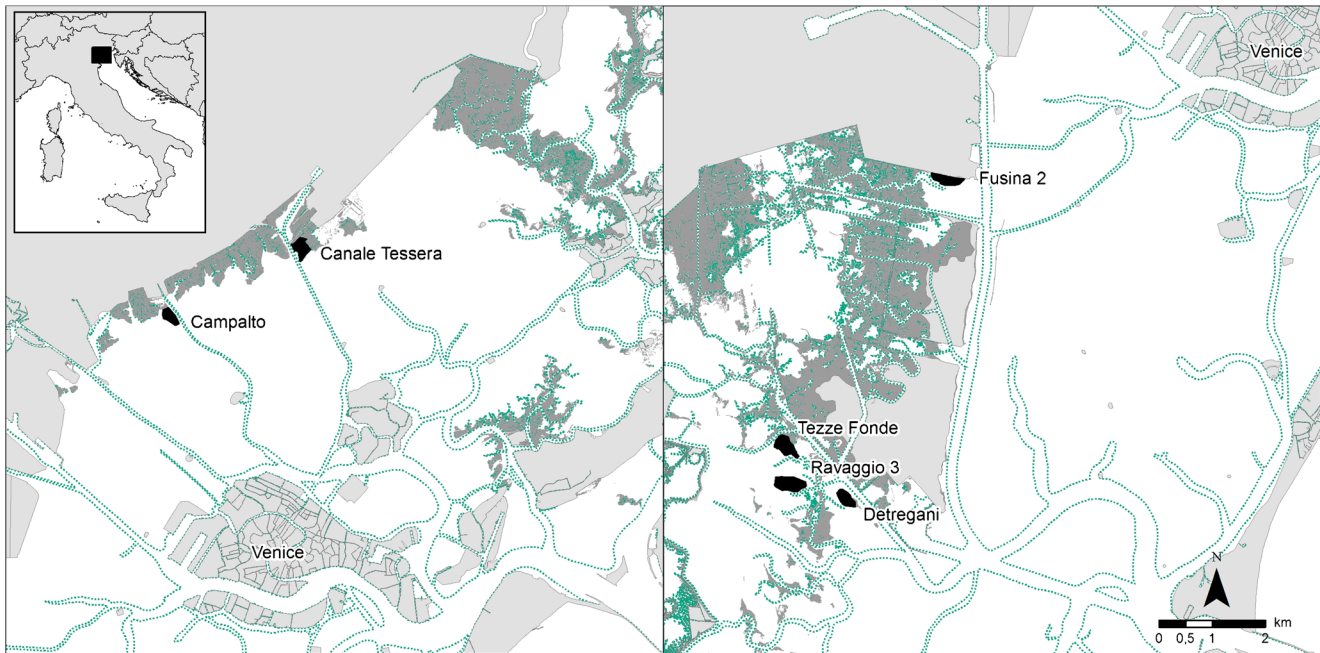
Fig. 1 Study sites (in *black*) with the surrounding salt marshes (*dark grey*) and islands (*light grey*); channels are *dotted*

14:00, avoiding days with strong wind, heavy fog or rain. Tidal levels ranged between −0.20 and +1.00 m, as recorded by tidal gauges located near the sites; data were downloaded from the Venice Municipality web site (http://www.comune. venezia.it). With tides exceeding +1.00 m, all the sites were completely flooded, so they appeared unsuitable for birds.

Habitat maps at the scale 1:2500 were made in 2009 from field observations made by plant ecologists and with the use of recent aerial pictures. Dominant habitat features were categorised as follows (Table 1):

- "dykes and mounds, with ruderal or halo-nitrophilous vegetation" (code: RV). These were areas slightly more elevated than the surroundings, with vegetation cover being from scarce to high. These habitats occurred along the edge of some sites or, with small extensions, within them. Bushes were very scarce, whereas trees were not present at any of the six sites.

- "areas with typical salt marsh vegetation". This was the dominant habitat feature at all sites and it was divided into three groups: 1) dominated by "*Salicornia* sp." (SA), 2) dominated by "*Limonium/Puccinellia/Aster/Juncus/ Spartina*" (LP) and 3) dominated by "*Sarcocornia/ Halimione*" (SR).
- "tidal pools, tidal creeks and interior tidal flats" (PC), the last term indicating some depressions, always along the edge, that originated through surficial erosion. There was some aquatic vegetation, including both algae (*Ulva* sp., *Enteromorpha* sp.) and seagrasses (*Nanozostera noltii* and *Ruppia* sp.).
- "bare areas" (BA), surfaces with very scarce vegetation cover, almost completely flat and with higher elevation and coarser sediments than PC.

Characterisation of the six dredge island in terms of extensions of their habitats was analysed by applying principal

Table 1 Morphological characteristics for the six dredge islands considered in the study

Site	Age (years)	Size (ha)	RV (Dykes and mounds, ha)	SA (*Salicornia*-dominated, ha)	LP (*Limonium*-dominated, ha)	SR (*Sarco cornia*-dominated, ha)	PC Ponds and creeks, ha)	BA (Bare areas, ha)
Campalto	16	6.86	0.38	2.35	1.36	0.56	2.2	0.01
Canale Tessera	14	9.49	1.05	1.06	4.2	2.06	0.82	0.30
Detregani	14	8.31	0.07	2.47	0.11	1.16	4.35	0.15
Fusina 2	8	13.41	2.95	0.95	1.64	3.2	1.68	2.99
Ravaggio 3	11	14.59	1.55	0.79	1.2	2.96	0.52	7.57
Tezze Fonde	16	12.31	0.05	2.92	2.55	2.89	3.54	0.36
Total		64.97	6.05	10.54	11.06	12.83	13.11	11.38

components analysis (PCA) to the matrix of the surface values (ha) of the six habitats * six dredge islands. The PCA obtained identifies three groups of dredge islands in the ordination graph: the first one includes Tezze Fonde, Detregani and Campalto, dominated by SA and PC; the second group (Ravaggio 3 and Fusina 2), opposed to the first, shows spatial dimensions associate to BA, SR and RV; the third group is made only by Canale Tessera and it is heavily characterized by LP.

Some birds were not observed in any of the above-described habitats, but were observed resting, perched on the containment poles; these birds (about 6 % of the total) were excluded from the habitat–species relationships analysis reported below.

Initially, sites were surveyed from the boat at a distance of 100–150 m and birds were spotted with binoculars and counted whenever possible. This allowed us to count species such as the Curlew *Numenius arquata* and a few other larger waterbirds, which often flew away as soon as the boat reached the sites. Once landed on a dredge island, the observer walked slowly throughout the whole site, recording all the birds observed and their behaviour (as in Gregory et al. 2004). Visits lasted 40–45 min at each site, thus allowing subsequent comparisons of the data. Data analysed were raw, meaning that no attempts were made to take the different detectability of birds in different habitats into account; we are aware that some elusive species, such as the Common Snipe *Gallinago gallinago* might be under-represented in the results.

The behaviour of birds was classified as follows: 1) "feeding", 2) "repeatedly flying over the site"; 3) "making anxiety calls, distraction displays or seen with young": this was considered a clue for birds nesting in the study sites; 4) "singing"; 5) "resting, preening"; 6) "unknown", i.e. birds flushed by the observers before it was possible to record their behaviour. We named the periods of the year as follows, considering the prevailing bird phenology in the lagoon of Venice: 1) wintering period: December–January; 2) pre-breeding migration period: February–April; 3) nesting season: May–July; 4) post-breeding migration August–November. This classification is purely indicative and periods in reality overlap, due to the different phenology among the species and even among individuals of the same species.

Species observed during the study were grouped into the following functional guilds, according to their ecology and systematics: 1) ducks (Anatidae); 2) cormorants (Phalacrocoracidae); 3) herons (Ardeidae); 4) raptors (Falconiformes and Strigiformes); 5) waders (all the Charadriiformes except Laridae and Sternidae); 6) gulls and terns (Laridae and Sternidae); 7) aeroplanckton feeders (swallows, bee-eaters, swifts); 8) Passerines.

Statistical analysis

The analysis of the relationships between species occurrence, their behaviour and habitat characteristics was performed using multivariate techniques, such as cluster analysis, principal component analysis, correspondence analysis and multidimensional scaling (n-MDS). Comparison among waterbird assemblages in relation to tidal level and seasons were made with an analysis of similarity (ANOSIM), a non-parametric multidimensional ordination method for detecting differences between groups of community samples. ANOSIM generates the R statistic which ranges from 0 to 1 and gives an absolute measure of how separated groups are ($R > 0.75$, well separated; $0.25 < R < 0.75$, overlapping to some extent but different; $R < 0.25$, barely separable: Liordos 2010). Similarity percentages (SIMPER) analysis, based on the similarity matrix obtained from the Bray-Curtis index, was used to calculate the contribution of each species to the dissimilarity between sites or seasons.

Relationships among relative species abundance were studied with k-dominance curves (Lambshead et al. 1983) and diversity indices (Magurran 2004):

1) Shannon diversity $H' = -\Sigma$ fr ln(fr) where fr is the frequency of records of each species (n_i/n; where n_i is the number of records of the species i);
2) Pielou index $J = H'/H'_{max}$, where $H'_{max} = \ln S$ and H' is the Shannon diversity index;
3) Simpson's Index of Diversity $1 - D$, where $D = \Sigma(n/N)^2$, n = the total number of organisms of a particular species and N = the total number of organisms of all species.

Correspondence analysis has been applied to the abundance values (no. of birds) of 100 species (i.e., all the species observed apart from one, which was recorded only perched on the containment poles) * six habitats. Species–habitat relationships were evaluated with the Density Kernel application. Bird habitat selections explored using the Jacobs preference index. The index (D) was calculated for/with each habitat type as follows:

$$D = (r-p)/(r + p - 2rp),$$

where:

- r is the proportion of birds observed in a particular habitat type;
- p is the proportion of the surface of this habitat out of the total available area.

The index may range between −1 (habitat completely avoided) and +1 (exclusive habitat). Values equal to 0 indicate that the habitat is used in proportion to its availability. Chi-

square test and ANOVA were used to compare differences in distribution and among groups. Numerical and statistical analysis were performed using Microsoft Excel 2007, PAST version 2.05 (Hammer et al. 2001) and STAXS2000 version 1.0.

Results

During the study, 101 species were observed, of which 63 were non-Passerines and 38 were Passerines. The number of individuals counted was 23,399; the most abundant order was that of Charadriiformes (17,225 birds, 74 % of the total), followed by that of Passerines (4175 birds, 18 %) and Anseriformes (923 birds, 4 %). Altogether, these three orders accounted for the 96 % of the total number of observed birds.

Composition of the bird community

The number of birds ranged between 230 and 2774 per survey (Fig. 2); the number of species ranged between 12 and 40. The periods with the highest number of species (86) were the post-breeding migration, followed by the pre-breeding migration and wintering season (51 species each); the nesting season had the lowest number of species (45). Nineteen species were resident and were observed in all four periods; 35 species were observed in only one period, 23 of which were observed only in the post-breeding migration. Multivariate ordination (n-MDS) showed that the bird communities differed among sites, with Fusina, Canale Tessera and Campalto grouped apart from Detregani, Tezze Fonde and Ravaggio (Fig. 3). The first group of sites were used by less waders and more Passerines than the remaining three. The ANOSIM test gave a general R of 0.44 (with $P < 0.0001$), a value which indicate distinct groups with

some overlapping. The SIMPER analysis between this two groups of sites shows an average dissimilarity of 80.4 %, with Dunlin *Calidris alpina*, Yellow-legged gull *Larus michahellis*, Black-headed gull *Chroicocephalus ridibundus* and Curlew representing about 60 % of this dissimilarity.

Considering all the 101 observed species, about 50 % of the birds counted refer only to two species, i.e., Dunlin (31.7 % of the total) and Yellow-legged Gull (18.2 %). The first ten species, in decreasing order of abundance, comprised 82.2 % of the overall number of birds; 16 species were observed with just one individual. The k-dominance curve for each site is shown in Fig. 4. We observed marked differences among sites, with the Dunlin representing only 20 % of the total at Canale Tessera, but about 70 % of the total at Detregani. Number of species ranged between 48 (Campalto) and 63 (Ravaggio 3), and diversity (H') between 1.24 (Ravaggio 3) and 1.80 (Fusina 2). Two sites (Ravaggio 3 with 6827 birds and Detregani, with 5692 birds), accounted for 53 % of the individuals observed; the poorest site was Campalto (1689 birds). Bird numbers were not dependent on the size of the dredge islands: Campalto, Fusina 2 and Tezze Fonde had fewer birds than expected, with the remaining three sites having more birds than expected (Chi-squared test:$\chi_2 = 4.89$, $P < 0.001$, d.f. = 5). Trend of the three diversity indices is reported in Fig. 5. Highest H' were reached between the end of July and that of September, and the lowest between the beginning of October and that of February. Diversity values were different across sites (ANOVA: $F_{5,186}$; P always <0.001) but the ANOSIM tests failed to identify well separated groups of sites. Moreover, comparisons among the four periods of the year showed overlapping but different bird communities (ANOSIM: global $R = 0.32$, $P < 0.001$) with the autumn migration and nesting season showing the highest and significant differences with the remaining periods (Table 2).

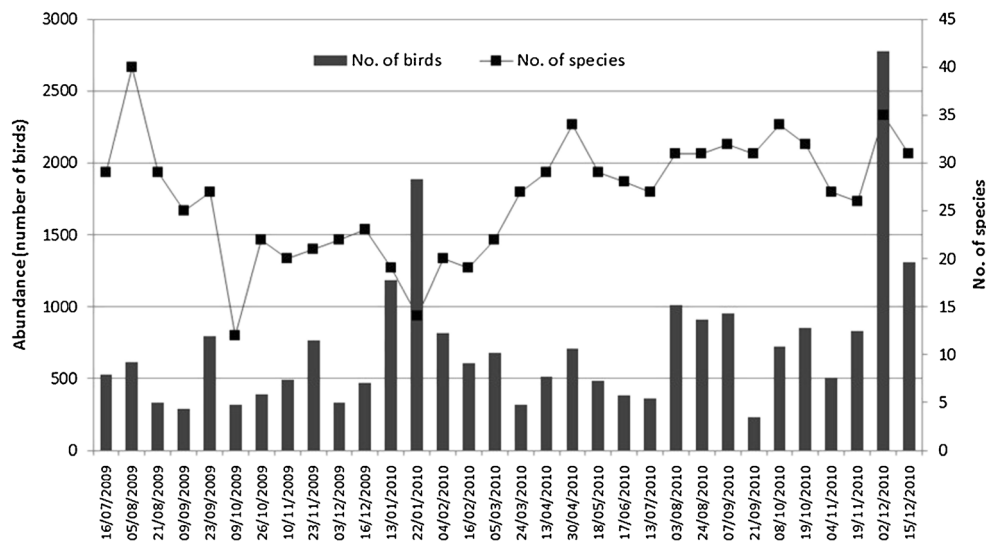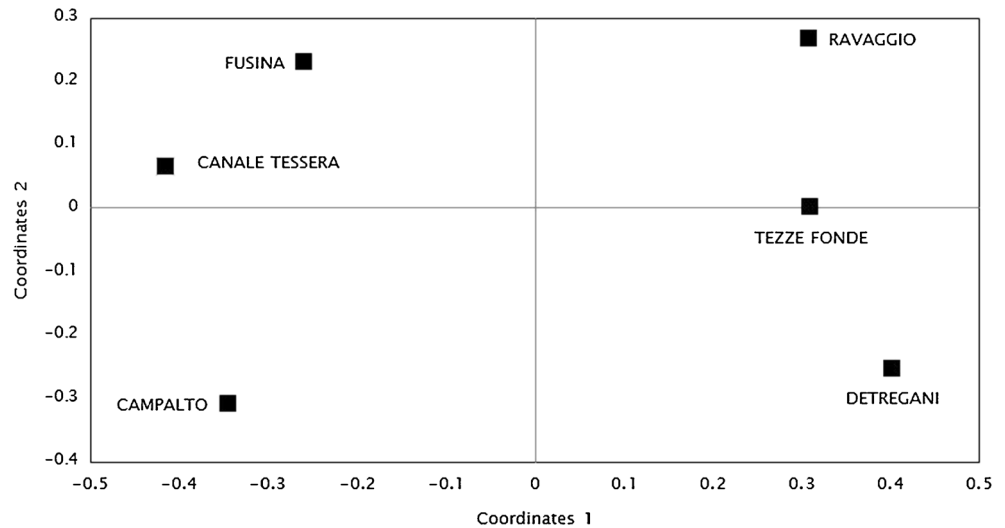**Fig. 2** Total number of birds and species observed per visit

Fig. 3 N-MDS ordination plot showing distribution of study sites according to bird occurrence observed over 18 months (Stress value: 0.05)

Abundance and temporal variation of bird guilds

At our study sites, ducks occurred throughout the year, but with only two to four species; the maximum was recorded during the post-breeding migration, as was also the case for herons (eight species observed). Waders richness peaked (22 species) during the post-breeding migration, with the second-richest period (15 species) being the pre-breeding migration. A similar pattern with the highest richness during post-breeding migration was shown by gulls and terns (nine species overall), and birds of prey (nine species). Among the 43 species of Passerines, only four were observed throughout the whole year, whereas 36 occurred only during the post-breeding migration.

Among ducks, the most abundant species were the Mallard *Anas platyrhynchos* (583 birds; 2.5 %) and the Shelduck *Tadorna tadorna* (293 birds; 1.3 %), both which were observed resting, feeding or nesting. Among cormorants (177 birds, 0.75 %), the occurrence of the Great Cormorant *Phalacrocorax carbo* was negligible, whereas the Pigmy Cormorant *P. pygmeus* was observed several times feeding inside the ponds during high tides or resting on the containment poles. Herons were far more abundant (788 birds; 3.4 %); the commonest species was the Little Egret *Egretta garzetta* (711 birds, 3.0 %), followed by the Grey Heron *Ardea cinerea* (57 birds, 0.2 %), both which were observed feeding on the ponds and resting. Diurnal and nocturnal raptors accounted for 0.3 % of the total, with 73 birds; among these, the majority were Western Marsh Harriers *Circus*

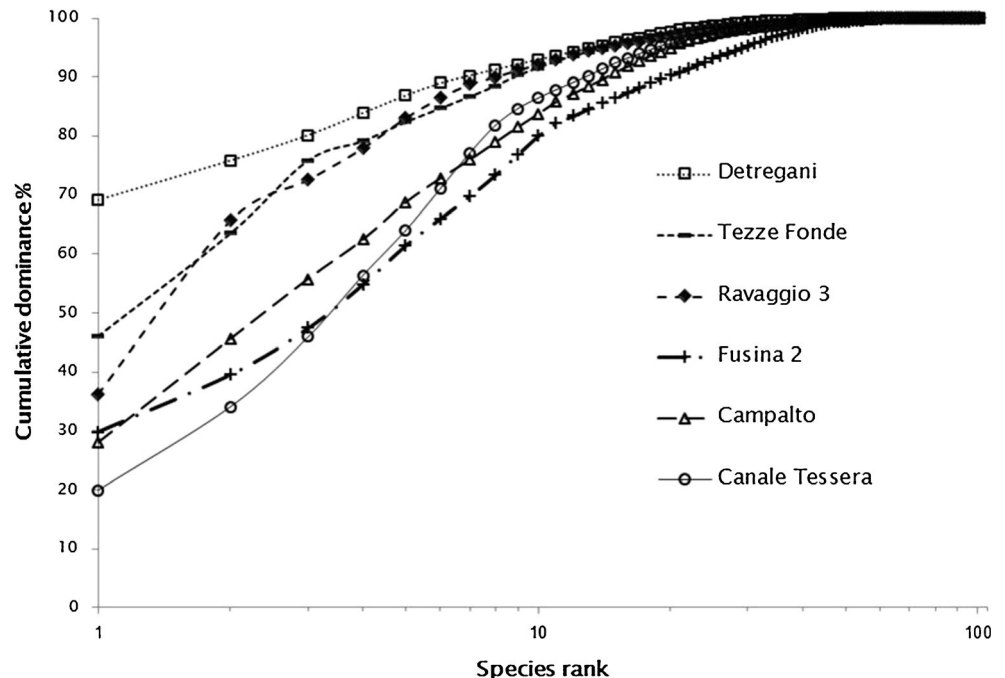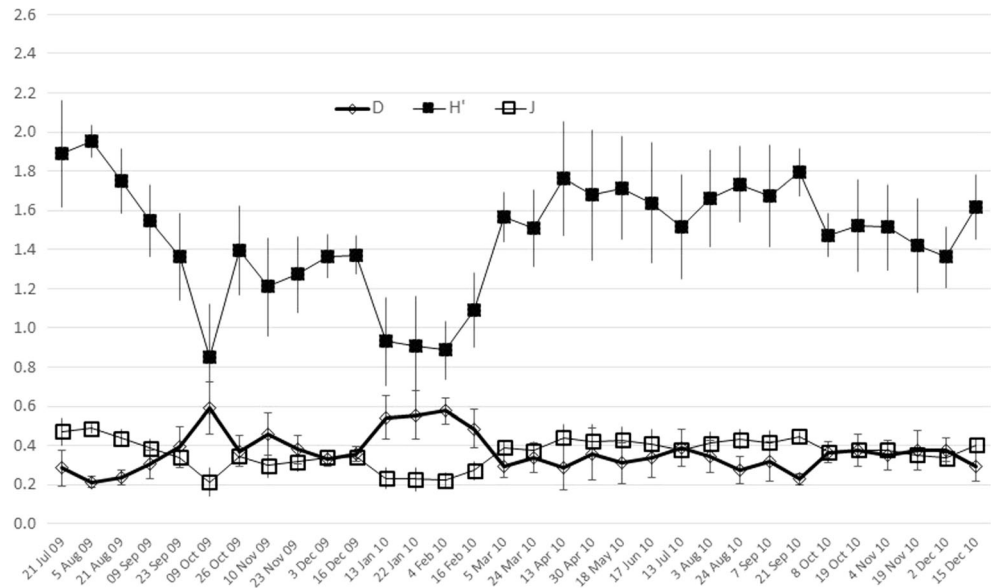**Fig. 4** K-dominance plot for bird assemblages on the six dredge islands

Fig. 5 Diversity indices (mean values at six sites ± SE) for each survey. Abbreviations: *D* Simpson index, *H'* Shannon index, *J* Pielou index

aeruginosus (22 birds, 0.1 %), Common Buzzards *Buteo buteo* (19 birds, 0.1 %) and Hen Harriers *Circus cyaneus* (11 birds, <0.1 %). Only one nocturnal raptor, the Short-eared Owl *Asio flammeus* was observed three times, hunting over the islands or resting throughout the vegetation.

Waders were the most abundant guild, with 11,109 birds (47.5 %): the commonest species were the Dunlin (7417 birds, 31.7 %), the Curlew (1174 birds, 5 %) and the Grey Plover *Pluvialis squatarola* (909 birds, 3.9 %). These three species used dredge islands mostly for foraging in the interior tidal flats or in the tidal ponds and secondarily for resting, often atop the containment poles. The abundance of waders increased into the winter period with peaks observed during the mid-winter period (Fig. 6). The density (mean ± SE) of waders feeding during the wintering season (six surveys made in December and January) for the three most abundant species was 50.1 ± 19.9 birds/ha for Dunlin, 6.9 ± 5.4 for Grey Plover and 4.8 ± 1.5 for Curlew.

The mean ± SE ($N = 192$, i.e. 6 sites*32 visits) density of feeding waders per ha of suitable habitat and according to tidal levels is shown in Fig. 7; waders were found within a high range of tide levels, with the lowest values either at levels below 0 cm, i.e., when the natural tidal flats surrounding the dredge islands began to become exposed, and at high tide levels, above +80 cm when dredge islands became mostly or totally flooded. Differences among densities were highly significant ($\chi^2 = 141.9$, d.f. = 5, $P < 0.001$).

Among the remaining waders, the Common Snipe (234 birds, 1 %) was observed in most of the surveys, with birds along the edge of tidal pools or amidst the salt-marsh vegetation, most often when the ground surface was covered with a few centimeters of water. Among gulls and terns, the Yellow-legged Gull, was the most abundant (4269 birds: 18.2 %) and was frequently observed perched on the containment poles or sitting on the ground. Less abundant were the Black-headed Gull (1568 birds; 6.7 %), the Little Tern and the Black Tern *Chlidonias niger* (both 77 birds, 0.3 %). Aeroplankton feeders were represented by the Barn Swallow *Hirundo rustica* (243 bird, 1 %), the Bee-eater *Merops apiaster* (22 birds, 0.1 %) and the Sand Martin *Riparia riparia* (44 birds, 0.2 %). Among Passerines, the most abundant species were the Meadow Pipit *Anthus pratensis* (987 birds; 4.2 %), followed by the Common Reed Bunting *Emberiza schoeniclus* (686 birds, 2.9 %), the European Starling *Sturnus vulgaris* (874 birds, 3.7 %), European Goldfinch *Carduelis carduelis* (648 birds; 2.8 %) and Yellow Wagtail *Motacilla flava* (153 birds, 0.7 %).

Several species observed at our study sits had high conservation status: 28 of them were included in the Annex 1 of the EU Birds Directive, 14 were listed as SPEC 1, 2 or 3 (Birdlife International 2004) and 20 species are considered as "threatened" (i.e., classified as Critically Endangered, Endangered or Vulnerable) in the Italian Red List (Peronace et al. 2012). Among the species of

Table 2 Results of ANOSIM pairwise comparisons among seasons: *R* values are reported, with *P* values in brackets. Significant comparisons are in bold

	Spring migration	Nesting season	Autumn migration	Wintering season
Spring migration		0.06 (0.26)	**0.47 (0.006)**	0.18 (0.10)
Nesting season	0.06 (0.007)		**0.70 (0.003)**	**0.52 (0.005)**
Autumn migration	**0.47 (0.007)**	**0.70 (0.003)**		0.05 (0.25)
Wintering season	0.18 (0.10)	**0.52 (0.005)**	0.054 (0.25)	

Fig. 6 Number of wader species and individuals observed at the six dredge islands
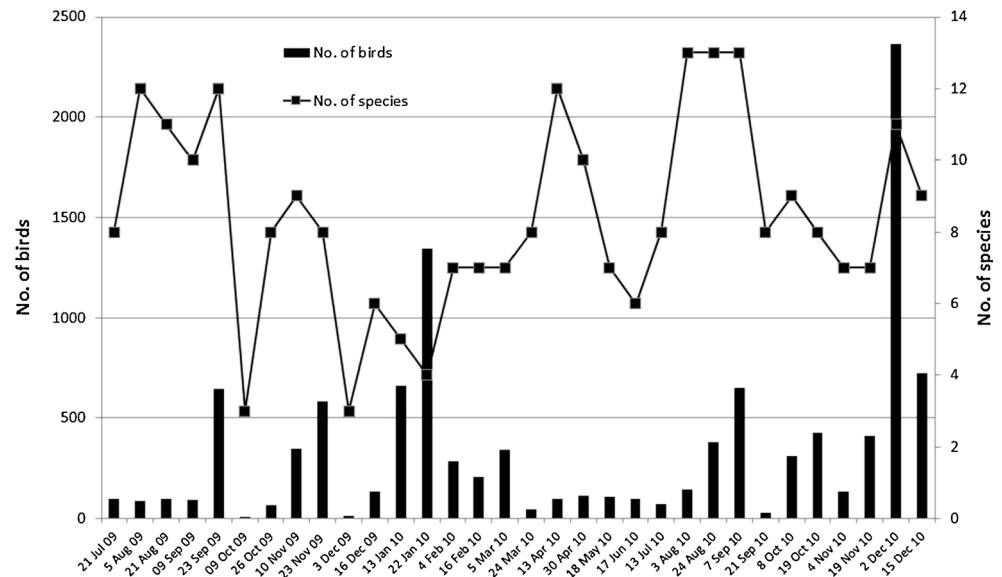
European concern, the regular roccurrence of the Pigmy Cormorant (SPEC 1) as well as the Lapwing *Vanellus vanellus*, Curlew, Redshank and Corn Bunting *Emberiza calandra* (all SPEC 2), is notable.

Breeding species

Fifteen species nested at the study sites; among these, several species were of conservation concern. The most threatened of these were the Kentish plover (EN) and the Shelduck (VU). The commonest species that nested at each site were Black-winged Stilt *Himantopus himantopus*, Redshank and Yellow Wagtail *Motacilla flava*. The number of breeding species at each dredge island ranged between three (Detregani) and ten (Canale Tessera and Ravaggio 3). Overall, we estimated the occurrence of 243 breeding pairs: the most abundant species

(Table 3) were Yellow-legged Gull (119 pairs), Black-winged Stilt (20 pairs), Redshank (14 pairs).

According to the occurrence of nesting species, the cluster analysis (not shown) identifies three possible site groups: Detregani-Campalto, Fusina 2-Canale Tessera, Tezze Fonde-Ravaggio 3. ANOSIM test performed on these groups gave a global R of 0.47, with a P value (=0.06) only at the threshold of significance. The SIMPER analysis shows the largest cumulative contribute, about 60 %, to the overall dissimilarity was due to the Black-winged Stilt, Zitting Cisticola *Cisticola juncidis*, Redshank and Mallard.

Species and habitat relationships

The simultaneous ordination of the six habitats, as described by the 100 species, was obtained using the first two axes

Fig. 7 Density (mean ± SE, birds/1 ha of suitable habitat) of feeding shorebird and tidal levels, all 32 surveys considered. Below the 0 level natural surrounding tidal flats become exposed, whereas above 80 cm dredge islands are totally inundated
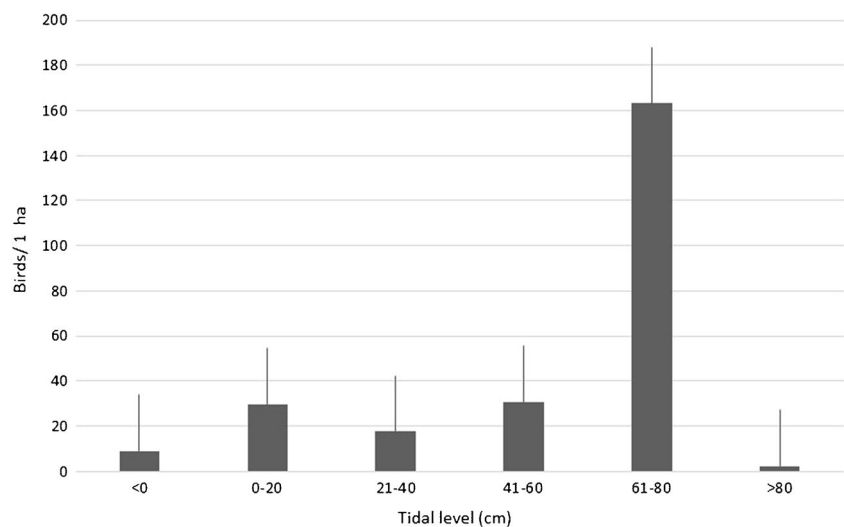
Table 3 Density of breeding species: no. of pairs/10 ha, total surface of dredge islands considered

	Campalto	Canale Tessera	Detregani	Fusina 2	Ravaggio 3	Tezze Fonde	Mean	± 1 SE
Tadorna tadorna	0	1.05	0	0	0	0	0.18	0.18
Anas platyrhynchos	2.92	4.21	0	0.75	1.37	1.62	1.81	0.62
Haematopus ostralegus	1.46	1.05	0	0	0.69	0.81	0.67	0.24
Humantopus himantopus	2.92	10.54	3.61	1.49	1.37	0.81	3.46	0.27
Recurvirostra avosetta	1.46	1.05	0	0	0	0	0.42	1.48
Charadrius alexandrinus	0	0	0	0.75	0	0	0.12	0.12
Tringa totanus	2.92	5.27	6.02	0.75	0.69	2.44	3.01	0.91
Larus michahellis	0	0	0	0	75.39	7.31	13.78	12.38
Galerida crestata	0	0	0	0.75	0	0	0.12	0.12
Alauda arvensis	0	1.05	0	1.49	1.37	0.81	0.79	0.27
Motacilla flava	1.46	3.16	2.41	2.24	4.11	3.25	2.77	0.38
Saxicola torquatus	1.46	0	0	0	0.69	0	0.36	0.25
Cisticola juncidis	0	3.16	0	1.49	1.37	0	1.00	0.52
Carduelis carduelis	0	0	0	0	0.69	0	0.11	0.11
Emberiza calandra	0	1.05	0	1.49	0	0	0.42	0.27
Total	14.58	31.61	12.03	11.19	87.73	17.06	29.03	12.13

extracted from the first two eigenvectors of the correspondence analysis (Fig. 8). The first two axes explain the 81.6 % of the total variability (axis 1 = 58.7 %, axis 2 = 22.9 %) The "density" of species (dots in Fig. 8) shows the preference of the observed species for the PC habitat (first group, bottom left), opposed to another group of several habitats (RV, BA and SR) with a high density of species. Fewer species were found in the SA and LP habitats.

The Jacobs' index was used to evaluate a possible preference of the observed species for the habitats occurring at
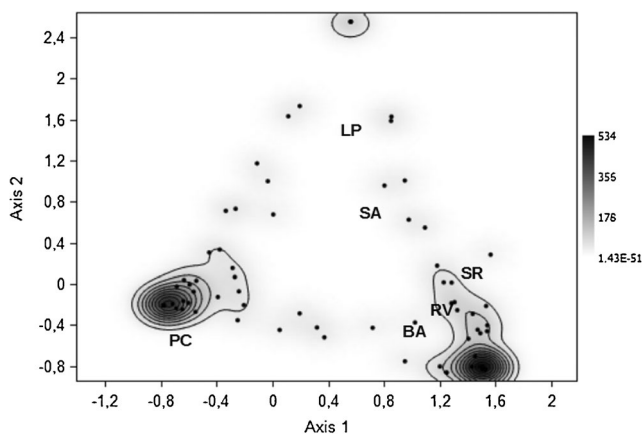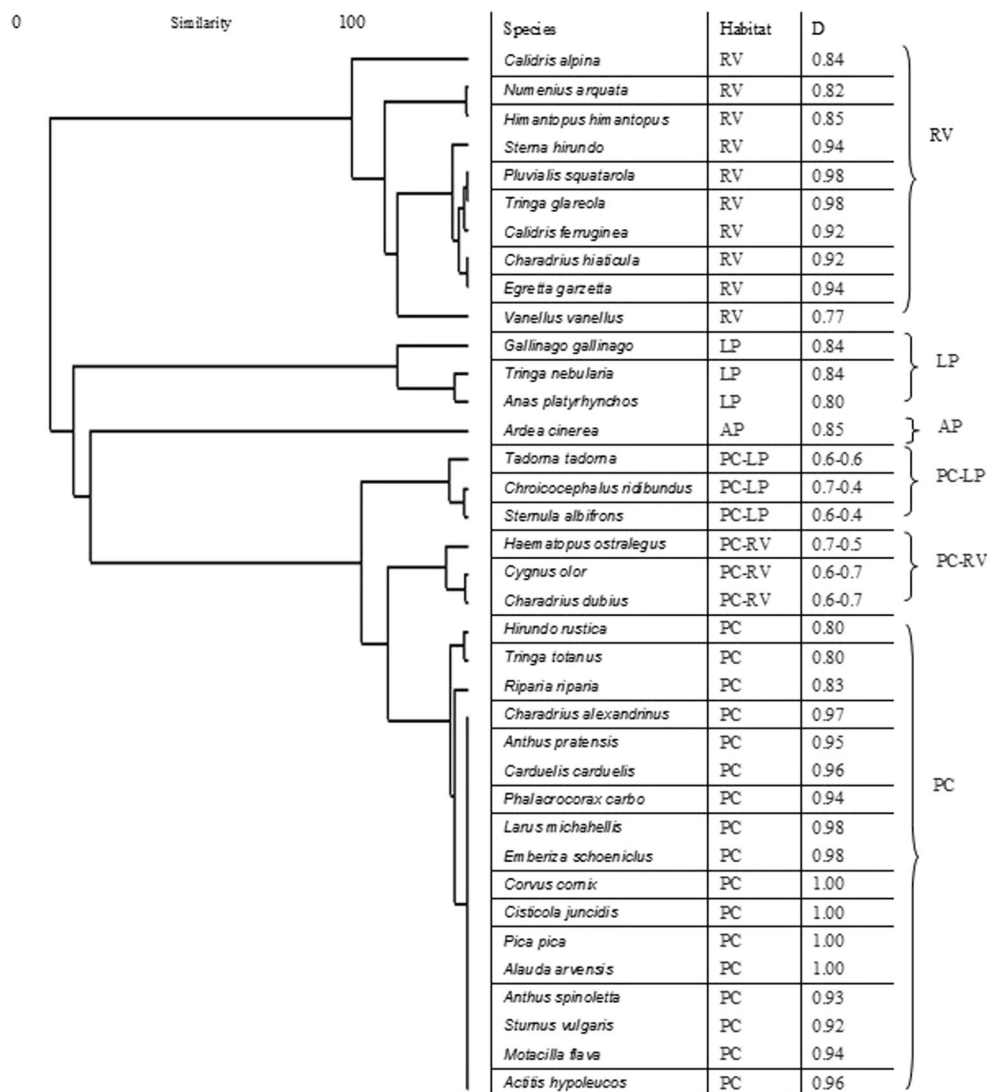

Fig. 8 Simultaneous ordination of the 100 species and the six habitats, using the kernel density estimator with the first two axis extracted from the first two eigenvalues of CA. Symbols and abbreviations: ● = species; *grey areas*, maximum density of species; *BA* bare areas; *LP Limonium/Puccinellia/Aster/Juncus/Spartina* dominated; *PC* tidal pools, tidal creeks and interior tidal flats; *RV* dykes and mounds, with ruderal or halo-nitrophilous vegetation; *SA Salicornia* sp. dominated; *SR Sarcocornia/Halimione*-dominated

dredge islands, considering the abundance of birds that used the different habitats. The highest preference was shown for the habitat PC (D = 0.71) and RV (D = 0.34). Habitats that were less used, comparing their availability, were LP (D = −0.19), BA (D = −0.48), SR (D = −0.74) and SA (D = −0.94). In other words, the habitat "Tidal pools, tidal creeks and interior tidal flats", covered about 20 % of the total extension and was used by 60 % of the individuals observed. The Jacobs' index was also calculated for each of the 100 species considered; 86 of these showed a strong preference for a single habitat, with a Jacobs' index >0.8. Using a reduced list of 37 species (those with at least 32 individuals, i.e., a mean of 1 bird/survey), we obtained the dendrogram of the hierarchical classification of the species, according to their similarity (Fig. 9). Species or groups of species clearly preferred one particular habitat: we observed six groups of species, each of which associated with a single habitat. Seventeen species, mostly waders, preferred the PC habitat, whereas ten species, mostly Passerines, preferred the RV habitat. Smaller groups of species were associated with the remaining habitats.

Behaviour of birds

About 67 % of the birds observed were feeding, 13 % were resting and 7 % breeding; for the remaining 13 %, behaviour could either not be ascertained or it was classified as "flying over the site". Differences of different behaviours among the guilds were statistically significant ($\chi^2 = 12{,}537$, $P < 0.001$, d.f. = 21). Feeding behaviour was particularly common (more than 80 % of birds involved) among waders, herons and

Fig. 9 Dendrogram of the
hierarchical classification of the
species obtained applying the
mean linkage to the matrix of the
correlation coefficients calculated
from the abundance values of the
matrix 37 species * 6 habitats.
The most preferred habitat for
each species is reported in the
third column, with the observed
Jacobs' index values (*D*) in the
fourth column. Abbreviations: *BA*
bare areas; *LP Limonium/
Puccinellia/Aster/Juncus/
Spartina* dominated; *PC* tidal
pools, tidal creeks and interior
tidal flats; *RV* dykes and mounds,
with ruderal or halo-nitrophilous
vegetation; *SA Salicornia* sp.
dominated; *SR Sarcocornia/
Halimione*

Species	Habitat	D	
Calidris alpina	RV	0.84	RV
Numenius arquata	RV	0.82	
Himantopus himantopus	RV	0.85	
Sterna hirundo	RV	0.94	
Pluvialis squatarola	RV	0.98	
Tringa glareola	RV	0.98	
Calidris ferruginea	RV	0.92	
Charadrius hiaticula	RV	0.92	
Egretta garzetta	RV	0.94	
Vanellus vanellus	RV	0.77	
Gallinago gallinago	LP	0.84	LP
Tringa nebularia	LP	0.84	
Anas platyrhynchos	LP	0.80	
Ardea cinerea	AP	0.85	AP
Tadorna tadorna	PC-LP	0.6-0.6	PC-LP
Chroicocephalus ridibundus	PC-LP	0.7-0.4	
Sternula albifrons	PC-LP	0.6-0.4	
Haematopus ostralegus	PC-RV	0.7-0.5	PC-RV
Cygnus olor	PC-RV	0.6-0.7	
Charadrius dubius	PC-RV	0.6-0.7	
Hirundo rustica	PC	0.80	PC
Tringa totanus	PC	0.80	
Riparia riparia	PC	0.83	
Charadrius alexandrinus	PC	0.97	
Anthus pratensis	PC	0.95	
Carduelis carduelis	PC	0.96	
Phalacrocorax carbo	PC	0.94	
Larus michahellis	PC	0.98	
Emberiza schoeniclus	PC	0.98	
Corvus cornix	PC	1.00	
Cisticola juncidis	PC	1.00	
Pica pica	PC	1.00	
Alauda arvensis	PC	1.00	
Anthus spinoletta	PC	0.93	
Sturnus vulgaris	PC	0.92	
Motacilla flava	PC	0.94	
Actitis hypoleucos	PC	0.96	

Passerines. Resting was the commonest behaviour among
gulls and terns, which rarely fed on the dredge islands, apart
from the Little Tern. The cluster analysis identified three
groups: ducks–herons, raptors–aeroplancton feeders–cormo-
rants and gulls + terns–Passerines–waders. These three groups
were well separated (ANOSIM test: global $R = 0.89$,
$P < 0.05$).

The percentage of birds observed while feeding, out of the
total observed, was high in all surveys and reached the highest
values in late autumn/winter, and the minimum in April–June.
Considering only feeding birds, the habitat PC had a greater
use than expected from its relative availability ($D = 0.87$),
whereas RV was used in proportion to its availability
($D = 0.04$). In contrast, SA and BA were almost completely
avoided ($D = -0.96$, for both). Both PC and BA habitats
offered a clear visibility of the birds occurring there to the
surveyors, whereas the other habitats did not; it is thus likely

that this somewhat reduced the number of birds actually seen
foraging in the latter habitats.

Discussions

We observed 101 species of birds, a result that compares well
with other similar studies performed at dredge islands: 48
species in 1 year by Melvin and Webb (1998), 91 species over
3 years (Gallego Fernández and García 2007), or 121 species
(Erwin and Beck 2007). Much higher values, such as 280
species (Erwin and Beck 2007) or 289 species (Guilfoyle
et al. 2007) reflect the very long period of those surveys per-
formed at dredge islands in subtropical coastal wetlands,
which are richer in species than temperate wetlands. Other
types of man-made wetlands are known to support a rich bird
community: 103 species were observed over 3 years in a

restored fresh-water site in Belgium (Beauchard et al. 2013), 48 species in agricultural ponds in Spain (Sebastián-González et al. 2010), 69 species in a saltpans-lagoon complex in NE Italy (Boldreghini and Dall'Alpi 2008) and 67 species in salt evaporation ponds and other artificial wetlands in Sri Lanka (Bellio et al. 2009). Considering that the lagoon of Venice is used throughout the year by about 300 species, about 30 % of these were observed at least once at the six dredge islands. The high number of species observed at our study sites, despite their relative small size, was certainly due to the occurrence of different suitable habitats and to the relatively low degree of anthropogenic disturbance, which we deem to be of particular relevance in a wetland that is as intensively used by man as the lagoon of Venice. The importance of disturbance, both human- and naturally induced, in shaping bird communities at wetland sites has been often studied elsewhere (see for Italian examples Malavasi et al. 2009) but detailed analysis are lacking for our study area.

The occurrence, and sometimes even the reproduction, of several species of conservation concern among the 101 species we observed emphasizes the importance of our study sites for bird conservation and confirms the findings of other studies, i.e., that dredge islands may offer suitable habitats for species that are uncommon elsewhere and that usually exploit only particular wetland habitats (Erwin and Beck 2007; Guilfoyle et al. 2007). Over the last decade it has been observed (Scarton 2008, 2010) an increase in the number of breeding pairs at dredge islands, and a concomitant decrease of their number at natural saltmarshes, which were the traditional nesting sites; it is likely this is an adaptive response to the raise in mean sea level and high tides frequency which have been documented very recently in the lagoon of Venice (about 10 cm between the years 2000 and 2013: Comune di Venezia 2014). Due to the expected sea level rise in the next decades (Ferrarin et al. 2013), the importance of artificial intertidal sites as an alternative nesting sites for waterbirds may become more and more evident.

Overall, the abundance and richness values observed at the study sites are typical of temperate wetland sites, with a few dominant species and many other species with few or very few individuals (see Redolfi De Zan et al. 2011 and Malavasi et al. 2009 for Italian wetlands; Tourenq et al. 2001 for the Camargue; Ysebaert et al. 2000 for the Schelde estuary). Diversity reached a peak during the post-breeding migration, when the whole lagoon of Venice is used as a stopover site by a very large number of birds migrating south; the availability of additional feeding and resting habitats, such as those occurring in the dredge islands, may thus play a significant role in enhancing survival of the individuals during migrations.

Among the most abundant wintering species the Dunlin, Curlew and Grey Plover regularly used dredge island habitats, in particular, the inner tidal flats and the tidal ponds for foraging. Due to the their mean elevation above sea level, these feeding habitats are still available to waders even when the surrounding tidal flats are completely submerged by the tide. According to our results, the feeding areas located within dredge islands might play an important role for waders at a lagoon scale, especially in winter. This confirms the importance of man-made coastal wetlands for the foraging of waders, as already observed at salt ponds (Múrias et al. 2002; Dias et al. 2014), abandoned basins for underground salt deposits (Davidson and Evans 1986), rice fields (Fasola and Ruiz 1996) and newly created intertidal habitats (Evans et al. 1998; Mander et al. 2007).

The densities of the three most common waders observed feeding at the dredge islands are in the range of those reported for the tidal flats of the whole lagoon of Venice (4.5 birds/ha: Scarton and Bon 2009) or of those observed elsewhere in Europe (0.4–98.0 birds/ha: van de Kam et al. 2004). Comparisons must be made cautiously, due to large differences in the size of the tidal flats considered by the different authors, but they indicate that dredge islands have at least some functional attributes similar to those of tidal flats. The mean daily occurrence (totaled for all six dredge islands) of dunlins, grey plovers and curlews in the winter months was 607, 97 and 53 birds, respectively. Comparing these data with the totals censused in the whole lagoon in the same winters (Bon and Scarton 2012), fractions between 2.3 % (Dunlin) and 9.6 % (Grey Plover) of the whole wintering populations of these waders were observed during a single survey. Since our study sites comprised about 6 % of the total dredge island area available in 2009–2010 in the lagoon, it is likely that large fractions of these shorebird populations exploit the dredge island habitats for foraging during a single winter. These results agrees with findings of Evans et al. (1998) and Dias et al. (2014) on the use of aquatic man made habitats as alternative feeding sites.

Nevertheless, our field observations showed that when tidal flats became exposed during the receding tide, waders began to leave the dredge islands, indicating that the surrounding tidal flats must be more profitable as foraging locations. A very likely causal factor is that tidal flats are richer in preys than the sediments contained inside dredge islands. This is probably due to different grain size composition, which in turn affects the distribution of many benthic wader preys (Spruzen et al. 2008; Jing et al. 2007). Evans et al. (1998) observed that after 4 years, sediments of man-made intertidal habitats were still poorer in prey biomass than tidal flats. Our study sites had a mean age of 13 years, which indicate that reaching comparable biomass densities may take even more years; comparative data between tidal flats and dredge islands prey biomass at our study area are lacking at the moment to support this hypothesis.

Considering only Passerines, the ten most abundant species included typical wetland species (such as *A. pratensis*, *E. schoeniclus*, *M. flava*, *C. juncidis*) as well as non-wetland

species, in particular, several that are well-adapted to human presence, such as the European Starling, the Hooded Crow *C. cornix* and the Magpie *P. pica.* This was likely due to the generally low distance of the dredged islands from the densely human-populated mainland and to the occurrence at dredge islands of patches of ruderal and halo-nitrophilous vegetation. Among non-wetland species, we did not observe an intensive use of the salt marsh habitats by the House Sparrow *Passer europaeus*, in contrast to the findings of Malavasi et al. (2009) for a Mediterranean costal wetland. Moreover, our study sites also lacked most of the typical reedbed dwellers since the occurrence of *Phragmites australis* was negligible and was limited to only two dredge islands.

The nesting community was low in species (15), while it comprised several species of conservation concern. Between 2005 and 2007, Scarton et al. (2013a, b) found that populations of national relevance were nesting in the 88 dredge islands existing at that time, and this still holds true; nevertheless, the large occurrence in these artificial sites of Yellow-legged Gull, a species which may negatively affects survival, fecundity, foraging ecology and nesting habitat availability for many species (see for a detailed review of this topic Oro and Martınez-Abrain 2007), is a cause of concern and should be limited.

Birds were not randomly distributed, either across sites or habitats. Jacobs' index showed that birds disproportionally used tidal ponds, creeks, inner tidal flats and, far less, dykes and mounds with ruderal vegetation, whereas *Salicornia*- or *Sarcocornia*-dominated areas were almost avoided. This was even more evident considering only the observations of feeding birds, with tidal ponds showing almost the maximum positive selection. This was clearly due the large percentage of waders among the birds recorded, whereas Passerines preferably used areas with non-halophytic vegetation. It is certainly possible that the lower detectability of birds among some habitats might have slightly biased these results, but walking throughout the site allowed us to flush out and count all the birds occurring there, even those that were more reluctant to leave (such as the Common Snipe). A high availability of feeding resources and clear visibility of possible predators are the probable reasons for the prevalent use of ponds, creeks and especially inner tidal flats, as observed elsewhere (Jing et al. 2007; Van Dusen et al. 2012).

Conclusions

The results obtained from this study can be used for designing new dredge islands and to manage those already existing. It is essential that low elevation habitats, such as tidal ponds and tidal creeks are always present and maintained. Inner tidal flats formed naturally at dredge islands, both following construction operations (sediment was discharged at various locations

but always in the center of the containment site, which usually produced lower elevation areas around the edge), or due to surface erosion of the softer sediment areas. Given the high values of inner tidal flats for foraging waders, their occurrence should be planned at each site; moreover, reshaping of the soil at already existing dredge islands, which do not show this habitat feature, would greatly increase their value for birdlife.

Ruderal vegetation and bushes, which are confined to areas slightly elevated and thus less prone to flooding, were used by many Passerines as foraging or resting sites, mostly during pre- and post-breeding migration, or in winter. The planning or construction in new dredge islands of a few mounds with a higher elevation than the surrounding area may thus increases the diversity and value of these artificial habitats islands for this group of birds. On the other side, one should note that bushes are also used by predators such as Corvidae or falcons, which need high perch to search for prey; the occurrence of these species, in particular falcons, may depress wader abundance at salt marshes otherwise suitable as feeding site (see Jing et al. 2007).

Finally, sedimentation due to tidal submersion and especially salt marsh vegetation encroachment, natural processes that occur during the ageing of dredge islands, reduce the extension of the open habitats; this contributes to making dredge islands more aesthetically, and maybe functionally, similar to the surrounding salt marshes. However, it greatly reduces the number of individuals and species that might find suitable sites for feeding and resting. For these reasons an active management, such as vegetation cutting, soil profiling and the disposal of new freshly dredge sediments should be performed to maintain a mosaic of suitable habitats and the resulting high value of dredge islands for a large number of birds.

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