Salt Marshes and Biodiversity

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Abstract

Estuaries and coastal lagoons around the world are wetlands of great importance and they are regularly targeted as prime conservation sites. Many include wildlife refuges and have nature reserves that were set up in areas preserved from development in order to keep valuable species and habitats, while maintaining traditions and sustained use.

Tidal wetlands are often mentioned in the literature as natural habitats with high biological productivity. The net primary production in a salt marsh is often higher than in temperate or tropical forests and this productivity is directly linked to the important role halophytes play in estuaries, in terms of the value-added.

Salt marshes may be a sink of heavy metals. The ability to phytostabilize contaminants in the rhizo-sediment is an important aspect in the self-remediative processes and biogeochemistry of this ecosystem, and will help filtering natural and anthropogenic loads of nutrients and pollutants discharged into the wetland.

There is also a provision of rare and unique habitats, which support nursery grounds for commercial fish and wildlife, including vital feeding grounds for many migratory birds. Rediscovered as a new source of amenity and leisure activities for the population living in urban areas, salt marsh halophytes and estuaries have an important role in the preservation of biodiversity.

In this paper we discuss the support of the salt marsh ecosystem to the estuarine birds, and consequently its contribution for biodiversity.

1 Wetlands and Civilization

The wealth of life in estuarine systems has been known to our early ancestors and wetlands of this type were source of food and amenities to groups of hunter-gatherers, many thousand years before the foundation of cities and permanent human settlements.

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Wetlands were also instrumental to the rise of Civilization. High biological productivity means better feeding opportunities and easier food-gathering. This allowed free time after completing the basic tasks of picking up food enough for survival, therefore leaving room for abstract thinking and other elaborate uses of the human mind.

This connection has deep roots and includes amazing examples. For instance, let us consider the Epic of Gilgamesh, the oldest-known example of written literature in the world, telling the saga of a king in the early Sumerian city of Uruk (ca. 2500 BC). Successive versions of this 4,000-year-old poem with a surprisingly actual plot have been recovered from archaeological sites in the territory of modern Iraq, where the standard version was discovered by Austen H. Layard in 1849. It was kept in the library of Ashurbanipal in Nineveh and did survive from the seventh century BC written in clay tablets manufactured from sediments presumably extracted from wetland soil. The story was written in cuneiform characters, tiny wedge-shaped symbols pressed on the wet clay by expert hands holding a blunt-shaped piece of reed used as a stylus [1].

The people from nearby Egypt also knew well about the biological wealth associated to wetlands. Gifted artists left us lively scenes of wildfowl hunts in the papyrus beds of the Nile Delta. Papyrus itself was harvested extensively for manufacture of their prime writing material, a time-honored ancestor of the paper this book is printed on.

2 Wetland Fees and Services

Wetlands have great ecological value, and they deliver a wide range of ecosystem services that have been evaluated as some of the most valuable services for humanity [2–4]. Services associated to estuarine and salt marsh ecosystems in a global scale include: nutrient cycling, primary production, habitat for wildlife, and shoreline stabilizers. The most important benefits are obtained in the fields of sea defense, immobilization of pollutants, and the provision of rare and unique habitats, which support nursery grounds for fish and breeding/feeding grounds for birds.

Salt marshes are listed as sensitive habitats that must be protected under the European Habitats Directive [5]. Their important role has been confirmed by the recent inclusion of these ecosystems in the Water Framework Directive (WFD). Multiple services of wetlands and their value are well known. Vascular plants in salt marshes are crucial to the dynamics of the estuarine ecosystem, strongly influencing the processes of retention of pollutants, reduction of eutrophication, and mitigation of carbon dioxide release to the atmosphere. We know that the major carbon sink of the planet are the oceans (38,630 Pg C), followed by the terrestrial zones. Considering the terrestrial sink only (1,400 Pg C), the more productive habitats and most important zones retaining carbon are in wetlands, which contribute 1/2–1/3 (455–700 Pg C) to this component of the world carbon sink [6].

Areas of salt marsh in estuaries are very important N sinks associated to the production of plant biomass (i.e. the incorporation of N in standing biomass, detritus, litter, and sediments) [7–10] and also through denitrification [11]. Therefore, these processes may contribute to counteract eutrophication in coastal areas [12]. In fact, most of the land-derived nitrogen that loads to coastal environments, in non-human-impacted environments, could eventually be denitrified in estuarine and shelf regions [13, 14].

Wetlands of the estuarine type are often mentioned in the literature as prime examples of natural habitats with very high values of net primary production, directly linked to the important role they play in estuaries, in terms of the value-addition. The net primary production of a tidal salt marsh can be higher than net primary productions of the temperate or tropical forests. Typical values for Net Primary Production in a tropical forest may reach 2.50 kg m^{-2} $year^{-1}$ and in a temperate forest it will stay at 1.55 kg m^{-2} $year^{-1}$. Wetlands of the tidal salt marsh type in the Tagus estuary have Net Primary Production between 1.18 and 3.50 kg m^{-2} $year^{-1}$ [15], in line with production figures around 3.00 kg m^{-2} $year^{-1}$ for coastal wetlands in NW France [16]. Higher values are not uncommon elsewhere, up to an impressive 8.00 kg m^{-2} $year^{-1}$ in the southern Coastal Plain of North America [6]. These figures stand well above typical production values for most other habitats, including fertilized crops in cultivated areas [6, 16].

There is no miracle to this. The modern ecologist knows that wetlands are so productive when compared to most ecosystems because they are blessed with a rare combination of key environmental factors that are essential for plant growth. Carbon dioxide is readily available from the atmosphere, and in tidal wetlands water is seldom a limiting factor. There is often a regular supply and adequate recycling of nitrogen, phosphate and other nutrients. Sunlight needed to photosynthesis reaches near to the ground uncluttered by overhead vegetation canopies and it penetrates also the water column, travelling down to the limits allowed by turbidity and other factors. Due to their high productivity, these ecosystems have great importance concerning the recycling of organic matter by the microbial decomposers, in order to maintain ecological balance [17].

There is however one major drawback. Water masses involved in estuarine circulation typically hold dissolved salts in concentrations that far exceed the tolerance levels of most vascular plants. The salinity of water in estuaries is a complex issue and depends on the interaction of many factors, including the amount of marine water entering and leaving the estuary associated to the tidal cycle, the input of freshwater transported in the river flow upstream, and the local balance of precipitation versus evaporation.

3 Life in Wetlands

Living in wetlands requires special adaptations and environmental constraints faced by the estuarine organisms are often most demanding. Many estuarine organisms are in fact euryhaline and those living in the tidal areas must also be able to withstand abrupt changes to their physical environment. This includes cyclic submergence by tidal water alternating with periods of exposition to the atmospheric agents at low tide.

Fish and invertebrates in the water column may simply move in with the incoming tide and later leave with the receding ebb. However, the vascular plants and any organisms with limited capacity for locomotion must take in situ the changing conditions to their environment. An array of well-known adaptations is described in virtually any textbook dealing with wetland ecology [6, 18] and may include burying deep into the substrate, perhaps combined with an increase in the relative size of underground structures, when compared to those parts left aboveground.

Most vascular plants are unable to tolerate the high salt concentrations usually present in the tidal areas within estuaries and so they are excluded from the local vegetation. But for the few species with comparatively high salt tolerance (halophytes) there is an increased opportunity to establish viable populations and to expand their area around and colonize a bigger share of this habitat.

When compared to nearby areas free from the direct influence of saline tidal water, saltmarsh vegetation typical from estuaries of the temperate zone has only a limited number of species, therefore making for reduced biodiversity within these habitats. However, these halophytes compete to cover a larger share of the substrate available to them and in this process they originate a complex mosaic of salt prairies and open shrubby vegetation. Patterns in species distribution and density may be discernible and are formed according to the combined action of factors like water permanence and subtle gradients in topography [6].

When saltmarsh habitats are considered on a broader scale there is however a very substantial biodiversity increase to be gained from their presence in estuaries. Halophytes with their unique adaptations are able to colonize vast areas that otherwise would be devoid of significant vegetation. Therefore they bring increased habitat complexity and greater species diversity to the regions where they occur.

There is another and perhaps more important effect. The exceptionally high biological productivity rates which are so typical of most saltmarsh areas often result in a generous supply of detritus, food particles and nutrients that may be exported to nearby estuarine habitats and eventually into coastal waters [11].

Extensive mud flats and other sediment deposits in the tidal fringe of estuaries are by no means the barren wastes they usually look like. In fact, the influx of detritus and organic particles originating at nearby saltmarsh habitats allow these vast open spaces to support exceptionally rich invertebrate communities. There are many annelid worms, small crustaceans and shellfish (Mollusca) that spend most of their lives crawling underwater or buried into the sediments when they are exposed at low tide, and may therefore escape easy detection by the inexperienced [18].

Due to the extreme environmental constraints in estuarine habitats these invertebrate communities usually comprise a comparatively small number of species (hence they have reduced intrinsic biodiversity), but may have in turn huge populations with vast numbers of individuals, making up for a large biomass of food items that are preyed upon by many waders and other wetland birds [18].

Saltmarsh vegetation in estuaries also provides living habitat for animal communities. In the temperate regions there is a profusion of aquatic invertebrates (crustaceans and gastropod molluscs) among the strands of halophytes, and these communities may also include small spiders (Arachnida), insects and other terrestrial arthropods.

This bounty of food items attracts the larger consumers that may just move in to feed as appropriate, coming from different habitats in the adjoining areas. There are also migratory birds that occur seasonally and visit at specific times in the year, according to their own routines and long-range movements.

Shall we try to integrate these elements and see how they fit together in a case study highlighting the connections of saltmarsh halophytes, migratory birds and wetland conservation in areas close to important population centers.

4 The Tagus Estuary: Saltmarsh Halophytes and Birds

4.1 Study Area

The Tagus estuary is a large body of transitional water with a NE-SW direction on the western shore of the Iberian Peninsula, SW Europe (Fig. 1). The estuary spans 16 km across at maximum width and covers a total area of 320 km^2 (from aerial surveys) which include ca. 97 km^2 of tidal flats. The overall volume is $1{,}900 \times 10^6$ m^3 and water residence time averages 25 days. The tides are semi-diurnal and there is a tidal range of 2.6 m from the lowest neap tide to the highest spring tide [19].

Water depth may reach 46 m in small areas on the entrance channel but mean water depth in the Tagus estuary is only 10.6 m [19]. Sediment beds in shallow water are therefore common and up to 30 % of the estuarine area may become exposed at low tide. Mudflats predominate in the tidal areas but there are also large sand flats and vast deposits of dead oyster shells.

Most of these sediments hold no vascular plants but extensive tracts of saltmarsh vegetation are present in fringes along the margin and in small islets nearby. Saltmarsh vegetation covers a total of *ca.* 17.24 km^2 and colonizes *ca.* 18 % of the tidal areas on the Tagus (based on remote sensing) [20].

The northern (right) bank of the estuary is straight and narrow, contrasting sharply to the left bank (on the eastern and southern sides) in open lowland, with smaller bays and inlets allowing ample room for the development of saltmarsh vegetation.

Communication to the Ocean is made through a narrow channel oriented ENE-WSW (about 10 km long and 2 km across) opening to a sheltered bay and affording protection against high-energy oceanic waves. This makes for an exceptionally good natural harbour inside the estuary and was instrumental to the very existence

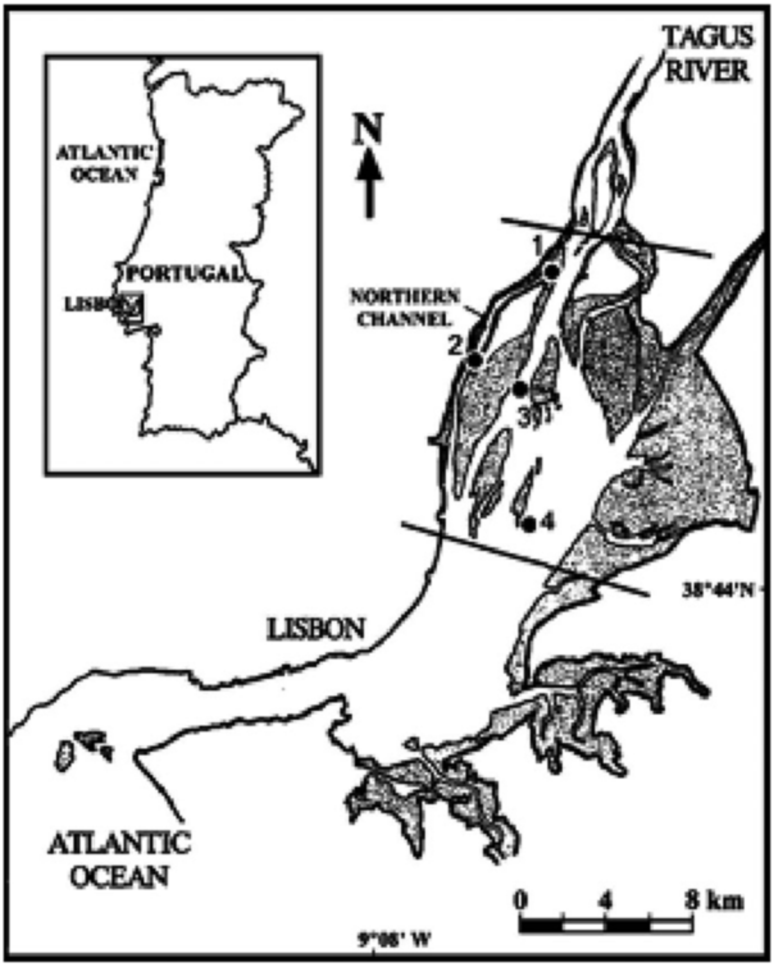

Fig. 1 Map of Portugal with the Tagus estuary area enlarged (Reprinted from Ref. [19])

of Olisipo (the classic Roman name for Lisbon city, allegedly established centuries before by the legendary Greek sailor Odysseus). It helped also the initial settlement associated to fishing activities and marine trade that reached historic predominance in the region, and later expanded to the point of making major contributions to the World's maritime history.

Unfortunately, some important areas colonized by halophytes in the estuary have been lost to industrial development and land reclamation projects starting around 1960. Often this was caused by inadequate evaluation of the economic and social relevance of these habitats. There was also competition for space coming from the salt industries in the past and many saltmarsh areas in the Tagus have been managed to make saltpans were tidal water was evaporated in order to concentrate the salts. These were subsequently used for commercial purposes, including keeping dried codfish brought into the estuary by the overseas fishing fleet, until the fisheries were lost in recent years and widespread refrigeration became a viable alternative. Many traditional saltpan complexes retain great ecological value within the estuary but were abandoned by economic reasons and now they are much sought after for quick conversion to industrial fish farms.

Table 1 Mean Biomass values in kg m^{-2} ($n = 5$) ± standard deviation for the period considered. The corresponding NPP and biomass losses, $p < 0.01$ (From Ref. [17])

	Oct	Dec	Feb	Apr	Jun	NPP	Losses (%)	Turnover ($year^{-1}$)
S. fruticosa								
Leaves	2.83 ± 0.97	0.63 ± 0.15	0.05 ± 0.02	0.07 ± 0.02	0.08 ± 0.02	2.79 ± 0.96	98.23 ± 1.11	0.98 ± 0.01
Stems	1.62 ± 0.70	0.70 ± 0.21	0.21 ± 0.07	0.12 ± 0.05	0.11 ± 0.03	1.61 ± 0.50	92.90 ± 4.76	0.93 ± 0.05
Roots	4.37 ± 0.50	4.57 ± 0.18	7.18 ± 0.37	5.35 ± 0.47	4.25 ± 0.16	3.01 ± 0.50	40.65 ± 3.36	0.42 ± 0.05
S. perennis								
Leaves	0.17 ± 0.04	0.06 ± 0.02	0.04 ± 0.00	0.04 ± 0.00	0.06 ± 0.01	0.13 ± 0.04	77.38 ± 6.66	0.77 ± 0.07
Stems	0.42 ± 0.04	0.15 ± 0.06	0.08 ± 0.00	0.04 ± 0.02	0.08 ± 0.02	0.38 ± 0.04	89.80 ± 4.02	0.90 ± 0.04
Roots	3.90 ± 0.33	4.17 ± 0.43	4.55 ± 0.21	4.86 ± 0.09	4.09 ± 0.15	1.01 ± 0.25	16.35 ± 2.33	0.21 ± 0.05
H. portulacoides								
Leaves	0.21 ± 0.06	0.07 ± 0.02	0.06 ± 0.01	0.05 ± 0.00	0.06 ± 0.02	0.17 ± 0.05	78.22 ± 3.97	0.78 ± 0.04
Stems	0.73 ± 0.12	0.32 ± 0.05	0.19 ± 0.05	0.18 ± 0.05	0.19 ± 0.03	0.57 ± 0.15	77.58 ± 8.07	0.78 ± 0.08
Roots	4.13 ± 0.11	3.58 ± 0.28	4.48 ± 0.27	4.42 ± 0.07	4.39 ± 0.23	1.02 ± 0.29	16.84 ± 8.64	0.23 ± 0.06
S. maritima								
Leaves	0.15 ± 0.06	0.06 ± 0.02	0.00 ± 0.00	0.10 ± 0.02	0.08 ± 0.02	0.15 ± 0.06	97.33 ± 1.09	0.97 ± 0.01
Stems	0.28 ± 0.07	0.15 ± 0.03	0.34 ± 0.07	0.27 ± 0.05	0.18 ± 0.08	0.22 ± 0.04	55.01 ± 19.17	0.65 ± 0.07
Roots	2.56 ± 0.60	1.51 ± 0.06	3.68 ± 0.49	3.39 ± 0.62	3.21 ± 0.37	2.83 ± 0.35	38.10 ± 16.06	0.99 ± 0.20

4.2 Salt Marsh Halophytes

There are many densely populated areas and industries around the Tagus estuary. Lisbon city has the largest metropolitan area, in the north side, but there are also major industrial and urban zones around Barreiro, Seixal and Montijo cities in the south side. This geographical setting makes this estuary vulnerable to discharges from industries and effluents of activity sources. Particularly in the south side there are large areas of salt marsh with a dense vegetation of halophytes. The local distribution of these species shows a zonation, evident in transects from the upper marsh areas to the lower marsh and mudflats [8].

Halimione portulacoides (L.) Aellen (Amaranthaceae) is one of the more abundant species in the upper marsh and coexists with *Sarcocornia* species, while the lower marsh is dominated mostly by *Spartina maritima* Loisel (Poaceae). Length of the submersion period and the physical-chemical characteristics of these two distinct areas, along with inter-specific competition among halophytes, are the major factors that contribute to this zonation. Different plant coverage in the upper and lower marsh also represents an important factor that will influence sediment characteristics like contaminant retention and sediment redox state [21]. A strong seasonal variation of plant biomass in these ecosystems (Table 1) together with a variation in metal concentrations in plant tissues (Fig. 2), indicates a possible similar variation in the metal biogeochemistry [17].

These areas of salt marsh are subjected to long periods of submersion and their sediment is often waterlogged and with low levels of oxygen, being adverse to plant growth [22]. However salt marsh plants are well known for pumping oxygen from the atmosphere to the sediment, turning the redox conditions of the root zone oxidative [23].

All these sediment – plant interactions are very important when considering contaminant retention. Tidal flooding of the salt marsh supplies considerable amounts of heavy metals from nearby urban and industrialized areas, which tend to accumulate in the sediments and in plant tissues. These metals retained in the sediment are present in various forms [24] depending on the bonds they establish with the different sediment components (Fig. 3). This is a dynamic process and very much influenced by the sediment and external factors (hydrodynamics, weather and seasonal variation), but also by the vegetation that

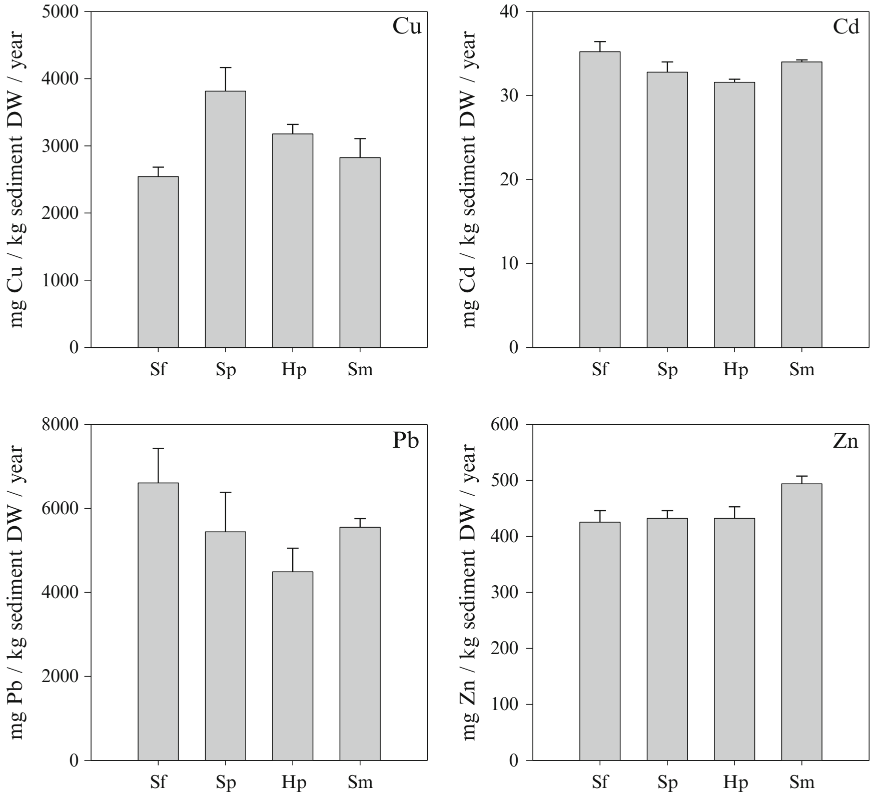

Fig. 2 Average metal concentrations in the sediments from the Tagus estuary, studied for 1 year in salt marsh areas colonized by four halophyte species (Sf – *S. fruticosa*, Sp – *S. perennis*, Hp – *H. portulacoides*, Sm – *S. maritima*) (From Ref. [17])

colonizes the area [26]. There is also evidence that microbial activity may influence metal speciation, through interaction with metal ligands [27–29]. These modifications include reactions of metal precipitation by metallic sulfides and redox reactions with changes on the metal specie and associations [30].

From the ecosystem point of view, metal cycling provides a better understanding on the role of plant detritus in the trophic transport of metals, and also on the processes involved in the contamination of a salt marsh and adjoining estuarine areas (Fig. 4). This helps establishing the paths of cycling metals within the salt marsh, and is no longer restricted only to the fluxes between plants and sediment, but considers also the whole trophic web. These results further support observations from previous studies that point out salt marshes as a sink of heavy metals, and give better insight on the major cycles of metals studied in the two more important metal retaining matrixes [31].

In the Tagus as elsewhere, the exceptionally high biological productivity so characteristic of the estuarine halophytes is often harvested in adjacent habitats. This includes the traditional captures of migratory fish and cephalopods of high commercial value, but there is also a crucial link between the primary production of halophytes on the Tagus saltmarsh and the vast numbers of migratory birds using regularly this estuary [32].

4.3 Birds

Birds are unique among all terrestrial vertebrates because most of them have exceptional capacity for travelling quickly over long distances and for their ability to reach remote spots that remain

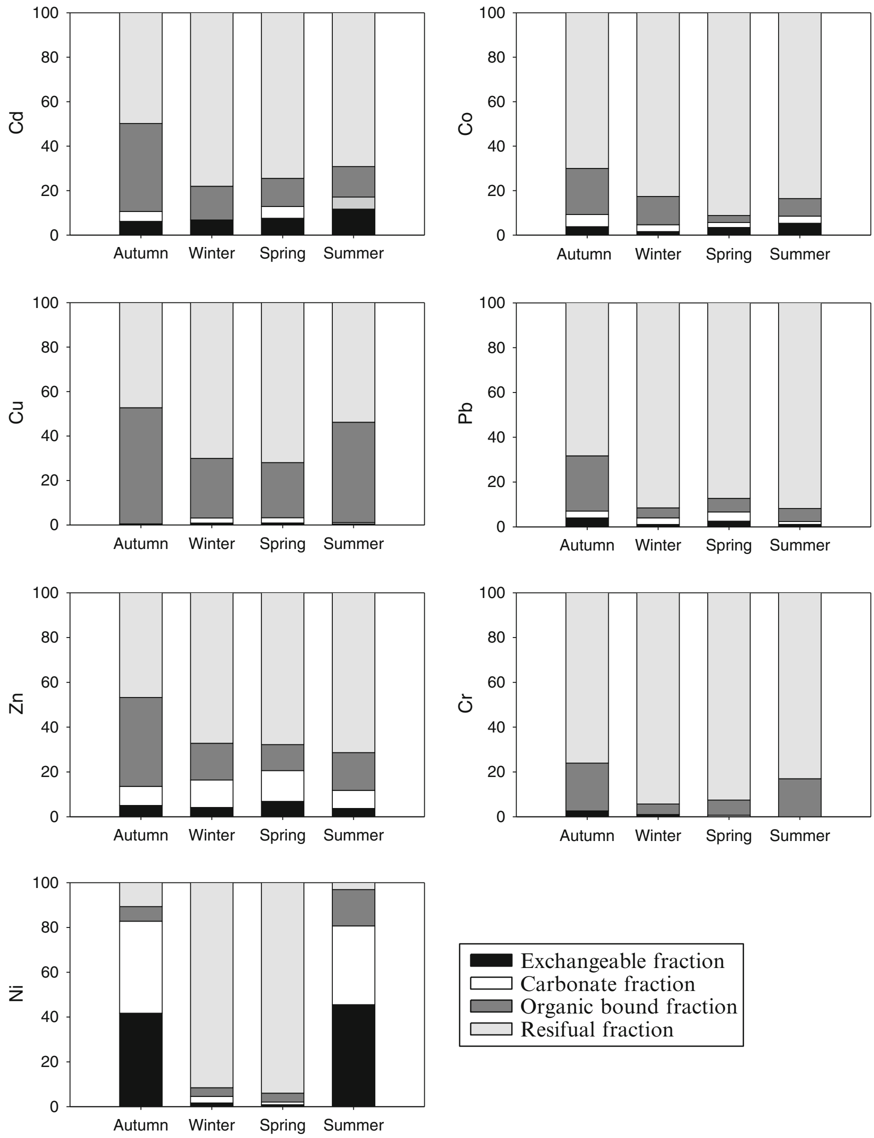

Fig. 3 Metal speciation in the rhizosediments of *H. portulacoides* surveyed for 1 year in the salt marsh areas of the Tagus estuary (From Ref. [25])

virtually inaccessible to non-flying animals. Migratory birds put these capacities to best use and many species turn up regularly in estuaries and other wetlands, where they feed upon the wealth of prey available from tidal areas and sheltered waters.

Estuarine birds are usually grouped into categories that remain widely used despite having no taxonomic value. The Waders (or Shorebirds) include many small to medium size Charadriidae and Scolopacidae that have in common characteristic body shape and similar feather patterns, but are most notorious for their habit of walking on mudflats and other tidal habitats with their feet pressing directly onto the wet ground. Waders are included in the Waterfowl, a broader informal group of species also living in aquatic habitats that includes the herons and egrets (Ardeidae), the Ibises and Spoonbills (Threskiornithidae), together with smaller families. As a group however, the

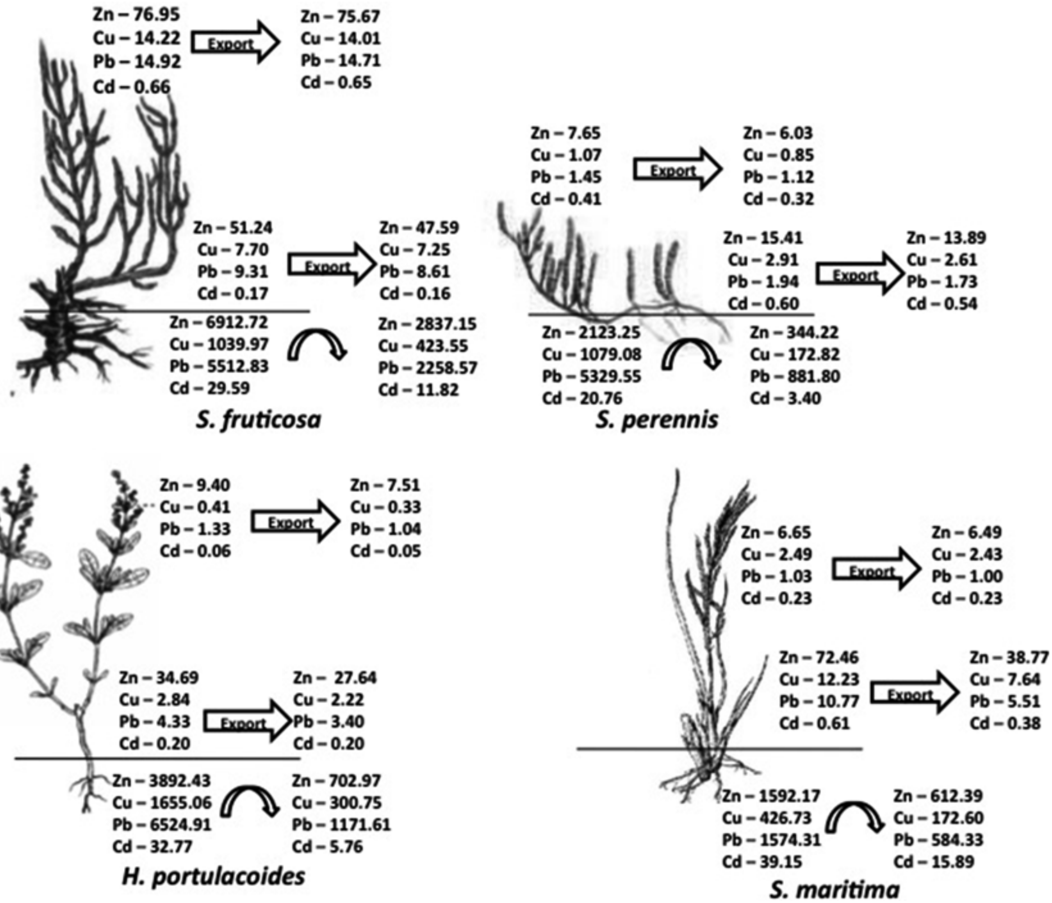

Fig. 4 Metal Primary Accumulation (MPA, mg) and losses due to litter generation for the species and plant organs studied in salt marsh areas on the Tagus (Sf – *S. fruticosa*, Sp – *S. perennis*, Hp – *H. portulacoides*, Sm – *S. maritima*) (From Ref. [17])

term waterfowl is often associated to the vast array of duck, geese and swans (Anatidae).

Most waterfowl species are highly migratory and they travel long distances every year. Waders are especially noteworthy and include some of the most extreme examples of long-range migrations in the animal kingdom. In the northern hemisphere they usually fly north in spring to reach the breeding areas (mostly in the northern tundra or in wet meadow habitats) and raise their offspring. They come back again a few months later, flying south to reach wintering areas located mostly in estuaries and coastal lagoons [32].

The Tagus is the largest estuary in Iberia and one of the most important wetlands in Europe. It stands out as a key site for migratory waterfowl on the Eastern Atlantic Flyway, and plays a strategic role as a staging area straight in the path of extremely busy migration routes in the Western Palearctic [32]. With its vast tidal areas supporting rich invertebrate communities, there is no surprise to find the Tagus regularly listed among the top wetlands for migratory waterfowl in the region.

Waterfowl populations are monitored on the Tagus estuary since the late 1960s [33–35], and there is an historic background with almost four decades of regular standard midwinter counts available for the most important species there [32, 36].

The Tagus estuary regularly holds large wintering populations of migratory waterfowl (ca. 45,000–116,000 birds were counted there in January, 1992–1996) and for many species it stands out clearly as the most important wetland in Portugal. Results of the January counts available for wader populations in the Tagus demonstrate that some species occur regularly in numbers that stand clearly above the threshold of international importance, based on the technical criteria that were set up by the International Waterfowl and Wetlands Research Bureau. According to an early version of these criteria [37], the status of international importance is reached when a wetland regularly supports a population of at least 20,000 waterfowl, or where data on population are available it regularly supports 1 % of the individuals in a population of one species or subspecies of waterfowl.

The 1 % criterion was initially developed as a tool for selecting wetlands that are key sites for the populations of migratory waders and has been further refined to become "Criterion 6" under the umbrella of the Ramsar Convention. This updated version states that "A wetland should be considered internationally important if it regularly supports 1 % of the individuals in a population of one species or subspecies of water bird". It must be stressed that this 1 % threshold is applicable throughout the range of that population and at any time of the year [32].

The Tagus estuary is a very important stopover site for many long distance migratory species in the Palaearctic-African bird migration system [32, 38] and the post-breeding passage of some wader populations may be quite impressive there on occasions.

Most of the migratory waders on the Tagus estuary feed primarily in vast tidal flats and prey upon the rich supply of small invertebrates that live buried in (or crawling on) the sediments of the tidal fringe. Small *Hydrobia* snails (Gastropoda, Mollusca), *Nereis* worms (Polychaeta, Annelida) and small *Carcinus* crabs (Decapoda, Crustacea) have been identified as important food items, but other prey occur in the area and may also be taken.

Most wader species will take prey from sediments slightly covered by tidal water but they are able to use these areas only at certain periods in the tidal cycle, when prey is accessible and water depth is not excessive. The vast majority of wading birds must in fact walk, and they will keep their feet on the ground. Therefore they have to retreat before the advancing tide, and must fly to dry spots in higher ground. When the high tide sets in, and as long as their feeding areas stay submerged, waders must wait for the tide to turn and will concentrate (often in large flocks) at high tide roosts inside the estuary.

High-water roosts are essential features in the life-cycle of waders but other estuarine birds may also need them eventually. These roosts often occur in extensive areas of halophyte vegetation, including large man-made saltpans that remain comparatively free from human disturbance. Small islets of halophytes may be very important in the tidal cycle and they are often used as temporary roots around high water, while they are not covered yet by the incoming tide and can still provide safe haven to the waders perching on them above water (Figs. 5, 6, and 7).

In contrast, duck do not have such a dependence on high water roosts because they are able to float buoyantly and may swim around on the water surface while waiting for the tide to turn. Within the estuary they feed primarily on small size food particles sieved from the water column or from the surface of wet sediments in tidal flats, and they will sometimes concentrate in large flocks at the outer edge of halophyte stands. There are wonderful adaptations to this mode of feeding and a noteworthy example is provided by the Shoveler *Anas clypeata* with its broad spoon-shaped bill lined with filtering lamellae.

Duck populations on the Tagus estuary are mostly migratory (except for the Mallard *Anas platyrhynchos*) but they tend to travel shorter distances than the waders. Some of them move to the estuary later in the season, when feeding habitats further north in Eurasia are temporarily lost due to winter freezing [39].

Flamingos *Phoenicopterus roseus* are now a familiar sight in many tidal flats and saltmarsh areas on the Tagus estuary and they occur also in other coastal wetlands in Portugal. They made a spectacular comeback to the area, increasing from only a very few birds in the remotest parts of the estuary around 1974 [40], to a remarkable

Fig. 5 Grey plover *Pluvialis squatarola* flocking at high water on a temporary roost in the Tagus estuary. The waders are perched on halophytes growing in old saltpan complexes, and must wait for the ebbing tide to resume feeding in the tidal flats (*Photograph by A. Teixeira*)

Fig. 6 Waders flocking at high water on this temporary roost in the Tagus estuary must perch on halophytes, but waterfowl like Mallard *Anas platyrhynchos* (foreground) may just swim on the water surface (*Photograph by A. Teixeira*)

1,321 birds in 1981 [41] and their numbers keep high in recent years. This situation reflects increased protection to waterfowl species on the Tagus estuary, and results from successful recovery of the Western Mediterranean and North African populations [42, 43].

Avifauna of the Tagus estuary is not restricted to the aquatic species only. Predators like Osprey

Fig. 7 Waders follow the receding tide and leave their high water refuges to feed again in mudflats around halophytes in the Tagus estuary salt marsh. Most of the birds in this picture are migratory Dunlin *Calidris alpina* (*Photograph by A. Teixeira*)

Pandion haliaetus, Marsh Harrier *Circus aeruginosus* and Peregrine *Falco peregrinus* are common there but they are unable to swim and will not walk on wet ground.

Halophytes in Tagus salt marshes are habitat to some Passerine birds but these tend to be overlooked and even ignored by the non-specialist because they are small and unobtrusive. Some of these species are common and may be found in nearby habitats, simply moving into the areas colonized by halophytes to collect small invertebrates and maturing seeds. These food items are often picked up from hedges of *Atriplex halimus* in the upper marsh, and from tall bushes of *Sarcocornia fruticosa* and *Inula crithmoides*. Common passerine species on the Tagus include Fan-tailed Warbler *Cisticola juncidis*, Mediterranean Warbler *Sylvia melanocephala*, and House Sparrow *Passer domesticus*. Such birds occur regularly in habitats around the estuary and most of them are resident, making a sharp contrast to the long-distance migratory waders feeding in the tidal flats.

There is a notable exception however. The Bluethroat *Luscinia svecica* is a migratory passerine found in the autumn and winter months in the Tagus salt marshes, where they hide mostly in dense thickets of *S. fruticosa* from the upper tidal areas and in hedges made up from bushes of *A. halimus*. They feed on a mixed diet of small aquatic invertebrates and terrestrial arthropods. These food items are picked from the halophytes or directly from the sediments, in areas of dense salt marsh vegetation penetrated by an intricate network of tidal creeks [8]. Bluethroats on the Tagus are part of a population with special habitat needs, associated to salt marshes. Described as *Luscinia svecica namnetum* [44] they breed typically in halophytes around salt-pans in Brittany, NW France [45] but later they migrate SW to their wintering grounds, mostly in the Portuguese estuaries [46]. The salt marsh halophytes on the tidal areas of the Tagus estuary are therefore a key habitat for the winter populations of this endangered migratory bird [47].

Estuaries are often biodiversity hotspots because they offer plenty of food opportunities and may attract many visiting species. Even though the local communities of halophytes and estuarine invertebrates may have only a limited number of species (well adapted to survive in this unique environment) they often comprise very large populations made up from vast numbers of individual organisms. They bring increased diversity, and new habitat types that may not be available anywhere else in the region.

In the Tagus estuary there are just a few species of halophytes, and their combination makes for the patchwork vegetation in the salt marsh areas. The top ten species in the list are (in no particular order): *Spartina maritima; Halimione portulacoides; Sarcocornia fruticosa; S. perennis; Atriplex halimus; Suaeda vera; Arthrocnemum glaucum; Inula crithmoides; Aster tripolium,* and *Juncus maritimus.*

These halophytes increase biodiversity on a regional scale and help keeping in the Tagus juvenile fish and other marine organisms that rely on abundant food and increased protection from predators provided by the estuarine habitat [48]. They are a driving force to the attraction of large numbers of migratory birds.

In a recent study carried out on a sheltered bay at Seixal, on the southern part of the estuary, from a total of 94 bird species observed in the area during the annual cycle there were 42 species occurring in typical estuarine habitats (tidal banks/salt marsh/open water). This figure corresponds to an important 45 % of the total number of species in the area, and compares to only 23 species (24 %) observed in the non-estuarine habitats. It is worth noting that another 29 species (31 %) were using both habitat types, on an opportunity basis [49].

Recent studies have contributed valuable information to help demonstrate the importance of the Tagus estuary as biodiversity hotspot [20, 31] and they further support the outstanding role of this wetland as staging post for long-distance migratory birds travelling in the Eastern Atlantic Flyway, including Palearctic waders and waterfowl wintering in the area [32, 40, 50]. Within the estuary, halophyte vegetation and adjacent beds of tidal sediment are often the key areas for these bird populations, and usually they are attractive to many different species that occur in vast numbers [49, 51].

A Nature Reserve has been declared on the Tagus estuary in 1976 to afford adequate protection to an area of 14,192.44 ha. Created first in the national legislation (Decreto-Lei nº 565/76, from July 19th) it was included subsequently in the Ramsar list as a prime contribution to the goals of the Convention on Wetlands of International Importance, especially as Water-fowl Habitat when the Portuguese Government decided to join that Convention in 1980. It was no surprise and made a logical outcome to the many efforts deployed worldwide to protect wetlands and to keep salt-marsh areas working as important bird sanctuaries.

Portugal has joined the European Union in 1986 and some wetland areas in the Tagus estuary were later included in a Special Protection Area (SPA) declared under article 9 of the Wild Birds Directive (79/409/CEE). The SPA included all the areas already protected by the Nature Reserve (established one decade before) but covered also new areas and parts of adjacent habitats.

However, the practical outcome of this increased legal protection was not straightforward. Strict measures were adopted to help protect important species and habitats, but their application became later the subject of intense negotiation, and adjustments were made to allow building important structures and large transport facilities helped by EU regional funds. The environmental questions were eventually settled, and improved territorial planning has emerged from this process.

Attitudes of people living in urban areas around the estuary have changed dramatically in recent years. Compared to only a few decades ago (ca. 1970–1980) there is now widespread public awareness for environmental issues and many citizens praise activities that put lasting value to healthy estuarine ecosystems. These include many different uses, like kayaking, bird watching, and jogging on the water front. Shooting small birds or otherwise molesting protected species has been illegal for many years, but nowadays these practices are virtually banned around the estuary. Birds of prey also become respected by the public and they are no longer seen as mere targets for extermination. Hunting waterfowl lost terrain to other activities. All these results did come from sustained investments at environmental awareness and education that were deployed by the public services and by dedicated organizations for many years.

Sometimes leading, but often riding in the wake of these changes in public attitude, most local authorities and managers around the estuary have come to appreciate the potential for using the estuarine habitats as complementary spaces to their urban amenity gardens. In fact, most halophytes remain "green" all year round and they need no freshwater irrigation or routine gardening for maintenance (these are costly items and represent a growing burden to the stressed budgets of local administrations). The potential for using these sites has been there for many years [52], but now there is a public perception of their value, with a fashionable "wild" look associated to the salt marsh areas and presence of waterfowl species in the tidal flats.

Complementary to the official designation of the Nature Reserve in 1976, there is growing action from the local authorities to have smaller "nature reserves" designated in areas of great natural value within their administrative boundaries. Legal protection for these spaces may now be granted merely on the basis of municipal decisions and some new "local nature reserves" have been approved already in wetlands around the Tagus estuary. This new attitude is far-reaching and must be considered a welcome departure from the traditional goals of local powers, usually fighting for more "economic development measures" irrespective of long-term consequences and environmental cost.

5 Conclusions

Salt marsh halophytes and estuaries have an important role in the preservation of biodiversity: (i) Salt marshes are among the most productive ecosystems in the world and perform important ecological functions, namely in terms of primary production and nutrient recycling. (ii) Salt marshes are important sinks of pollutants, including heavy metals. The ability to phytostabilize contaminants in the rhizo-sediment is an important aspect in this ecosystem self-remediative processes and biogeochemistry, and will help filtering natural and anthropogenic loads of nutrients and pollutants to the wetland. (iii) There is a provision of rare and unique habitats, which support nursery grounds for commercial fish and wildlife, including vital feeding grounds for many migratory birds.

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