ECOLOGICAL PERFORMANCES OF PLANT SPECIES OF HALOPHILOUS HYDROMORPHIC ECOSYSTEMS

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Abstract

Coastal wetlands are very special environments, characterized by soils permanently or seasonally saturated by salt or brackish water. They host microorganisms and plants able to adapt to anoxic conditions. This paper proposes a review of recent scientific papers dealing with the study of coastal wetlands from different points of view. Some studies examine the species composition and the pattern of the spatial distribution of plant communities, depending on the depth of the salt water table, as well as on other related factors. A significant number of studies analyse instead the coastal wetlands in their ability for the phytoremediation (phytostabilisation and/or phytoextraction) and highlight the importance of interactions between the rhizosphere of the halophytes and the physical environment. Finally, more recent studies consider the plant species of the coastal wetlands as a source of useful products (food, feed, oils) and expose the results of promising researches on their cultivation.

Keywords: *coastal wetlands, halophytes, heavy metals, phytoremediation, halophyte cultivation*

Introduction

Soil permanently or seasonally saturated by water (hydric or hydromorphic soil) is the key factor that select a particular pool/assemblage of microbial, plant and animal species inhabiting the anaerobic soils of wetland areas.

Wetlands are found over a wide latitudinal range, from the tundra to the tropics and on every continent except Antarctica. Depending on differences in climate, flora, fauna, substrate, hydrology and other factors, including anthropic ones, wetlands can vary in their specific aspects (mangroves, marshes, swamps, bogs, etc.), but anyway they represent transition ecosystems between truly terrestrial and aquatic environments.

The Ramsar Convention recognizes many ecosystem services coming from wetlands, each of them has been the object of specific scientific investigations through more or less recent researches.

Concerning the researches of plant species and/or plant communities inhabiting wetland areas, we assisted over time to an evolution of the approach used in studying them. We passed from a quantitative-descriptive approach, aiming at

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recognize the main typologies of plant communities, to an attempt to identify the relationships among type of plant communities and physical environmental parameters determining them, to the specific attention towards dominating species and the ecosystem services they can perform and, finally, to an applicative blue growth approach.

Critical environmental issues, consequences of the climate change on coastal areas (rise of sea level, natural or anthropic subsidence), bring up the coastal or tidal wetlands (*sensu* U.S.A. Environment Protection Agency, 2014) for their buffer role on areas more and more densely inhabited in the next years. Coastal zones are considered key climate change hot spots worldwide as well as in Europe (EEA, 2010; Torresan *et al*., 2012). The need to maintain or to restore marsh area is strongly supported by the increasing cost of defending existing coastlines in the face of sea-level rise and climate change (French, 2006).

This paper aims to delineate the evolution over time of the researches and knowledge on coastal wetlands, as well as their potentialities in supporting the requirements of coastal populations. The review considers contributions coming from all over the European and Mediterranean territory, but offers a significant core of information on the Italian coasts of the Northern Adriatic sea. Here, from the Grado lagoons to the Po delta, a peculiar system of wetland areas lies on a vulnerable territory, subject to continuous morphological changes as well as to a not sustainable anthropic utilisation.

Materials and Methods

In preparing this review we adopted the following approach. First of all we analysed the literature (papers on journals and other available documents) describing the plant communities of the tidal wetlands of the Northern Adriatic Sea. This area has a significant meaning for the Italian territory because it hosts one of the major systems of the Italian wetlands (the Po delta and its lagoon, the Venice lagoon, the Grado and Marano lagoons) and has been the object of many studies, suitable to be integrated together.

All these lagoons have been more or less extensively contaminated from various industrial and/or extraction activities (the Idrija Hg mine (Slovenia), through the Isonzo river suspended load, carried by the tidal fluxes (Covelli *et al*., 2008)). After, we identified the key species that play the major roles in the plant communities of the tidal wetlands of the Northern Adriatic sea, and we investigated the literature concerning their distribution, depending on some important physical factors that govern the lagoon environments. Thirdly we examined the recent literature on these key species, in order to explore their ability in performing particular ecosystem services.

Finally, we considered the most advanced attempts to use some of these species in the perspective of an innovative and sustainable utilisation of the resources of the tidal wetlands (blue growth).

Results and Discussion

The plant communities of the tidal wetlands of the Northern Adriatic coasts

The main typologies of the tidal wetland plant communities have been firstly studied by Pignatti (1952-1953; 1959; 1966) describing the "barene" of the Venice lagoon. Other studies have been realized on the Emilia Romagna coasts (Ferrari *et al.*, 1985; Piccoli *et al.*, 1994; Pellizzari *et al.,* 1998) as well as cartographic maps of the halophytic plant communities present in the protected areas of this Region (Piccoli *et al.,* 1999; Piccoli *et al.,* 1999a; Piccoli *et al.,* 1999b). More recently, new studies concerning the Venice lagoon (Ghirelli *et al*., 2007; Cazzin *et al.,* 2009) have been performed. This last series of contributions gave the first cartographic map of the main plant community typologies in the Venice lagoon (Mion *et al*., 2010). The Grado and Marano lagoons have also been intensively studied by Poldini *et al*. (1999).

The wetland plant communities are quite similar all over the Northern Adriatic coast, from Friuli to Emilia. Figure 1 represents a typical spatial-temporal sequence of plant communities, widely present in the halophilous wetlands of this area, whereas the main species characterizing the three communities of such sequence, are indicated in Table 1.

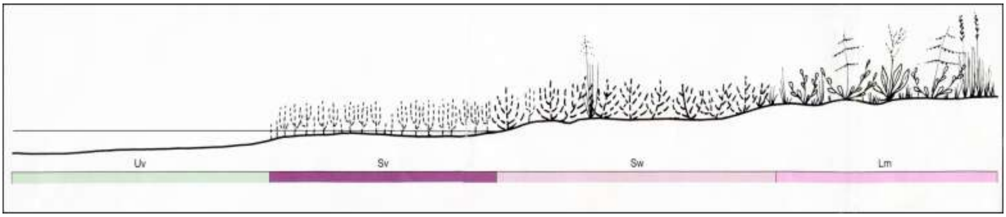

Figure 1. *Sequence of halophilous plant communities along a gradient of soil water content and sediment accumulation.*

Uv = *Ulvetalia*; Sv = *Salicornietum venetae* (*Thero-Salicornietea)*; Sw = *Puccinellio festuciformis-Sarcocornietum fruticosae* (*Sarcocornietalia fruticosae*); Lm = *Limonio narbonensis-Puccinellietum festuciformis* and *Limonio narbonensis-Artemisietum coerule- scentis* (*Juncetalia maritimi*).

The presence of water in the soil, the duration of the period of submersion and the amount of sediments accumulated are the environmental factors that determine the three main typologies of plant communities of Figure 1. Annual communities longtime inundated over the year, with the endemic *Salicornia veneta* (*Thero-Salicornietea* and *Salicornietalia europaeae*), are followed by perennial communities (*Sarcocornietea fruticosae* and *Sarcocornietalia fruticosae*), only occasionally or temporarily inundated, with *Sarcocornia fruticosa* (=*Arthrocnemum fruticosum*), and after, by plant communities of the *Juncetalia maritimae* (*Juncetea maritimi*), on salt soils always dry in summer, with a more rich specific composition (*Limonium narbonense*, *Artemisia caerulescens*) and high naturalistic value.

The halophilous plant communities of this sequence, can be spatially and ecologically associated with other very common wetland communities dominated

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by *Phragmites australis* with *Puccinellia palustris* (*Puccinellio festuciformis-Phragmitetum australis, Phragmito-Magnocaricetea* and *Scirpetalia compacti*) growing in brackish waters (Table 1, not shown in Figure 1).

Table. *Plant communities and species characterizing the halophilous series of Figure 1.*

Thero-Salicornietea ***Thero-Salicornietalia*** ***Salicornietum venetae (Sv)***	*Salicornia veneta*
Sarcocornietea fruticosae ***Sarcocornietalia fruticosae*** ***Puccinellio festuciformis-Sarcocornietum fruticosae (Sw)***	*Limonium serotinum* *Arthrocnemum fruticosum* *Arthrocnemum glaucum* *Puccinellia palustris* *Halimione portulacoides* *Arthrocnemum fruticosum* *Limonium serotinum*
Juncetea maritimi ***Juncetalia maritimi*** ***Limonio narbonensis-Puccinellietum festuciformis*** ***Limonio narbonensis-Artemisietum coerulescentis (Lm)***	*Limonium virgatum* *Juncus maritimus* *Juncus acutus* *Halimione portulacoides* *Elytrigia atherica* *Puccinellia palustris* *Aster tripolium* *Aeluropus littoralis* *Agropyron elongatum* *Artemisia coerulescens* *Inula crithmoides*
Phragmito-Magnocaricetea ***Scirpetalia compacti*** ***Puccinellio festuciformis-Phragmitetum australis***	*Phragmites australis* *Puccinellia palustris*

The halophilous plant communities of the series in Figure 1 have a high predictive value on the geomorphological equilibrium of the system, and each lagoon system has his particular ratio among the spaces occupied by the three main typologies of communities. Quantitative variation of these spaces can be used for monitoring sedimentation or erosion phenomena. A decrease of the *Juncetalia* and *Sarcocornietalia* communities, accompanied by an increase of the *Salicornietalia* communities (Mion *et al.,* 2010), due to the erosion of the sediments, has been observed and quantitatively estimated for the Venice lagoon (Mion *et al.,* 2010) over a six years period.

The relationships between the tidal salt marsh communities and the environmental factors

The sequence of plant communities of Figure 1 is an average schematic representation of very common situations in the tidal wetlands, to be explored on the ecological factors that determine and sustain them.

The considerable number of studies performed in an area of great environmental interest, such as the Venice lagoon (Silvestri & Marani, 2004; Ursino *et al.*, 2004;

Silvestri *et al.,* 2005) gives an important contribution to this topic. They, in fact, attempt to quantitatively describe the relationships among the tidal salt marsh communities, the environmental factors (soil water salinity, soil oxygen saturation, soil hydraulic conductivity, nutrients availability, biotic competition) and their changes. A quantitative description of such relationships would allow to model the behaviour of the plant species and communities and to forecast their responses if or when they are perturbed or modified.

The oxygen availability, necessary for aerobic respiration in roots, is one of the most important, driving factors for vegetation patterns in marsh areas. In turn, oxygen availability depends on the tidal network density and distribution, on the type of soil, on its hydraulic conductivity and unsaturated characteristics, on the differences in the evapotranspiration flux that modifies the soil aeration. The plant species response integrates this wide complex of factors that, reciprocally interacting, determine the heterogeneity observed at different marshes.

This explain the results of Silvestri & Marani (2004), that observed quite identical sequences of plant species, similar to that of Figure 1 and Table 1, in four different sites of the Venice lagoon. The plant species sequence is constant, but the sequence itself is found at preferential elevations, different in the four marshes, so that it appears shifted vertically at different sites (Figure 2).

Ursino *et al.* (2004) give great attention to the oxygen availability in the soil, even in the processes of colonization of unvegetated salt marshes. They emphasize the role of the interactions soil-vegetation for the increase of the substrate aeration, as the colonization progresses. Considering a salt marsh characterized by low soil conductivity, it may be hypothesised that the colonization by plant species starts near the channels, where oxygen availability is higher. This first colonisation induces an even higher oxygen availability through the plant evapo-transpiration, thereby creating a habitat suitable for other plant species (less resistant to anoxic conditions but more highly competitive) which may later displace the pioneer plants. As a consequence of the dynamics described, the preferential aeration zones migrate from near the channel toward the centre of the marsh, revealing an important ecogeomorphic feedback.

In their study on the Venice lagoon, Lang *et al.* (2010) concluded that the small-scale variation of oxygen availability plays a key role for the biodiversity of saltmarsh ecosystems, with an elevation around the maximum tidal excursion (Figure 3).

Finally, the crucial role of elevation, sediment redox potential and soil oxygen availability were confirmed again by the results obtained by Mossman *et al.* (2012) which, after the reestablishment of the original tidal flow on a reclaimed territory of 7.5 ha, studied the natural restoration processes of wetlands on the North Norfolk coast (UK). The authors confirmed also the different behaviour of the pool of plant species that participate in the wetlands reconstruction. *Salicornia europaea* occurred predominantly at lower elevation, but was not influenced by redox potential. *Puccinellia maritima* favoured low redox potentials, independently of elevation. In contrast, *Suaeda maritima* tolerated a wide range of elevations, but

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was absent from areas with low redox potential. *Atriplex portulacoides* was apparently more averse to low redox potential than to low elevation. *Elytrigia atherica* was restricted to both high redox potential and high elevation.

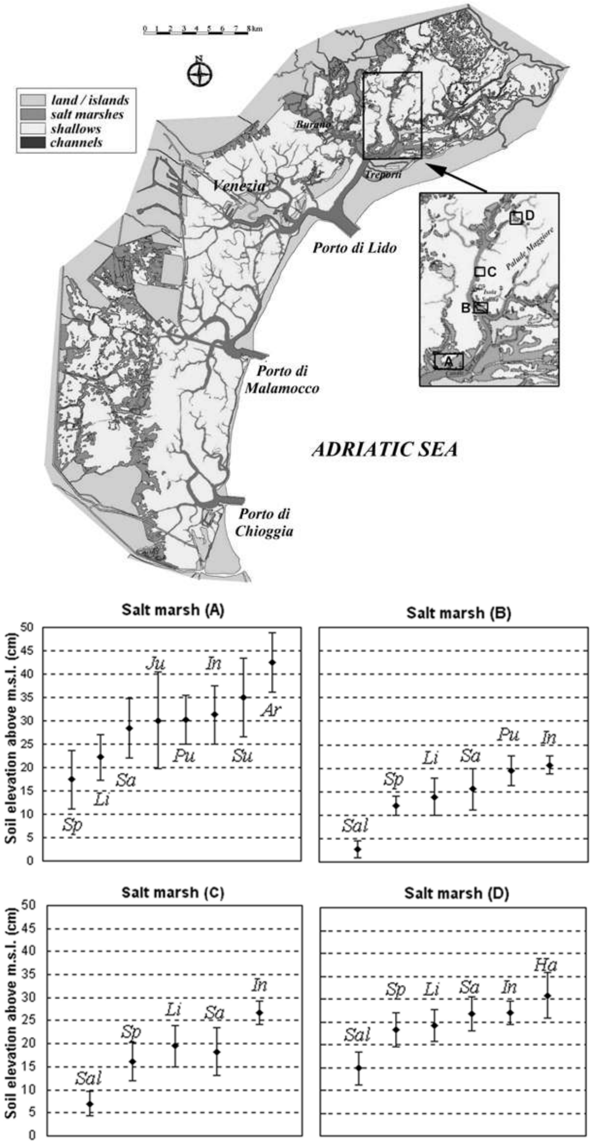

Figure 2
The four areas of the Venice Lagoon studied by Silvestri & Marani (2004) and the means and standard deviations of soil elevation for each plant species in the salt marshes A, B, C, and D
Figure from Silvestri & Marani (2004).

Arthrocnemum macrostachyum (Ar)
Aster tripolium (As)
Halimione portulacoides (Ha)
Inula crithmoides (In)
Juncus maritimus (Ju)
Limonium narbonense (Li)
Puccinellia palustris (Pu)
Salicornia veneta (Sal)
Sarcocornia fruticosa (Sa)
Spartina maritima (Sp)
Suaeda maritima (Su)

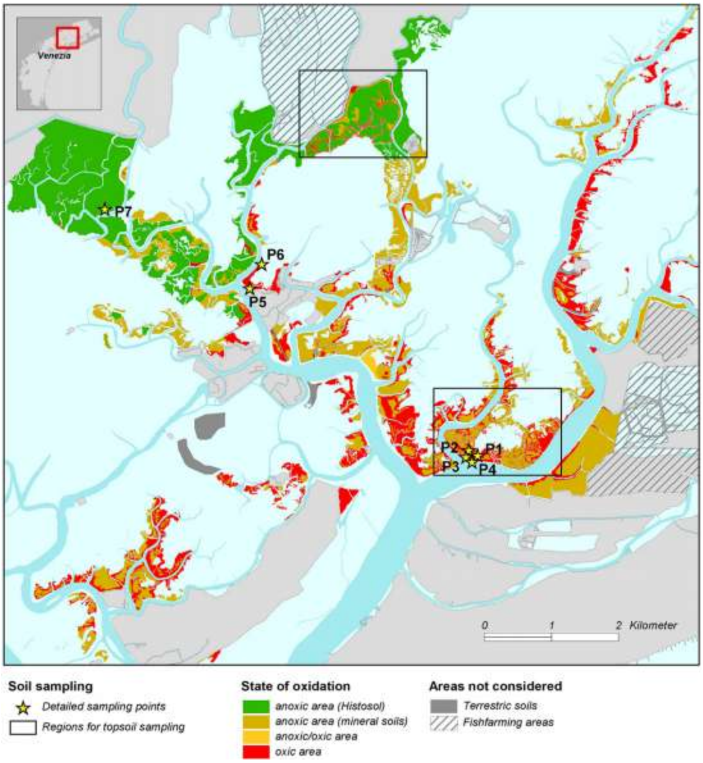

Figure 3
Distribution of oxic and anoxic areas of the salt marshes of the Northern Venice Lagoon (Lang et al., 2010)

The ecosystem services offered by the tidal salt marsh wetlands

Tidal wetlands, one of the most biologically diversified ecosystems, provide or drive a wide series of ecological services, such as provision of food and other materials, flood control, storm protection, water purification and waste treatment, support to soil formation, primary production and nutrient cycling, and, finally, people recreation (De Groot *et al.,* 2006). It has recently been reported (Day *et al.,* 2008; Day *et al.,* 2011) that natural coastal wetlands could adjust to climate change and to sea-level rise, stressing the need for maintaining an ecological balance both in rivers and the coastal areas into which they drain. A new better approach to the coastal defence (Temmerman & Kirwan, 2015), should combine the restoration and maintenance of coastal wetlands, which continuously build land, trapping sand and mud supplied during inundations, with the conventional engineering techniques.

A conspicuous research activity has been focused on the mechanisms through which plant species act on water depuration and waste treatment in wetlands, especially concerning the retention capacity for heavy metals. First of all it has been observed that salt marsh sediments from not vegetated areas contain lower concentrations of metals than sediments under vegetated areas (Caçador *et al.,* 1996; Doyle & Otte, 1997). The same was observed in pore water (Otero & Macias, 2002). Secondly, the type of plant cover can affect the overall retention

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capacity of a salt marsh as well as the functioning of the salt marsh as a sink (phytostabilisation of metals in rhizosediments) or source of metals (phytoextraction by accumulation in aboveground plant tissue) for subsequent plant removal (Mukherjee, 2001). Species inhabiting anoxic or oxidic zones of the wetland areas contribute in different way to the stabilization of heavy metals (Reboreda & Caçador, 2007a; 2007b) as well as monocotyledonous and dicotyledonous species (Otte *et al*., 1991; Fitzgerald *et al.,* 2003), due that the first ones create a more oxygenated environment in their rhizosphere, having a more developed aerenchyma tissue system. Plant species that accumulate more metals in belowground tissues and surrounding sediments contribute more effectively to reduce their bioavailability (Weis & Weis, 2004; Duarte *et al*., 2010). On the contrary, metals accumulated in above ground tissues may eventually be excreted through leaves (Burke *et al.,* 2000; Weis *et al.,* 2002) or accumulate in leaf and stem litter (Windham *et al*., 2003), returning to the marsh system that acts as a potential source of metals (Weis & Weis, 2004; Pereira *et al*., 2007). *Spartina maritima*, for example, seems more appropriate for belowground phytostabilisation of Cu and Cd, whereas *Halimione portulacoides* would be more effective for phytoextraction (Reboreda & Caçador, 2007b). Salt marshes extensively colonised by *H. portulacoides* are thus expected to translocate more Cu, Cd and Pb to aboveground_parts, acting as potential sources of these metals to the marsh ecosystem. The higher redox potential observed in sediments colonised by *Halimione portulacoides* may in part explain the observed differences in the speciation of Cu, Zn and Pb.

The very important role of plants in metal cycling in tidal wetlands, their different behaviour, the implications for phytoremediation and polluted wetlands management, justify a strong interest in deepening this kind of knowledge. On the one hand, the interactions between plants and surrounding sediments are very complex, often species-specific. The rhizosphere, which alters the chemistry of the sediment in contact with the roots, can be considered as an independent system inside the sediments where the plants grow. On the other hand, particularly in the management of polluted or constructed wetlands, it is necessary to determine which species and zones are more appropriate to induce phytostabilisation of heavy metals in low available chemical phases, or which species, acting as phyto-extractors, should be periodically removed (Almeida *et al.,* 2011). Water fluxes and the rhizosphere control metal mobility (Cervantes *et al*., 2010); changes in redox conditions, due to drying, generate peaks of concentration of soluble metalloids, such as As, that may be mobilised upon rewetting (Du Laing *et al*., 2009). *Juncus maritimus*, compared with *Scirpus maritimus*, seems to provide a better ecosystem service through phytostabilization (Hg complexation in the rhizosediment) and through phytoaccumulation (Hg sequestration in the belowground biomass). In *Scirpus maritimus* colonized areas, Hg is more extensively exchanged between belowground biomass and the rhizosediment (Marques *et al.,* 2011). Both *Juncus maritimus* and *Scirpus maritimus* have potential for the phytostabilization of Cd, and the last one also for Pb phytostabilization (Almeida *et al.,* 2006). The two species displayed important and distinct seasonal variability in the exchange of metallic contaminants between roots and sediment around them. Comparing *J. maritimus* and *Spartina patens*, metal burden distribution between above and belowground structures depends on the metal, and *J. maritimus* retains, for instance, much more Cd and Cu in the aboveground than in the belowground structures (Almeida *et al*., 2011). *Phragmites australis*, a species with a world wide distribution, covering extremely huge areas (Engloner, 2009), has enough potential to be used for mercury stabilization and restoration of sediments/soils rich in mercury (Naser *et al.,* 2012). Their roots exhibited the highest mercury accumulation followed by rhizome and leaves during the reproductive phase (autumn). At this time, *P. australis* penetrates at maximum the sediments by its roots and oxidizes the root zone by the movement of oxygen downward, through aerenchyma tissues, thus increasing the remobilization of mercury and hence its availability to plant roots (Weis & Weis 2004; Naser *et al.,* 2012). The behaviour of *P. australis* points out the great interest to well understand, from a general point of view, the physiological and biochemical mechanisms which enable plant species to continuously and actively interact with sediments, pooling the heavy metals in its roots and rhizomes, protecting leaves against heavy metal toxicity, adopting the heavy metal exclusion, adjusting the rhizosphere-sediment environment during the seasonal changes. Therefore, based on the plants' natural traits for metals, the selection of appropriate plants for a particular environment, contaminated with specific toxic metals, decides the effectiveness of a phytoremediation system. This especially if inundation of contaminated land, in order to restore wetland, will be increasingly applied to treat metal contaminated surface water or remediate sites with elevated soil metal concentrations (Weis & Weis, 2004; Tack & Vandecasteele, 2008; Caçador *et al.,* 2009; Vymazal, 2011; Spencer & Harvey, 2012; Teuchies *et al.,* 2013). The conversion of agricultural field to restored wetlands might reduce human food chain contamination. Transfer coefficients in the marsh were found to be low if compared to many other studies and only a very small fraction (≤0.05%) of the sediment metal pool cycled annually through the aboveground vegetation. The estimated amount of trace metals deposited on a tidal marsh was about 300 times larger than the vegetation pool (Teuchies *et al.,* 2013). Hovever, when assessing remediation techniques in a contaminated marsh, the balance between retention and export of metals from the marsh, the biology of the plant species involved and the marsh ecology must take into account (Caçador *et al*., 2009).

New perspectives for the utilisation of plant species of the coastal wetlands: the case of the genus Salicornia L. (Chenopodiaceae/Amaranthaceae)

Many very interesting perspectives on the economic utilization of halophyte plant species are now opening, especially in the framework of the climate changes and the consequent environmental criticisms, such as the sea level rise, the salinization of the coastal soils, the scarcity of irrigation freshwater. Particular attention can be due to the genus *Salicornia* L., a cosmopolitan genus of succulent halophytes,

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having its major centre of diversification in the Central and South West Asia, where the wide presence of saline soils in temperate and hot deserts provide optimal conditions for the diversification of this group (Kadereit *et al.,* 2007; Akhani, 2008: Kadereit *et al.,* 2012). Some of the *Salicornia* species, such as *Salicornia europaea* L. and *Salicornia bigelovii* Torr. are annual species inhabiting, respectively, the tidal zone of European coasts and of South-Eastern USA, California and Mexico coasts, on periodically or daily submerged soils, with very high salt concentration.

The ability of *Salicornia* species to grow in salt-affected habitats makes them very interesting species for cultivation in constructed wetlands, to recycling the nutrient-containing effluents from saline aquacultures (Buhmann & Papenbrock, 2013; Pavan *et al.,* 2015). In addition, the species of *Salicornia* possess a commercial value (Shpigel *et al.*, 2013). The high mineral content, vitamins, antioxidant compounds and polyunsaturated fatty acids in the shoots make *Salicornia* a healthy food vegetable for human consumption (Ventura *et al*., 2010; Ventura *et al*., 2011a; Ventura *et al.,* 2011b; Ventura & Sagi, 2013). The high oil content in the seeds, particularly rich in polyunsaturated fatty acids, makes *Salicornia* also a promising oilseed crop, which could be used as a feed supplement for ruminants in arid regions (Miyamoto *et al*., 1996; Swingle *et al*., 1996; Glenn *et al*., 1997; Glenn *et al.,* 2013). The dwindling supply of freshwater throughout the world, makes mariculture and use of saline water for crop irrigation an ever more valuable alternative to freshwater use.

Figure 4
Accessions of Salicornia bigelovii *from Mexico cultivated in Eritrea, Africa. The best selected lines produced up to 320 g m−2 of seed and were planted in November and harvested in April, avoiding the summer hot period. From Zerai et al. (2010) and Glenn et al. (2013).*

In a modern vision of the soil-plant relationships, given the very important role of the plant growth promoting microbial organisms of the soil, attention should be focused not only on the halophyte plant species, but also on the bacteria from their rhizospheric soil, and their impact on plants growing on salty soils (Mapelli *et al.*, 2013), or cultivated under induced soil salinity (Ullah & Bano, 2015). Results obtained by Mapelli *et al.* (2013) on *Salicornia strobilacea*, a widespread species of the genus *Salicornia* in Southern Tunisia, indicated that a peculiar bacterial microbiome is stably associated with *S. strobilacea* roots, possibly having a role in promoting plant growth and stress tolerance, acting on the plant hormonal balance, reducing the concentration of stress signalling molecules, such as the precursors of ethylene or supplying nutrients to the plants and enhancing their fitness. The Plant-Growth-Promoting Rhizobacteria (PGPR), isolated from the rhizosphere of *Salicornia virginica* (Ullah & Bano, 2015), showed reliability in growth promotion of maize crop in all the physiological parameters, so that they can be used as bio-inoculants for the plant growing under salt stress.

Conclusions

This review demonstrates that, due to their special physiological characteristics and biochemical composition, the halophytes are a promising group of plants for different applications (Buhmann & Papenbrock, 2013) in different environmental contexts.

The "biosaline concept" of Holaender (1979), stating that … *poor soils, high solar insolation and saline water, which prevail in arid lands, should be viewed as useful resources rather than as disadvantages. . . for non-traditional production of food, fuels and chemicals…*, could also be applied to the tidal wetlands. In this perspective, Glenn *et al.* (2013) stress the possibility to cultivate the halophyte, because: *…whether halophyte crops eventually achieve widespread application, will depend on future demands for agricultural products and competing uses for non-saline water and land, rather than on biological limitations of halophytes or technical problems in irrigating with saline water...* The development of specialized saline agriculture offering high-value products, is a serious alternative to conventional agriculture relying on non-saline soils and freshwater. In saline agriculture, saline water is considered to be a resource rather than a threat, thus opening a further opportunity for producing biomass and other bio-products (Singh *et al.,* 2014).

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PERFORMANCES ECOLOGIQUES D'ESPECES VEGETALES D'ECOSYSTEMES HALOPHYLES HYDROMORPHIQUES

Résumé

Les zones humides côtières sont des environnements très particulaires, caractérisés par des sols toujours ou saisonnièrement saturés par eau salée ou saumâtre. Ils accueillent microorganismes et plantes ayant en commun la capacité d'adaptation aux conditions anoxiques des sols mêmes. Cet article examine des travaux scientifiques récents, traitant de l'étude des zones humides côtières de différents points de vue. Certaines études analysent la composition floristique et le pattern de la répartition spatiale des communautés végétales, en fonction de la profondeur de la table d'eau salée, ainsi que d'autres facteurs liés à elle. Un nombre important d'études analysent les zones humides côtières dans leur capacité pour la phytoremédiation (phytostabilisation ou/et phytoextraction) et soulignent l'importance des interactions entre la rhizosphère et l'environnement physique. Enfin, des études plus récents considèrent les halophytes des zones humides côtières comme source de produits utiles (nourriture, biocarburants), présentant les résultats de prometteuses recherches sur leur cultivation.

Mots-clé: zones humides côtières, halophytes, métaux lourds, phytoremédiation, cultivation des halophytes.

PERFORMANCES ECOLOGICHE DI SPECIE VEGETALI DI ECOSISTEMI IDROMORFI ALOFILI

Riassunto

Le zone umide costiere sono ambienti particolari, caratterizzati da suoli permanentemente o stagionalmente saturi di acqua salata o salmastra, occupati da microrganismi e piante capaci di adattarsi a condizioni anossiche. Il presente lavoro propone una rassegna di contributi scientifici recenti che trattano lo studio delle aree umide costiere da diversi punti di vista. Alcuni studi esaminano la composizione floristica e il *pattern* di distribuzione spaziale delle comunità vegetali, in funzione della profondità della falda salata, oltre che di altri fattori ad essa collegati. Un consistente numero di studi analizza invece le aree umide costiere nella loro capacità di fitodepurazione (fitostabilizzazione e/o fitoestrazione) e mette in evidenza l'importanza delle interazioni tra la rizosfera e l'ambiente fisico circostante. Infine, lavori più recenti considerano le alofite delle aree umide costiere come fonte di prodotti utili (cibo, mangimi, olii) e riportano i risultati di promettenti ricerche sulla loro coltivazione in ambienti estremi.

Parole chiave: *zone umide costiere, alofite, metalli pesanti, fitorimedio, coltivazione delle alofite*