

Floristic composition and functional zones pattern of the beach-dune system along the Danube Delta coast - Romania

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Received on <06-06-2016>, reviewed on <20-06-2016>, accepted on <30-06-2016>

Abstract

This paper presents the floristic composition of vegetation for each feature on a beach-dune system sector from the western Black Sea coast, Romania. The studied site is a relatively small fragment of the 10 km shore on the southern part of the Danube Delta Biosphere Reserve (DDBR) that may be susceptible to anthropogenic pressure in the coming years. Out of the 38 identified species, ten are threatened species according to the national Red List of endangered plant species. Compositae and Poaceae are the families with the highest number of species. The analysis of floristic spectrum shows a mixture of elements of plant communities, but Pontic and Ponto-Caspian elements are prevalent.

Physiognomically, the foredunes in the Danube delta coast have a typical morphology, with a smooth profile and do not exceed 2 m high. They are vegetated by herbaceous annual and perennial plants, but in terms of abundance the native dune builder rhizomatous grasses are rare.

The fore dunes from this Black Sea coast sector serve as vital habitat and refuge for *Convolvulus persicus* L. within the western limit of its geographical range. This endemic Ponto-Caspian element defines a particular habitat type within the Black Sea biogeographic region: "Pontic shore dunes with *Convolvulus persicus* L." Currently, the main threats of this habitat are cattle grazing and the increasing touristic activities (human trampling, horse riding and all-terrain vehicle riding).

Keywords: Pontic shore-dunes, vegetation zones, *Convolvulus persicus* L., regional endemic, ecological refuge, habitat type

Rezumat. Spectrul floristic și modelul zonelor funcționale ale sistemului plajă-dune din zona costieră a Deltei Dunării

Lucrarea prezintă compoziția floristică a vegetației pentru fiecare subunitate de relief a unui sector a sistemului plajă-dune frontale din cadrul coastei de nord-vest a Mării Negre, România. Zona de studiu reprezintă un aliniament de 10 km de țărm aflat în extremitatea sudică a Rezervației Biosferei Delta Dunării (RBDD) și expus riscului creșterii presiunii antropice în următorii ani. Din cele 38 de specii de plante cormofite, identificate între plaja înaltă și spatele dunelor frontale, potrivit Listei Roșii naționale, 8 sunt specii rare și amenințate. Analiza spectrului floristic scoate în evidență prezența unui amestec de elemente care compun comunitățile de plante, însă elementele pontice și ponto-caspice sunt dominante. Morfologia dunelor frontale de pe coasta deltaică este tipică, însă profilul lor are pante line și au înălțimi sub 2 m. Aceste dune sunt vegetate de plante anuale și plante erbacee perene, însă din punct de vedere al abundenței, gramineele cu rizomi, i.e. acele specii care sunt constructoare de dune, sunt rare.

Dunele frontale din acest sector costier al Mării Negre sunt habitat vital și refugiu ecologic pentru specia *Convolvulus persicus* L., a cărui limită vestică a arealului de răspândire este în Delta Dunării. Extinderea populațiilor acestui endemit ponto-caspic în ultimul deceniu a contribuit la individualizarea unui tip particular de habitat în cadrul regiunii biogeografice continentale Marea Neagră (Pontică), denumit "Dune de țărm pontice cu *Convolvulus persicus* L." Principalele amenințări ale speciei și habitatului definit de aceasta sunt pășunatul vitelor comute mari și turismul estival (călcatul în picioare, cursele de cai, cursele ATV).

Cuvinte-cheie: dune de țărm pontice, zone de vegetație, *Convolvulus persicus* L., endemit regional, refugiu ecologic, tip de habitat

Introduction

Due to the action of wind, waves and tides, sandy shores are some of the most dynamic landscapes on Earth (Maun, 2004). For the most part, in the beach-dune system the shore is colonized by annual plants starting with the drift line. This limit is delineated by the high water mark and it is characteristically associated with the line of marine detritus, usually a macro algal litter (Deidun, Saliba, & Schembri, 2009). The strip zone with marine organic debris forms the drift line habitat (Rodwell, 2000; Gheskiere, Vincx, Weslawski, & Degraer, 2005), which also is named the strand zone or pioneer zone (Maun, 2009). This fringe habitat is colonized by specialized plants species. Most of them are pioneer annuals that are classified as nitrophilous-halophytes (Salisbury, 1952; Doing, 1985; Pakeman & Lee, 1991) and the colonization is strongly dependent on the shelter and

nutrients that can be provided by the flotsam and the jetsam that washes up on the strandline (Crawford, 2008; Chapman, 2013).

Although the development and the botanical composition of strandline communities often varies considerably from one year to another, commonly no more than three or four species are able to grow on any beach (Doing, 1985). For instance, along the temperate coasts, there are rarely quoted more than six plant species in a particular place and they mainly belong to Chenopodiaceae and Brassicaceae families (Lee & Ignaciuk, 1985). On the European coastlines, the most typical strandline species are *Cakile maritima* Scop. (Wright, 1927; Davy, Scott, & Cordazzo, 2006), *Salsola kali* (L.) Scop., *Atriplex littoralis* L., and *Crambe maritima* L. (Doody, 1991; Davidson et al., 1991). In addition, perennial members of Convolvulaceae (*Calystegia soldanella* L. Roem. & Schult.), and Poaceae (*Ammophila* sp.,

Elymus sp., *Leymus* sp.) are most frequent on the landward drift lines (Doody, 1991; Maun, 2009).

Besides the biological diversity value and the great ecological value of the drift line habitats (Davidson et al., 1991; Gheskiere, Vincx, Weslawski, & Degraer, 2005; Deidun, Saliba, & Schembri, 2009), all these plants help to combat the erosion of the upper beach (Doody, 2012). From the geomorphological point of view, the seaward edge of vegetation represents the border where the sand accumulation by wind and the building of the foredune start (Hesp, 2013). Along a prograding shore, plant species from the drift line and high beach are important biotic geomorphological agents because of their role in trapping the sand and building dunes. Consequently, where sand accumulates within and behind individual plants, embryo dunes are initiated landward of the high beach, which subsequently become foredunes (Hesp, 1983, 1989, 2004; Carter & Wilson, 1990; Davidson et al., 1991; Packham & Willis 1997; Davinson-Arnott, 2010; Hesp, 2013; Montreuil, Bullard, Chandler, & Millet, 2013;) with a different vegetation.

But only particular plants are specialized as "dune-building" species; as Maun, 2009; Durán & Moore, 2013 demonstrated, the plant zonation from drift line-high beach system is the primary factor that controls the maximum size of foredunes and therefore the amount of sand stored in a coastal dune system. Beside wind velocity and rates of sand transport, the morphological development of embryo dunes depends on plant density, plant distribution, height and cover. Tall, dense species such as *Ammophila arenaria* tend to produce higher hummocky dunes, whereas lower, spreading plants such as pan tropical creeping vine *Ipomoea pes-caprae* tend to produce lower less hummocky dunes (Hesp, 2004). In the absence of vegetation, dune systems can exhibit significant mobility, where all or part of the dune can migrate (Short & Hesp, 1982), commonly landward, due to onshore winds (Davis & Fitzgerald, 2004).

The seashore and coastal sand dunes are among the most endangered and threatened ecosystems worldwide because of escalating anthropogenic pressures as a result of coastal development, direct human use - mainly associated with recreational activities - high erosion rate, and global sea level rise. Despite many and unique ecological services that are provided by dune ecosystems (Heslenfeld, Jungerius, & Klijn, 2004; Brown & Mc Lachlan, 2006; Maun, 2009; Everard, Jones, & Watts, 2010; Frosini, Lardicci, & Balestri, 2012; Durán & Moore, 2013) in Europe, almost all coastal countries (European Environmental Agency 1999; Doody 2012) face losing and degradation of sand dune landscape, which are leading to a dramatic biodiversity loss, caused by the alteration and disappearance of many

habitats and the rarefaction and/or local extinction of the most typical and extremely specialized native species (Buffa, Fantinato & Pizzo, 2012). On the other hand, coastal dune habitats are included in the CORINE biotope classification (Devillers, Devillers-Terschuren, & Ledant, 1991), EUNIS habitats (http://eunis.eea.europa.eu/upload/EUNIS_2004_report.pdf). At the European Union level, some of them were assessed as priority habitats or habitats of community interest in Annex I of EU Habitats Directive (CE 43/92).

In a wild dune-beach system from Europe, based on the coastal dune classification (Psuty, 2004) and according to the last Interpretation Manual of European Union Habitats (EU 28), two habitat types are expected to exist at least: "2110 Embryonic shifting dunes" and "2120 Shifting dunes along the shoreline with *Ammophila arenaria*". But if on a sandy beach there occurs formation of annual plants with sea-rocket communities, and *Cakile maritima* is the characteristic species, then this type of vegetation should be considered under "2110 Embryonic shifting dunes habitat type as well" instead of "1210 Annual vegetation of drift lines habitat" as it was defined before EU 28.

The floristic diversity and specific plant communities from the Black Sea coast were particularly assessed by Géhu & Uslu (1989), Kavgaci (2007), in the Turkish area, Petrova & Apostolova (1995), Tzonev, Dimitrov, & Roussakova (2005), Făgăraș, Anastasiu, & Negrean (2010), Petrova (2011), in the Bulgarian area. Within the Romanian Black Sea coastline, particular studies on flora and vegetation were performed, especially within deltaic plain, by Pallis (1915), Panțu, Solacolu, & Păucă (1936), Dihoru & Negrean (1976 a, b), Popescu & Sanda (1976), Roman (1992), Sanda & Popescu (1992), Ciocârlan (1994), Hanganu et al., (2002), Strat (2005, 2007, 2009), Doroftei et al. (2011), Făgăraș (2013, 2014). Our research is the first detailed analysis of the floristic composition of the deltaic shore which gives full information about plant species distribution along of each morphological and functional feature of the beach-dune system.

However, in the last years, the shore vegetation within the Danube delta was assessed especially according to the Habitats Directive requirements (Făgăraș, 2013, 2014) as part of the first monitoring of conservative status of the habitats and species of Community interest from Romania in order to report the summarized and analysed results to the European Commission according to Article 17 of the Habitats Directive (Mihăilescu, Strat, Cristea & Honciuc, 2015). Nevertheless, for the Romanian coastline, published lists of phytodiversity in accordance with shore zonation of sandy shores features are scarce.

This paper presents the assessment of the plant diversity of the beach-dune system along the southern part of the Danube delta coast in accordance with the shore zonation of forms in order to identify dune-building plant species. Life forms spectra and floristic elements were also assessed and a distinctive habitat type for the western Black Sea coast is described. The main threats and the vulnerability of shore area and its habitats were also investigated.

Materials and Methods

Study site

The studied area is a sandy shore on the southern part of the Danube delta coast that is located between Sf. Gheorghe and Sulina mouth arms (Fig. 1). The general orientation of the deltaic

shore is north and the study area is called Sărăturile shore due to it is development as part of the marine beach ridge plain that has same name (Fig. 1), and, virtually, in the the future it is expected that this current foredune ridge will become the newer added part of the Sărăturile beach ridge plain as a result of the prograding processes.

The entire coast is microtidal, with a maximal tidal range of 0.12 m at spring tide (Bondar, Roventa, & State, 1973), which means that the coast is a wave-dominated type (Short, 1996). The wave energy climate is medium (Vespremeanu-Stroe & Preoteasa, 2007), with a mean wave-height of 0.8 m, but during storm surges the water-level fluctuations can reach a maximum of 1.2-1.5 m height (Giosan et al., 1999).

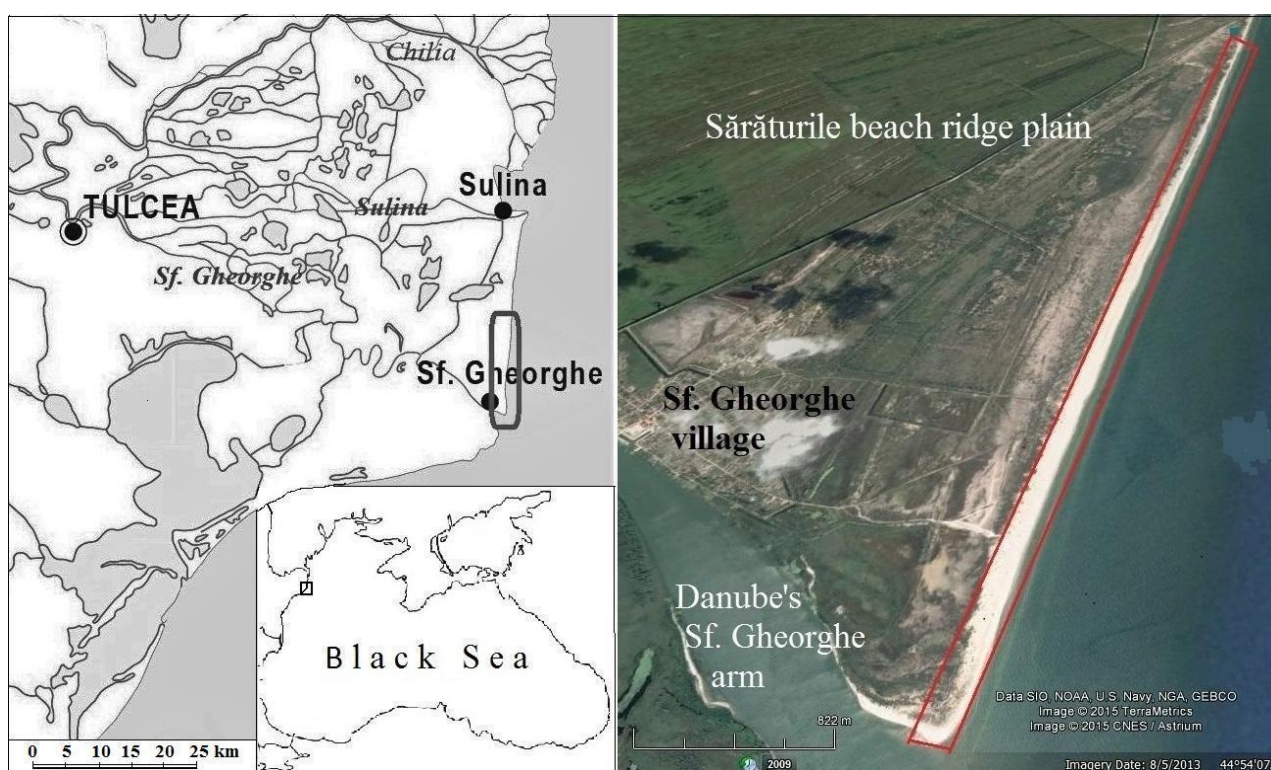


Fig. 1: Map of the study site

The climate of the area may be described as temperate continental with Pontic influences (Bogdan, 2008). The mean annual air temperature is 11.3 °C and the annual amplitude 22.3 °C. For the last 25 years, the mean annual rainfall amount is 281 mm and the potential evapotranspiration is around 730 mm per year, which means a severe water deficit but, due to the proximity of the sea, the relative humidity is high (annual mean: 87%). Based on the aridity De Martonne index value (13), the climate is semi-arid (Strat, 2010). According to the Rivas-Martínez system (Rivas-Martínez et al., 2004), the bioclimate of this area (Fig. 2) can be described as Mediterranean xeric continental type

(Strat, 2010). The Period of Plant Activity (i.e., months with mean temperature > 3.5 °C, Rivas-Martínez et al., 2004) is nine months and the average growing season length (defined as the average number of days a year with a 24-hour average temperature of at least 5°C) has changed from 254 days for the period between 1951-2000 to 268 days in first decade of the 21st century (Strat, 2015). Prevailing winds are northerly (Strat, 2001; Vespremeanu-Stroe, Cheval, & Tătui, 2012) and they are responsible for the biggest storms that have an average speed of 9.8 m/s and durations that range between 8 and 22 hours (RCMGG, 1994).

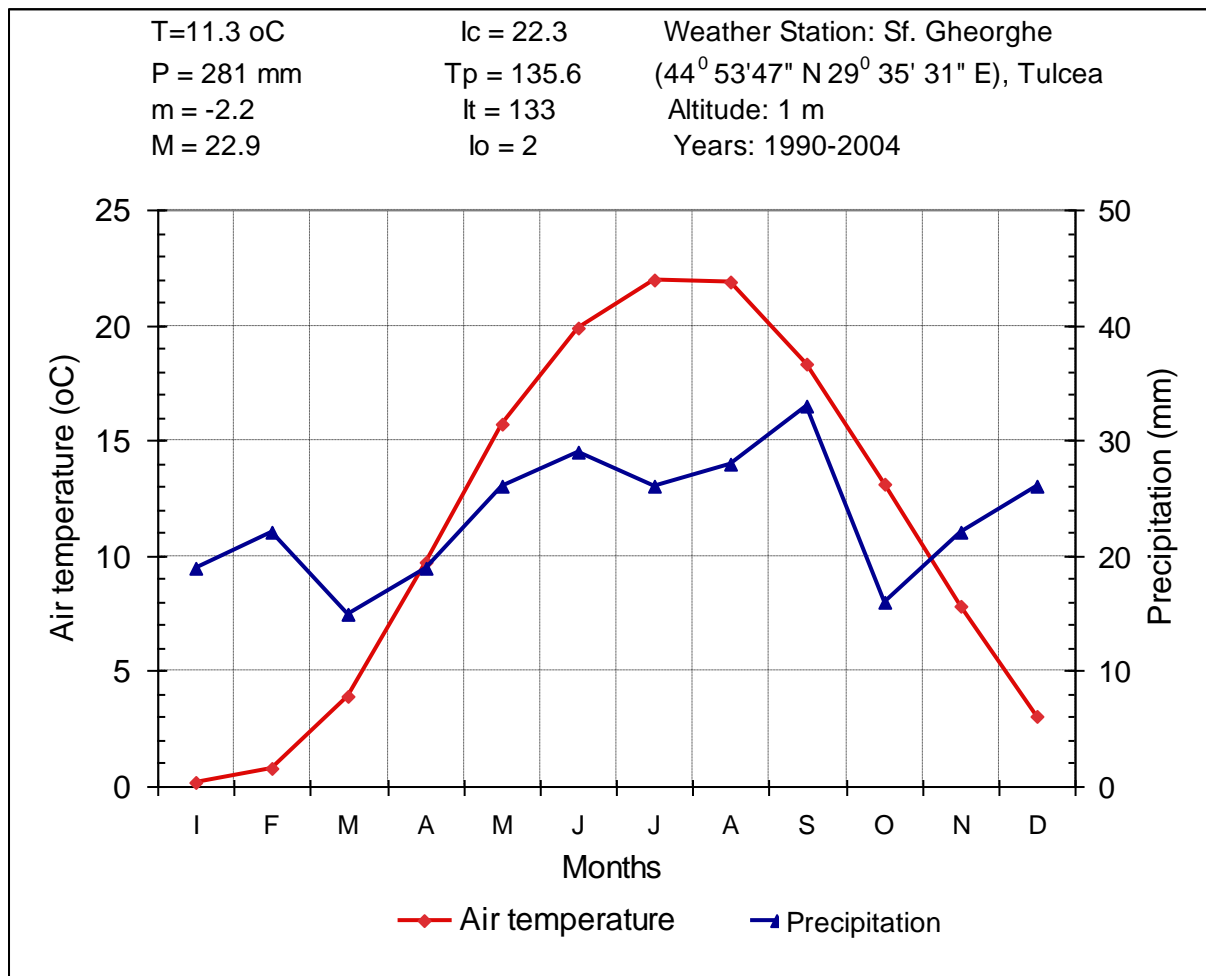


Fig. 2: Bioclimatic classification of Sărăturile beach ridge plain (South eastern Danube delta coastal stretch) for the period. Bioclimatic indices are calculated after Rivas-Martinez et al. 2004, as it follows: P = Yearly average precipitation, T= yearly average air temperature, m=Average of the minimum temperature of the coldest month, M = Average of the maximum temperature of the coldest month, Ic = Continentality index, Tp = Yearly positive temperature, Itc Io = Ombrothermic index

Geomorphologically, Sărăturile shore is composed by a beach-dune system that stretches 15 km northward Sf. Gheorghe arm mouth (Vespremeanu, 1987). The width of the beach decreases progressively from the southern sector (50-70 m), named Cape Buival (Fig. 3a), to the northern extremity, where it has around 20-30 m (Tătui, Vespremeanu-Stroe, & Preoteasa, 2013). On the southern extremity of shore, due to significant amounts of sediments delivered by Sf. Gheorghe mouth bar, in the last years the shore line has been advanced with 1-2 m/year (Tătui, Vespremeanu-Stroe, & Preoteasa, 2013) (Fig. 3b). The beach sediments are composed by medium-fine sands (Giosan et al., 1999) and shell debris.

The organic detritus that is washed up along the high water mark hardly makes a clearly defined strip zone. Accumulations of drift material have not macroalgal litter content since the sandy bottom of the littoral and infralittoral zone is not vegetated by macroalgae. Instead of macroalgal litter, the organic

debris from the drift line is composed locally by "camca", especially in the proximity of river mouths. The word "camca" is the local term for shredded leaves, decayed rhizomes, and aerial stems of *Phragmites australis* which accumulates on the beach and that are subsequently mixed with shells debris and sand. In addition to this, there are larger fragments of rhizomes and stems of reed and pieces of "plaur" or "plav" (the local names of floating reed fen), which originate from the Danube delta. Annual drift line plant species are often rooted in these pieces of *plaur*, along with plant species that are characteristic of the floating reed fen like *Solanum dulcamara* L. and the fern species *Nephrodium thelypteris* Schott. Shell debris and pieces of dung, which are dropped by cattle that graze on foredunes, are quite frequent.

The beach is followed by a well-defined foredunes alignment, which makes a rather continuous ridge with a smooth profile, but it not exceeds 2.5 m in height (Vespremeanu-Stroe & Preoteasa, 2007).

Hummock dunes, which are built around the erratic *Hippophae rhamnoides* L., *Eleagnus angustifolia* L., and *Tamarix ramossissima* Ledeb., and blowouts are

present, too. Ecologically, these foredunes are semi-fixed yellow dunes, because they are vegetated by annual as well perennial herbaceous plant species.

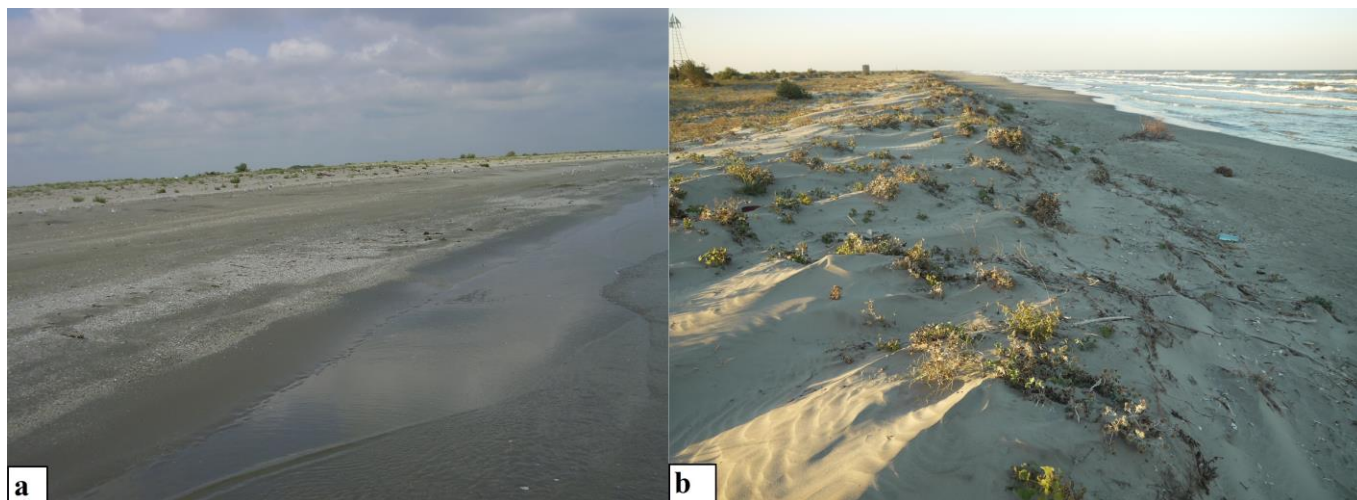


Fig. 3: The Sărăturile Shore. General view of the southern part, close to Sf. Gheorghe mouth arm (a). The new incipient foredune ridge from the southern part of Sărăturile shore (Picture taken in September 2014)

Concerning the functional areas within the Danube Delta Biosphere Reserve, the study site, together with the entire Sărăturile beach ridge, is located within a transition zone, where human activity is allowed (<http://www.ddbra.ro/rezervatia/delta-dunarii/prezentare-general/zonare-functionala-a19>). At 3 kilometers' westwards from the shore there is Sf. Gheorghe village with a current population of less than eighth hundred inhabitants (INS, 2013).

Field survey and data collection

The floristic surveys were carried out on the southern Danube delta coastline located between Sf. Gheorghe and Sulina distributary mouths. Species composition of the vegetation was recorded in July 2012 and August 2014. Unpublished field observations made by the author from 2003 to 2014 were also integrated. In order to record the floristic diversity and plant communities, a transect method was employed. Twenty-five strip transects one meter wide were established perpendicular to the shore line following each morphological feature of the beach-dune system according to Vespremeanu (1987, 2004): drift line, beach berm, embryo dunes, foredunes, which morphologically and functionally have three sections (seaward dune side, top dune and lee side), and, from place to place where foredunes have gaps as a result of storm-surges breaching, washover fans. The presence or absence of vascular plant species was recorded along each transect at 2 meter intervals using 1-m² quadrats and following every morphological feature of the beach-dune system. Species-specific cover was recorded using the Braun-Blanquet scale (Braun-Blanquet, 1932).

Species were identified by referring to standard floras (Panțu, Solacolu, & Păucă, 1936; Popescu & Sanda, 1976; Dihoru & Negrean, 1976 a, b; Ciocârlan, 1994; Doroftei et al., 2011) and floristic keys (Ciocârlan, 2000) of the Danube Delta. The nomenclature of taxa is according to *Flora Europaea* (Tutin et al., 1964-1980), the Euro+Med PlantBase (www.emplantbase.org), and the International Plant Names Index (www.ipni.org). For updated botanical names and authorities of plant species, www.theplantlist.org website has been used. Life forms and floristic elements were assessed according to Ciocârlan (1994, 2000). Endemic, rare and threatened species were classified according to Red Book of higher plants from Romania (Dihoru & Negrean, 2009).

Results

On the Sărăturile beach-dune system there were recorded 38 species of vascular plants that belong to 15 families, but not all are typical coastal plants species (Table 1). From them, a typical strandline is *Salsola kali* subsp. *ruthenica* (Iljin) Soó whilst typical coastal psammophytes are *Eryngium maritimum* L., *Leymus racemosus* (Lam.) Tzvel. subsp. *sabulosus* (Bieb.), *Convolvulus persicus* L., *Centaurea arenaria* subsp. *borysthenica* (Gruner) Dostál, *Medicago marina* L., *Polygonum maritimum* L. Compositae (9 species) and Poaceae (7 species) are the most represented families, accounting for 42 % of the identified species. Species richness ranged from 3 to 12 species per transect and 0 to 5 per quadrat. The estimated mean plant cover is around 30% but it is lower on the upper beach and seaward of foredunes and higher (around 45%) on the landward of foredunes.

Table 1: The plant list from Sărăturile beach dune system, the Danube Delta, North-Western Black Sea coast. Cont = continental; Euras = Eurasiatic; Medit = Mediterranean; Pont = Pontic; Pan = Pannonian; Balk = Balkanic; Atl. = Atlantic; Cosm. = Cosmopolitan; N. Amer. = North American. *Species that are listed on Romanian Red List

Nr. crt.	Family	Species name	Origin	Life form	Shore feature occurrence
1	Ephedraceae	<i>Ephedra distachya</i> L.*	Cont-Euras.	Chamaephyte	Landward side of the foredune
2	Amaranthaceae	<i>Atriplex litoralis</i> L.	Euras.	Therophyte	Drift line
		<i>Corispermum nitidum</i> Kit.	Pont. – Pan.	Therophyte	Foredune crest, Landward side of the foredune
		<i>Salsola kali</i> subsp. <i>ruthenica</i> (Iljin) Soó	Euras.	Therophyte	From drift line to the dune base from the landward side
3	Aristolochiaceae	<i>Aristolochia clematitis</i> L.	Medit.	Cryptophyte-Geophyte	Landward side of the foredune
4	Apiaceae	<i>Eryngium maritimum</i> L.*	Medit.	Hemycryptophyte	Berm, Foredune
5	Boraginaceae	<i>Tournefortia sibirica</i> L.*	Euras.	Cryptophyte-Geophyte	Driftline
		<i>Onosma visianii</i> Clem.	Pont. Pan.-Balk.	Hemytherophyte	Dune base from landward side
6	Brassicaceae	<i>Cakile maritima</i> subsp. <i>euxina</i> (Pobed.) Nyár *	Pont.	Therophyte	Seaward side of the foredune
7	Compositae	<i>Artemisia tschernieviana</i> Besser *	Pont.	Chamaephyte	Foredune crest and landward side of the fore dune
		<i>Centaurea arenaria</i> M.Bieb. ex Willd.	Pont.-Pan. – Balc.	Hemytherophyte	Foredune crest and landward side of the fore dune
		<i>Centaurea pontica</i> Prodan & Nyár.*	Endemism in Romania	Hemyterophyte	Foredune crest and landward side
		<i>Helichrysum arenarium</i> ssp. <i>Ponticum</i>	Pont.	Hemycryptophyte	Landward side of the foredune
		<i>Lactuca tatarica</i> (L.) C.A.Mey.	Cont. Euras.	Hemycryptophyte	Drift line
		<i>Petasites spurius</i> (Retz.) Rchb	Atl.-Pont.	Geophyte	Landward side of the foredune
		<i>Scolymus hispanicus</i> L.	Medit.	Hemyterophyte	Fore dune crest and landward side of the fore dune
		<i>Tripolium pannonicum</i> subsp. <i>tripolium</i> (L.) Greuter	Euras.	Hemycryptophyte	Drift line
		<i>Xanthium strumarium</i> L.	Cosm.	Therophyte	Fore dune
8	Convolvulaceae	<i>Convolvulus persicus</i> L.*	Pont. –Casp.	Hemycryptophyte	High beach, Fore dune
		<i>Cuscuta</i> sp	Cosm.	Therophyte	Parasite on <i>C. persicus</i> , <i>Eryngium maritimum</i> and <i>X. strumarium</i> , <i>E. seguieriana</i> from Foredune crest and landward foredune
9	Elaeagnaceae	<i>Hippophae rhamnoides</i> L.	Euras.	Phanerophyte	Foredune crest, Back dune
		<i>Elaeagnus angustifolia</i> L	Euras.	Phanerophyte	Landward side of the fore dune
10	Euphorbiaceae	<i>Euphorbia peplis</i> L.	Euras.	Therophyte	Drift line
		<i>Euphorbia seguieriana</i> Neck.	Cont. Euras	Hemycryptophyte	Foredune crest, Landward side of the foredune
11	Leguminosae	<i>Medicago marina</i> L.	Medit.	Hemycryptophyte	Foredune heels
		<i>Amorpha fruticosa</i> L.	N. Am. (invader)	Phanerophyte	Fore dune toe
12	Plantaginaceae	<i>Linaria genistifolia</i> subsp. <i>Euxina</i> (Velen.) D.A.Sutton	Pont.	Therophyte	Base of the lee side ore dune
		<i>Plantago coronopus</i> L.	Atl.-Medit.	Therophyte-Hemycryptophyte	Drift line, high beach
		<i>Plantago maritima</i> L.	Pont.-Medit	Hemycryptophyte	Driftline, seaward side of the beach
13	Poaceae	<i>Aeluropus litoralis</i> (Gouan) Parl.	Pont.-Medit.	Hemycryptophyte	Foredune crest, Landward side of the foredune
		<i>Cynodon dactylon</i> (L.) Pers.	Cosm.	Geophyte	Foredune crest, Landward side of the foredune
		<i>Elymus farctus</i> subsp. <i>bessarabicus</i> (Savul. & Rayss) Melderis	Pont.	Geophyte	Beach, Foredune toe, Foredune crest

		<i>Elymus elongatus</i> subsp. <i>ponticus</i> (Podp.) Melderis*	Pont.	Geophyte	Beach, Foredune toe, Foredune crest
		<i>Elymus athericus</i> <i>Elymus athericus</i> (Link) Kerguelen	Atl.	Geophyte.	Beach, Foredune toe, Foredune crest
		<i>Leymus sabulosus</i> (Bieb.) Tzelev.	Euras.	Geophyte	Beach, Foredune toe, Foredune crest
		<i>Secale sylvestre</i> Host.	Cont.-Euras.	Therophyte	Foredune toe, Foredune crest
14	Polygonaceae	<i>Polygonum maritimum</i> L.	Medit.	Therophyte	Landward side of the foredune
		<i>Polygonum arenarium</i> Waldst. & Kit.	Pont.-Medit.	Therophyte	Landward side of the foredune
15	Tamaricaceae	<i>Tamarix ramosissima</i> Ledeb.	Cont.-Euras.	Phanerophyte	Foredune toe

Life form spectra show that the vegetation of the entire beach-dune system is dominated by hemicryptophytes (39%) and subordinately by therophytes (31%). The rest of taxa are geophytes, phanerophytes, and chamephytes. In terms of floristic elements, around 45% of taxa are Pontic, Pontic-Mediterranean and Ponto-Caspian elements, which is normal considering geographical position of the Danube Delta.

According to the Romanian Red List (Dihoru & Negrean 2009), ten taxa that occur in the study area are threatened as follows: four of them were categorized as critically endangered (*Convolvulus persicus* L., *Argusia sibirica* L. (Dandy), *Petasites spurius* (Retz.) Rchb., *Euphorbia pepelis* L.), two endangered (*Cakile maritima* subsp. *euxina* (Pobed.) Nyár, *Artemisia campestris* subsp. *inodora* Nyman), and

four as vulnerable (*Eryngium maritimum*, *Polygonum maritimum* L., *Scolymus hispanicus* L., *Centaurea arenaria* Bieb. subsp. *borysthena* (Gruner) Dostál).

Based on the floristic survey of each morphological feature of the beach-dune system, the following distinct vegetation zones are characteristic of the Sărăturile shore - Danube Delta (Fig. 4): (1) the drift line or pioneer zone, consisting of dominant pioneer annual plant *Salsola kali* subsp. *ruthenica* (Iljin) Soó; (2) the berm (upper beach and embryo dunes), consisting mainly of pioneer annual plants and perennial dune-building species; (3) the foredunes, consisting of dune-building and burial-tolerant stabilizing, herbs, grasses, and shrubs. These functional zones have a perfect correspondence with the general worldwide coastal foredune zonation given by Doing (1985).

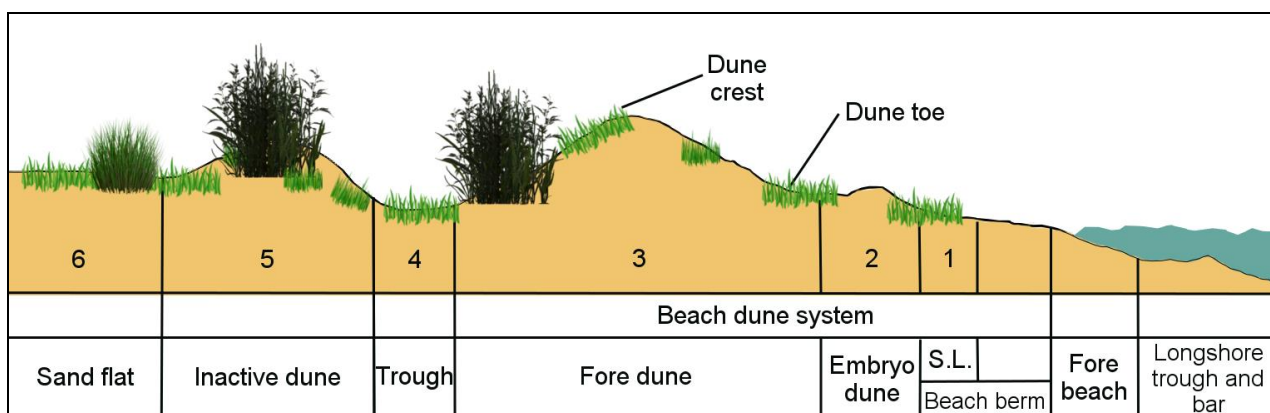


Fig. 4: Morphological features and functional ecological zone of the prograding shore Sărăturile, the Danube delta. 1. Strandline (S.L.) – vegetated with halophytic annuals; 2. Ebryo dunes/white dune, developing above swash limit. They are instable, subject to wave action, vegetated with annuals and rhizomatous herbs and grasses; 3. Fore dune/ yellow dune, instable, under wind blow action, vegetated with herbaceous annuals, perenial herbs and grasses, erratic shrubs (*Hippophae rhamnoides*, *Elaeagnus angustifolia*); 4. Trough (interdune/back dune zone), more wet than dunes, vegetated with annuals and shrubs; 5. Inactive dune (back dune)/grey dune, stable, well vegetated, with herbs and shrubs. 6. Sand flat, temporary inundated, vegetated with halophilous species plants (*Salicornia herbacea*, *Juncus maritimus*, *Statice gmelini*, *Plantago maritima*, *Spergularia* sp.).

a) The drift line or pioneer zone

Across the Sărăturile shore there was not a continuous band of drift line flora species. During the floristic survey, the typical drift line plant species were *Salsola kali* subsp. *ruthenica* (Iljin) Soó and *Argusia sibirica* (L.) Dandy but only *Salsola* was

spread on the entire shore. It makes ribbon-like stands which run along the water-line for hundreds of meters. On the drift line there are large plants which are associated with the wet sand that contains organic litter in contrast to the small stunted (10-15 cm) and unbranched individuals that were found on foredunes, above the limit of storm

inundation. On the drift line and upper beach, *Salsola* individual plants develop ephemeral nebka and shadow dunes as they trap sand (Fig. 5a).

Argusia sibirica (synonym *Tournefortia sibirica*) was the only perennial plant with stabilizing growth habit that it was found on the drift line zone. It occurs in the vicinity of the Sf. Gheorghe arm mouth where it makes the monospecific associations (Fig. 5b) named *Tournefortietum sibiricae* (Popescu & Sanda, 1975; Sanda, Ollerer, & Burescu, 2008) or is accompanied by *Salsola kali*. Branched stems of *Argusia sibirica* make clumps that develop small embryo dunes as they trap blowing sand. The occurrence of *Argusia sibirica* in

this particular area was reported in the early of the twentieth century (Panțu, Solacolu, & Păucă, 1936) but, based on our ascertainments in the last decade, the area covered by its populations has dramatically decreased, most probably because of the human pressure.

E. maritimum and *Xanthium strumarium* L. occurs along the entire shore. Only on the southern extremity, close to the Sf. Gheorghe mouth discharge, *Leymus racemosus* subsp. *sabulosus* L., *Plantago coronopus* L., *Atriplex littoralis* L., *Lactuca tatarica* C.A. Mey, *Plantago maritima* L., and *Euphorbia peplis* L. were recorded, but the abundance of species was very low.



Fig. 5: Drift line habitat with *Salsola kali* subsp. *ruthenica* (a) and *Argusia sibirica* (b)

b) The berm (upper beach and embryo dunes)

The upper beach is populated by annuals *Salsola kali* subsp. *ruthenica*, *Xanthium strumarium* subsp. *italicum* L., the biennial *Eryngium maritimum* L., and herbaceous perennials *Convolvulus persicus* L. and *Leymus racemosus* subsp. *sabulosus* L.

In the southern sector of the study area, close to the mouth of Sf. Gheorghe arm of the Danube river, on the landward side of the beach, after more than a decade, a new ridge of incipient foredune were initiated around both pioneer annuals and perennial plants (*Salsola kali* subsp. *ruthenica*, *Eryngium maritimum*, *Convolvulus persicus*, *Leymus racemosus* subsp. *sabulosus* Tzvelev., *Xanthium strumarium* subsp. *italicum*). This process is normally taking in account the pattern of the foredune development near the river mouth discharge site on a wave dominated shoreline (Psuty, 2004).

c) The foredunes

The floristic diversity of foredune is higher than of the high beach and embryo dunes, but species richness has varied along the entire shore. Following, taxa were recorded and listed regardless of their frequency: *Eryngium maritimum*, *Convolvulus persicus*, *Corispermum nitidum* Kit., *Euphorbia seguieriana* Neck., *Leymus racemosus*

subsp. *sabulosus*, *Secale sylvestre* Host, *Petasites spurius* (Retz.) Rchb., *Xanthium strumarium*, *Salsola kali* subsp. *ruthenica* (Iljin) Soó, *Polygonum arenarium* Waldst. et Kit., *Cynodon dactylon* L (Pers.), *Artemisia tschernieviana* Besser, *Centaurea arenaria* L., *Medicago marina* L., *Aeluropus littoralis* subsp. *littoralis*, *Ephedra dystachya* L, *Helichrysum arenarium* subsp. *ponticum*, *Cuscuta* sp., *Linaria genistifolia* (L.) Mill. subsp. *genistifolia*, *Scolymus hispanicus* L., *Scabiosa ucranica* L., *Cakile maritima* ssp. *euxina*, but the major foredunes plant species along the entire analyzed shore are *Eryngium maritimum* L, *Convolvulus persicus* L., *Xanthium strumarium* L., *Salsola kali* subsp. *ruthenica*, and *Secale sylvestre* Host. The lee sides of foredunes are bordered by a bush belt composed by the dominant species of *Hippophae rhamnoides* and *Elaeagnus angustifolia*, subsequently.

The occurrence of the sea buckthorn on the shore dune was noticed as sporadically early in the 20th century (Panțu, Solacolu, & Păucă, 1936), but it largely spread in the second half of former century after this shrub was used in afforestation works in order to stabilize the transgressive dune field from behind the shore (Ceuca & Bakos, 1985; Mănescu & Traci, 1995). We think that the forest plantation that was set up in the 1970s in the vicinity of the shore (Mușat, 1980) was the seed source of the sea

buckthorn populations from shore back dunes. This assumption is based on documented seed dispersal effect of frugivorous birds, as well as on the ability of this thorny scrub to colonize rapidly open habitats via suckering and self-seeding (Li Thomas & Beveridge Thomas, 2003). Archive photos show that, in the 1960, before afforestation works, the southern Sărăturile field landscape was defined by shifting dunes and a sand sheets transgressive field with very scarce vegetation (Mușat, 1980; Ceuca & Bakos, 1985). Technically, *Hippophae rhamnoides* has escaped from tree plantation and has displayed invasive behavior in the area of coastal dunes, but from the geomorphological point of view it has significantly contributed to the dune stabilization process.

Discussions

The sandy shore plant communities from the Danube delta show a certain degree of uniqueness within the Black Sea Basin, which is supported by various factors ranging from present geographical and physical characteristics to the past climatic events that drove dramatic changes of the Black Sea level and floristic migrations in the coastal zones. The synergy of all these features has made possible the occurrence of a wide range of species with different geographical distribution as well as of endemic species. This phytogeographic mix greatly increases the floristic value of the deltaic shore, contributing to define plant communities and systems not found elsewhere.

During the floristic surveys, *Cakile maritima* subsp. *euxina*, which is normally a drift line species, was found only on the fore dune toe and it was spread exclusively in the northern half of the Sărăturile shore. *Cakile maritima* subsp. *euxina* is endemic around the Black Sea (Rodman, 1974; Davy, Scott, & Cordazzo, 2006) and the Sea of Azov shore (Golub et al., 2006), being one of at least four subspecies distributed along the European coast lines (Ciccarelli et al., 2010), a fact that was confirmed by the morphologically distinct chemical races (Rodman, 1976). On the Romanian Black Sea coast, it is strictly annual and, consequently, it is wholly dependent on seeds for survival.

In the previous floristic studies (Ciocârlan, 1994), the occurrence of sea rocket along the Sărăturile shore was mentioned as sporadically and very rare, but it is known that this plant species tends to make ephemeral and shifting population depending on propagule dispersal by sea water and wind (Davy, Scott, & Cordazzo, 2006). Also, its fluctuating appearance and disappearance locally along a coast was noticed by Hewett (1970).

All *Cakile maritima* ssp. *euxina* individuals that were found during our field trip were vigorous, highly branched, and with light lavender flowers,

matured and in development fruit, which confirm the ability of this species to tolerate the foredunes environment (Boyd & Barbour, 1993). Also, all plant individuals were distributed as discrete units, being separated from each other by considerable distances, ranging between 50 and 100 meters. It should be noted that there were not identified dry stems from the previous year. This fact suggests that in the study area the occurrence of sea rocket is recent, and it migrates from the north to the south of Sărăturile shore. Given that the nearest sea rocket populations there are at Sulina, northwards of the study area, within the drift line habitat (Făgăraș, 2013), these population are the most probable seeds source for Sărăturile shore. Deciduous upper segments fruits of sea rocket, typically one-seeded, have been disseminated by the north longshore drift, and subsequently the swash have casted them on the back shore on the foredunes during of overwash events. This possibility is in agreement with the studies which have proved the role of marine currents as dispersal vectors of sea rocket (Fridrikson, 1966; Barbour & Rodman, 1970; Heyligers, 2007; Gandour, Hessini, & Abdelly, 2008; Cousens et al., 2013) due to its well adapted fruit for sea water dispersal, long seeds viability (Maun & Payne, 1989; Cordazzo, 2006; Heyligers, 2007; Ciccarelli et al., 2010), and seed bank persistence at least 2 years in foredunes (Boyd & Barbour, 1993).

Human trampling and cattle grazing are the major circumstances which would certainly reduce the probability of the successful establishment of *Cakile* seedlings on the beach that is close to the Sf. Gheorghe mouth and that is more exposed to human disturbances, but there are likely to develop stands along the insulated northern half of the shore in the coming years, especially since along Sulina shore *Cakile* populations are increasing and expanding.

Despite of the wide spread natural distribution of *Ammophila arenaria* on the European temperate upper beach and foredune, this main dune-building plant species (Wiedemann & Pickart, 2004; Maun, 2009) and ecosystem engineer do not occur on the Romanian Black Sea coast. Although during the past century it was noticed at Sulina (Prodan, 1935), its occurrence was never confirmed later on, there (Ciocârlan, 1994, 2000; Făgăraș, Anastasiu, & Negrean, 2010) or anywhere else on the Romanian coast. Along the Romanian Black Sea coast, this plant species is replaced by the ecologically equivalents *Elymus farctus* subsp. *bessarabicus* (Savul. & Rayss) Melderis, *Elymus elongatus* subsp. *ponticus* (Podp.) Melderis, *Elymus athericus* (Link) Kerguelen, *Leymus sabulosus* (Bieb.) Tzelev., *Elymus pycnanthus* (Godr.) Melderis, *Leymus racemosus* (Lam.) Tzelev. that are the main perennial dune grasses on the Romanian Black Sea coastal zone, but along the study area only *Elymus farctus* subsp.

bessarabicus, *Elymus elongatus* subsp. *ponticus*, *Elymus athericus*, *Leymus sabulosus* (Bieb.) Tzelev were identified and all have been sparse. Besides, although these *Elymus* species are dune building grass (Greipsson & Davy, 1996), they are less effective than *Ammophila arenaria*. According to Barbour (1977), the marram grass has twice root density of *Elymus*, which significantly increases its sand trapping ability and enhances the reinforcement power and stabilization of the sand dunes.

These perennial and rhizomatous grass forms small clumps on the embryonic dunes crest and the foredunes that are equally distinctive and eye-catching because of its stems with very broad bluish-green leaves and long whitish spikes. Infrequently, along the seaward edge, seedlings of *Elymus* grow in rows on the berm, both parallel and perpendicular to the shoreline. These seedlings form a semipermeable obstruction which causes precipitation of sand grains, and thus small embryo dunes and incipient foredune are created.

Competitive interactions with other species for nutrient resources and the absence of safe-sites for germination after the invasion of different species could be other causes for low dominance of *Elymus* in the study area as it has been claimed for different congener species in certain European coastal areas (Greipsson & Davy, 1996). Furthermore, due to paucity of palatable species they are overgrazed by cattle and rabbits. However, in the absence of any dominant beach grass, the foredunes from the study area have a general smooth profile and not a steep one as it is in case of dunes with *Ammophila*.

Among the perennials and sand stabilizers, *Convolvulus persicus* L. (Persian bindweed, sand bindweed) tends to become widely spread and a dominant species on Sărăturile shore. This plant species is endemic around the Black Sea and Caspian Sea coasts, where it grows on mobile sands. In the study area, on the fore dunes it makes monospecific stands as well as associations with *Eryngium maritimum*, *Centaurea arenaria*, *Corispermum nitidum*, *Secale sylvestre*, *Euphorbia seguieriana*, *Elymus farctus* (Viv.) Melderis subsp. *bessarabicus* (Săvul. et Rayss.), and with the invasive weed *Xanthium strumarium* L. Extremely rare before 1990s (Ciocârlan, 1994), in last two decades *Convolvulus persicus* it has spread almost on the entire Sărăturile shore (Strat, 2005, 2009), where it makes the *Convolvuletum persici* (Borza 1931) Burduja 1968 association (Sanda, Ollerer, & Burescu, 2008 frequently, especially on the top and landward side of foredunes.

Being firmly anchored in the sandy substrate and as a result of its sand burial tolerance and guerilla growth form of the vegetative reproduction, *C. persicus* is able to accumulate the wind-blown sand, to create nuclei of mini-dunes around of clump of

stems, particularly to stabilize the sand substrate, and, in the absence of tall perennial grasses, it tends to play a critical role in controlling the size and the morphology of foredunes. Without any other dominant rhizomatous competitors, the deltaic shore between Sulina and Sf. Gheorghe distributaries mouths is the optimal habitat for *C. persicus*. Furthermore, this plant species is the ecologically equivalent of the others representatives of Convolvulaceae family that are typical for sandy shores, similar to *Ipomoea pes-caprae* (Devall, Thien, & Platt, 1991) and *Ipomoea imperati* (Leonard & Judd, 1999) from tropical coasts (Devall et al., 1991), and *Calystegia soldanella* from temperate European (Di Sacco & Bedini, 2015) and American coasts (Wiedemann & Pickart, 2007). Also, *C. persicus* is present on the landward edge of the prograding beach as a consequence of rhizomes growing from foredunes toward beach. Its occurrence on the drift line is associated with the shore zones with dune scarp and the erosional beaches. But in contrast to *Ipomoea pes-caprae* and *Calystegia soldanella* which are glabrous plants, all above ground parts of *C. persicus* are pubescent, densely covered with very short hairs and thereby the plant has grayish-green color and a soft velvety texture (Fig. 6a). Below-ground, spreading rhizomes make a complicated network which can be followed up to 2.5 m depth and 5-6 m horizontally. In this way, the perennial below – ground plant parts contribute to the reinforcement of the sand dunes.

After the floristic survey, the surface covered by *C. persicus* populations in the study area was estimated at around 3.4 hectares which means that, based on previous data (Strat, 2005, 2009), in the last 10 years this plant species has spread out its area of occupancy more than twice. Its contribution to the general plant cover ranges from 5 to 60%. However, *C. persicus* gives to foredunes a distinctive physiognomy (Fig. 6b) which can be hardly found somewhere among the other shore dunes along western Black Sea coast for at least two reasons: Persian bindweed has been constantly a rare taxa on the Black Sea coast and, most of the coastal shifting dunes, that are its habitat, have been dramatically disturbed by human activities in the last decades (Tzonev et al., 2005; Kavgaci, 2007; Făgăraș, Anastasiu, & Negrean., 2010; Stancheva et al., 2011; Aykurt & Sümbül, 2014). Consequently, the plant is critically endangered in Bulgaria (Petrova, 2011), when only one surviving population is composed of few hundreds of stems that cover around 1000 m² (Vladimirov, Feruzan, & Tan, 2012), as well as in Turkey (Öztürk et al., 1998). However, under these circumstances, we consider that the Danube delta shore is the optimal habitat that exists at the western border of the geographic range of *C. persicus*, and this shore could be considered a veritable refuge for this plant.



Fig. 6: *Convolvulus persicus* (a) and seaward side of foredune populated by *Convolvulus persicus* and *Eryngium maritimum* (b)

Taking the above into consideration, we suggest that foredunes from the Danube Delta coast that are vegetated by *C. persicus*, along with the Pontic elements (*Artemisia tschernieviana*, *Centaurea arenaria*, *Centaurea pontica*), to be described as "Pontic shore dunes with *Convolvulus persicus* L. habitat" type. Furthermore, because *Ammophila arenaria* do not occur on the northwestern Black sea coast, it can be stated that the foredunes with *C. persicus* are the equivalent of "Shifting dunes along the shoreline with *Ammophila arenaria* habitat" type, which is portrayed by Habitats Directive (Natura 2000 code 2120) and that was originally described for the Atlantic, North Sea, Baltic Sea and Mediterranean Sea coasts.

Although in the Danube Delta Biosphere Reserve there are other three sites with *Convolvulus persicus* populations (Dihoru & Negrean 1976 a; Ciocârlan, 1994; Strat, 2005, 2009; Făgăraș, 2013) and another one is located in the southern part of the Romanian Black Sea coast, which is the site where this plant species was recorded for the first time in Romania and the Black Sea coast (Săvulescu, 1915), at the present time, corroborating the information gained from literature with our field investigation, we are of the opinion that within the Sărăturile shore there are the largest populations that are spread along the foredunes from the entire western Black Sea coast. Therefore, this dune habitat type has to be monitored and preserved, but for the effective protection and conservation it should be taken into account ecological data, life history, demography and genetic data related to *Convolvulus persicus* as well as the medium and the long-term evolution of the deltaic coast-line, the main threats of shore dunes, including invasive species, present and future human impacts. Besides, from the geomorphological point of view, due to its still high naturalness, the Sărăturile shore could be a key site for coastal foredune type from the Romanian Black Sea coast.

Currently, there are no nature management activities in the coastal dunes area from the study site and though the human disturbance is low for now, the main threats of the foredunes habitat are the cattle and horse grazing, and the tourism activities. According to Sørensen et al. (2009), there are three mechanisms by which plants are affected by mammal grazing: removal of foliar tissue (defoliation), return of nutrients via dung and urine (fertilization), and trampling. On the other hand, documented studies have shown that the long-term management of grazing by domestic livestock on sand dune vegetation has a positive effect on species diversity, plant communities and habitat condition (Plassmann, Jones, & Edwards-Jones, 2010).

The traditional way of pasturage within the Danube delta, including the study area, is to let animals free outside the village, without any herdsman, to fend for themselves. Foredunes are grazed especially during the warm season. Consequently, at the end of the summer the palatable plant species are overgrazed and animals start to graze another plant species which are normally avoided, like *Xanthium strumarium*. During the summer months, frequently, both ungulates – cattle and horses – cross dunes and the beach to get at the sea where they lay on the swash zone for cooling and drinking seawater, which increase the trampling intensity. Furthermore, animals take shelter in the shade of shrubs that are scattered on dunes, and horses roll, take dust baths and scratch the soil surface. Also, large amounts of dung remain on the dunes and beach. Therefore, at the end of the summer, the impact of grazing is readily apparent along of the entire foredunes ridge.

Although there is not any tourism infrastructures on the shore, tourists prefer this area precisely because of its still outstanding wildness. But if in the communist era the deltaic shore was practically untouched by humans because, technically, being

national border it was a forbidden place, in the last decade the tourist flows have been increased dramatically, although there are not any facilities for sunbathing, camping or other leisure facilities. On the other hand, horse riding and all-terrain vehicle riding tend to become very popular recreational activities during summer. Under these circumstances, the most exposed site to human pressure is the southern part of Sărăturile shore, stretching 3 km along the coast, from Cape Buival to north.

Conclusion

Plant spectra of beach-dune system from Sărăturile shore (the Danube delta) does conform to a conspicuous series of parallel bands, although the vegetation zonation is usually very compressed and the embryonic and mobile dunes plant species tend to be intermingled. The best represented life forms are hemicryptophytes (39%) and therophytes (31%), but dune builder rhizomatous grasses are very rare.

Based on literature survey, the dominant diagnostic species are different from those of the other European and even from the other areas of the Black Sea coast. The regional flora (Pontic, Pontic-Mediterranean and Ponto-Caspian elements) and the general environment have a prevailing role in determining foredunes habitats.

Species richness is higher in the drift line and upper beach from the southern sector than in the northern sector of the shore and vice versa on the landward side of foredunes. Five plant species are spread across the entire beach-dune system from the Danube delta – *Salsola kali* subsp. *ruthenica*, *Eryngium maritimum*, *Convolvulus persicus*, *Xanthium strumarium*, and *Elymus farctus* - but only the first three occur constantly in each morphological feature along the entire shore. Psammophytes species with predominantly coastal distribution – namely *Euphorbia seguieriana*, *Centaurea arenaria*, *Corispermum nitidum*, *Artemisia tschernieviana*, *Ephedra distachya*, *Scabiosa ucrainica*, *Petasites spurius*, *Medicago marina*, *Helycrisum arenarium*, *Linaria genistifolia* (L.) Mill. subsp. *genistifolia* - occur only on the top and landward side of foredunes, along with inland species that are frequently found in other vegetation types. Several species are infrequent (*Plantago coronopus*, *Plantago maritima*, *Tripolium panonicum* (Jacq.) Dobrocz, *Euphorbia peplis*, *Cakile maritima* subsp. *euxina*, *Scolymus hispanicus*, and *Ephedra distachya*). Since *Convolvulus persicus* makes monospecific associations, it is a characteristic species for other communities, and its populations cover a large area of foredunes, this regional endemic plant species defines a unique habitat type, both within the Danube delta and the western Black Sea coast. Accordingly, in conjunction with the

particular shore dune morphology, bioclimatic and biogeographical criteria, we suggest that this habitat to be named "Pontic shore dunes with *Convolvulus persicus* L." Regarding the above proposal, and taking in account the occurrence of another threatened plant species also, this shore has to be protected and preserved as a natural refuge for the sand bindweed. This regional endemic plant species is threatened because in the whole its geographical range it has an extremely local distribution and its populations are in decline as a result of negative human impacts in the coastal areas. In the study area, the main threats of *Convolvulus persicus* are summer tourism, cattle and horse grazing. The animals cause trampling impacts, both over plant community and shore microforms, which increases the vulnerability of dunes. However, future studies have to take into account that the domestic livestock grazing, carefully managed, could be a conservation management manner of this beach-dune system.

Acknowledgements

This paper presents partial results of the research program of Sfântu Gheorghe Marine and Fluvial Research Station, Tulcea, which belongs to Faculty of Geography, University of Bucharest. The author would like to thank the following students for their assistance with the collection of the field data: Toader Maria, Țepurică Cristian, Ionescu Diana. Special thanks to Gabriel Dascălu for graphic help.

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