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PHYTOSOCIOLOGICAL STUDY OF THE VASCULAR PLANT COMMUNITIES OF THE LOWER NERETVA DELTA (SOUTHEASTERN ADRIATIC)

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Jasprica, N.: Phytosociological study of the vascular plant communities of the lower Neretva delta (southeastern Adriatic). Nat. Croat., Vol. 32, No. 2, 465-483, 2023, Zagreb.

The Neretva delta (estuary) is an internationally important wetland included in the Ramsar list and is one of the Important Plant Areas (IPA) in Croatia. The paper presents data from phytosociological research collected in the lower Neretva delta in the period 2006-2021. Based on 28 phytosociological relevés, 15 associations and one subassociation were identified and classified into 13 alliances, 12 orders and 11 vegetation classes. The most valuable communities belong to halo-nitrophilous short-lived pioneer vegetation on sand and gravel beaches (*Cakiletea maritimae*) and salt-marsh herblands and scrub (*Therosalicornietea*, *Salicornietea fruticosae*). Anthropogenic impacts on the delta are strong, and the diversity of flora and vegetation is threatened by habitat degradation and loss, unsustainable exploitation of natural resources, and pollution.

Key words: Adriatic basin, coastal vegetation, ecological conditions, halophytes, NE Mediterranean, syntaxonomy, wetland

Jasprica, N.: Fitocenološka istraživanja vaskularnih biljnih zajednica u donjem dijelu delte Neretve (jugoistočni Jadran). Nat. Croat., Vol. 32, No. 2, 465-483, 2023, Zagreb

Delta (estuarij) Neretve je međunarodno značajno močvarno područje uvršteno na Ramsarski popis te je jedno od botanički važnih područja (engl. Important Plant Area, IPA) u Hrvatskoj. U radu su prikazani podaci fitocenoloških istraživanja prikupljeni u donjem dijelu delte Neretve u razdoblju od 2006. do 2021. Na temelju 28 fitosocioloških snimki utvrđeno je 15 asocijacija i jedna subasocijacija koje su uvrštene u 13 sveza, 12 redova i 11 vegetacijskih razreda. S obzirom na ekološku i zaštitnu ulogu najvrijednije zajednice pripadaju pionirskoj halo-nitrofilnoj vegetaciji na pješčanim i šljunčanim obalama (*Cakiletea maritimae*), vegetaciji slanjača s jednogodišnjim biljkama (*Therosalicornietea*) i polugrmovima (*Salicornietea fruticosae*). Antropogeni utjecaji u delti su intenzivni, a raznolikost flore i vegetacije ugrožena je degradacijom i gubitkom staništa, neodrživim iskorištavanjem prirodnih resursa i onečišćenjem.

Ključne riječi: ekološki uvjeti, halofiti, jadranski bazen, močvarno područje, obalna vegetacija, SI Mediteran, sintaksonomija

INTRODUCTION

The Neretva delta (i.e. the Neretva estuary, *sensu* Nikolić *et al*., 2010) was included in the Ramsar List as a wetland of international importance in 1993. The total area of the delta is 170 km^2, 70% of which belongs to the Republic of Croatia and the rest to Bosnia and Herzegovina. The delta is one of the Important Plant Areas (IPA) in Croatia

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(Jasprica, 2010). The IPA encompass the part of the river delta downstream of the town of Metković. The criteria for inclusion of the Neretva delta in the IPA were (a) the presence of important populations of one or more plant species of global or European conservation importance, (b) a flora extremely rich in relation to the biogeographical zone in the European context, and (c) the presence of habitats of global or European conservation or botanical importance. There are six main groups of habitats in the Neretva delta: (1) euri-Mediterranean evergreen forests and holm oak-macchia, (2) saline, shallow, muddy marshes with halophytes, (3) sub-Mediterranean and epi-Mediterranean dry grasslands, (4) thermophilic flood thickets, (5) mixed, rare pure, evergreen forests and holm oak-macchia, and (6) coastal lagoons (Jasprica, 2010). In addition, the presence of 19 important plant species in the delta was noted (Jasprica, 2010). Later, some new endemic species from the delta were described (e.g., Lakušić *et al*., 2013, Jandová *et al*., 2017).

The habitats that cover the largest part of the IPA area are mosaics of cultivated land (23.8%), orchards (19.2%), reeds, rushes and tall sedges (15.5%), and sub-Mediterranean and epi-Mediterranean (*sensu* Trinajstić, 1995) dry grasslands, and sub-Mediterranean thermophilous shrub (10.4%). The part of the delta in Croatia forms a unique ecological unit with the upstream part in Bosnia and Herzegovina, therefore all changes in the upstream part are also reflected in the downstream part (Jasprica & Carić, 2002; Jasprica *et al*., 2003).

Botanical research in the Croatian part of the delta has a long tradition, and the first botanical (floristic) records date back to the middle of the 19th century (Visiani, 1842, 1847; Petter, 1852). Research continued in the 20th century (Horvatić, 1949; Ilijanić & Topić, 1998, etc.) until recent times (for a detailed overview of botanical research in the Croatian part of the delta see Jasprica, 2010; Glasnović *et al*., 2015; Vuković *et al*., 2021). To date, more than 800 plant taxa (species and subspecies) have been identified in the delta. Recent taxonomic and floristic research has led to new findings (e.g., Jandová *et al*., 2017; Vuković *et al*., 2021). In general, flora is better studied than vegetation.

The study of vegetation was focused mainly on the collection and analysis of phytosociological data (e.g., Pandža *et al*., 2007). Even some new plant communities of different syntaxonomic levels were described for the first time (*locus classicus*) from the estuary (e.g., Horvatić, 1954; Jasprica, 2016; Jasprica *et al*., 2016; Preislerová *et al*., 2022).

The objectives of this study were to (i) determine vegetation diversity and community structure within the narrow coastal strip at the mouth of the Neretva river, and (ii) present ecological conditions which determine plant communities pattern in the area. The results of the study are expected to fill in the gaps with data that will ensure effective conservation of the ecosystems, i.e., prevent their further fragmentation or loss.

MATERIAL AND METHODS

Study area

The Neretva delta is located in the Mediterranean region, the Eastern Mediterranean subregion, the Adriatic province and the Epiro-Dalmatian sector (Rivas-Martínez *et al*., 2004).

The climate is Mediterranean. The average annual air temperature is 15.8 °C, and the average annual precipitation is 1081.2 mm (data for the Ploče meteorological stati-

on, data from the Croatian Meteorological and Hydrological Service for 1988 – 2019). The average monthly air temperature (25.7 °C) is highest in July, and lowest (7.0 °C) in January. The lowest air temperature (-7.2 °C) was recorded on 15th February 2012, while the highest (38.8 °C) was recorded twice – on 24th July 2007 and 2nd August 2017. The amount of rainfall is highest in November (154.6 mm average) and December (143.6 mm). The total rainfall from June to August is 121.0 mm.

North winds are the most frequent winds in this area. The sums of relative frequencies (in ‰) are the following: *tramontana* (N) – 49.5, *burin* (NNE) – 148.6, and *bora* (NE) – 84.7. The wind speed (annual average is 2.4 m s^{-1}) is highest in March. The area has 2668.9 hours of sunshine per year. On average, the relative air humidity is 68% (Jasprica *et al*., 2015). According to the Bioclimatic Classification of Europe (Rivas-Martínez *et al*., 2011), the area belongs to the Mediterranean pluviseason-oceanic bioclimate, and it is located within the lower meso-Mediterranean belt.

The geological profile consists of limestone and dolomite of Jurassic, Cretaceous and Eocene ages. These deposits are well stratified (Soldo *et al*., 2010). The most common soils are limestone-dolomite dark soil (calcomelanosol), brown soil on limestone (calcaric cambisol) and sirozem (regosol) on flysch (Martinović *et al*., 1978).

In the Croatian part of the delta there are several nature reserves: the ornithological reserves Pod Gredom (proclaimed in 1965), Orepak (proclaimed in 1974), Prud (proclaimed in 1965), the forest park Predolac-Šibanica (proclaimed in 1968), the ichthyological-ornithological reserve at the mouth of the Neretva river (proclaimed in 1974) and the important landscapes of the Modro and Desne lakes (proclaimed in 1974). The Neretva delta is part of the NATURA 2000 ecological network in Croatia (site code HR1000031) (Official Gazette, 2019). Several NATURA 2000 habitat types are present within this area (Jasprica, 2010). Additionally, the frequent and rapid changes in environmental conditions in this estuary with a very pronounced separation between brackish and marine layers were described (Jasprica *et al*., 2012).

The potential natural vegetation in the delta, i.e. that conditioned by the general climatic conditions and generally not influenced by man, should consist of riparian gallery poplar forests and thickets. Today, however, there are no such forests in the Croatian delta (Lovrić *et al*., 1989). Only fragments of freshwater and wetland plant communities remain after the changes in the upper reaches of the Neretva and the draining in the lower reaches (Horvatić, 1954, 1963; Horvat *et al*., 1974; Jasprica, 2007). In the Croatian part of the delta, 52 plant communities (associations) have been identified, and have been included into 23 vegetation classes (Jasprica & Kovačić, 2005; Jasprica, 2007). However, the presence of some plant communities has not yet been documented by phytosociological relevés.

Data collection and analysis

Field data were collected from 28 vegetation sample plots (relevés) in the period from 2006 to 2021 in the narrow coastal strip at the mouth of the Neretva delta, from the port of Ploče in the northwest to the village of Blace in the southeast (Fig. 1, Appendix 2). The data collected in 2006 originated from the Port of Ploče, the habitats of which have been altered by the impact of construction of a terminal for oil derivatives and bulk cargo. Vegetation was studied in accordance with the principles of the Braun-Blanquet approach (Braun-Blanquet, 1964; Westhoff & van der Maarel, 1980), adopting the International Code of Phytosociological Nomenclature (Theurillat *et al*.,

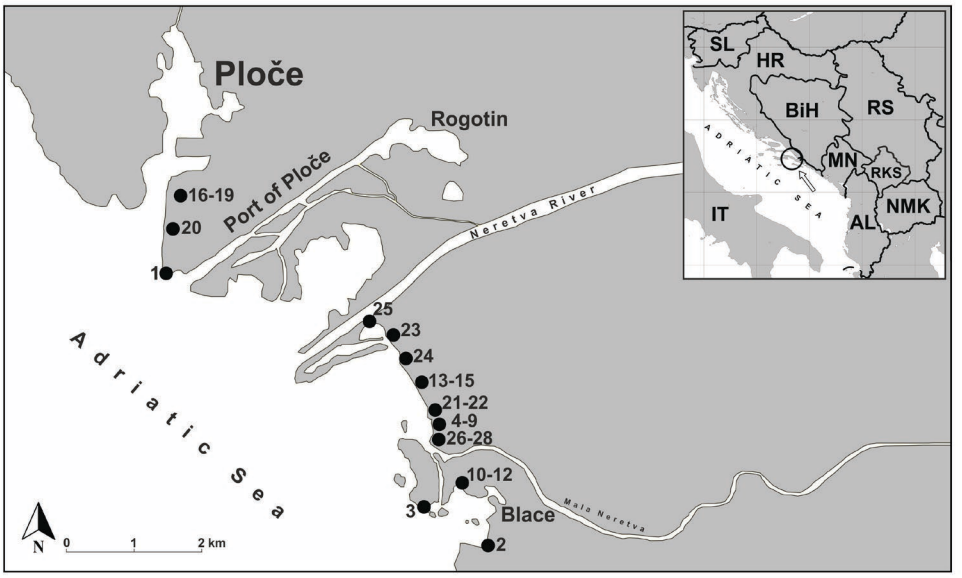

Fig. 1. Map of the studied area in the lower Neretva delta. Black circles with relevé numbers indicate the position of the relevés collected in the study. Relevé numbers correspond to the respective associations; see caption Figure 2, and Table 1. Abbreviations: IT = Italia, SL = Slovenia, HR = Croatia, BiH = Bosnia and Herzegovina, MN = Montenegro, RS = Serbia, RKS = Kosovo, AL = Albania, NMK = North Macedonia.

2021). The plot sizes largely corresponded to the previously recommended plot sizes for particular vegetation types (e.g., Chytrý & Otýpková, 2003).

Vegetation was classified using numerical methods and compared with traditional syntaxonomy. The matrix consists of 64 taxa × 27 samples (relevés). The relevé of the *Phragmitetum australis* was excluded from the analysis due to the presence of freshwater taxa. The relevés of the *Arundinetum micranthae* (*Artemisietea vulgaris*) from the area have already been published and not included in the analysis (see Jasprica *et al*., 2016, Table 1, p. 889). Additionally, *Zostera noltii*, *Posidonia oceanica* and *Cymodocea nodosa* form monospecific communities and they are not supported by relevés or elaborated here in detail (see Den Hartog, 2016 and references therein). The taxon scores originally recorded according to the Braun-Blanquet cover-abundance scale, were replaced by the 1–9 ordinal values (Whestoff & van der Maarel, 1980) before the numerical analyses. An agglomerative, hierarchical clustering algorithm based on Bray-Curtis similarity and Ward's method for determination of group linkages was used (McCune & Mefford, 2006). Differences between groups obtained in the classification were tested by analysis of similarities (ANOSIM). For these purposes the PC-ORD ver. 5 and PRIMERv7 software packages (McCune & Mefford, 2006; Clarke & Gorley, 2015) were used. The results (Fig. 2, Tab. 1) were interpreted from a syntaxonomic standpoint and the relevant syntaxonomic scheme is presented below. Geographical coordinates of relevés are given in Appendix 2.

The nomenclature of high-rank vegetation units also follows the syntaxonomical system (the EuroVegChecklist) proposed by Mucina *et al*. (2016), and followed by

Škvorc *et al*. (2017) except for the class *Dittrichietea viscosae* where the approach of Foucault & Jasprica (2019) was applied. The taxonomy and nomenclature of taxa follow *Euro+Med PlantBase* (Euro+Med, 2006+2022).

EUNIS habitat types were determined according to Chytrý *et al*. (2020, version 2021-06-01), and using the Database of the European Flora and Vegetation (www. floraVeg. eu). In addition, classification of the vegetation units (alliances) distinguished into habitat types of Annex I of the Habitats Directive 92/43/EEC was done according to the List of NATURA 2000 habitats declared by the Croatian Government (Official Gazette, 2019).

RESULTS

The dendrogram obtained from the hierarchical clustering analysis of the data matrix, makes it possible to distinguish two main clusters (A, B) of associations (Fig. 2). The first cluster (A) includes the communities found in the drier habitats of the *Rubo ulmifolii-Nerion oleandri* (rels. 23, 24) and *Dittrichion viscosae* (*Dauco majori-Foeniculetum vulgaris*, rel. 28), while the second cluster (B) includes (i) the relevés collected on the salt-marshes, and riparian galleries and thickets (B1), and (ii) halophilous vegetation of the low rocky sea coast, and sand and gravel beaches (B2).

Based on the data and their analysis, 15 associations and one subassociation included within 13 alliances, 12 orders and 11 vegetation classes were identified (Tab. 1). The complete syntaxonomic scheme is presented below:

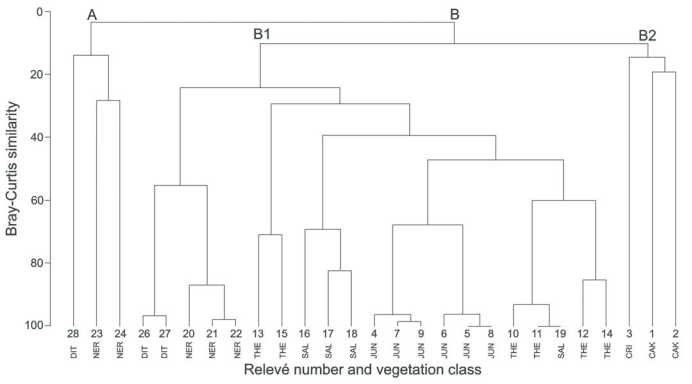

Fig. 2. Hierarchical cluster analysis dendrogram based on Bray-Curtis similarity distance and Ward's minimum variance method of the data matrix of 64 taxa × 27 relevés. The cluster A includes the communities found in the drier habitats, the cluster B1 indicates the relevés collected on the salt-marshes, riparian galleries and thickets, and B2 represents halophilous vegetation of the low rocky sea coast, and sand and gravel beaches. Relevé numbers represent the associations as follows: 1 = *Cakilo-Xanthietum strumarii*, 2 = *Euphorbio pineae-Glaucietum flavi*, 3 = *Limonietum anfracti helichrysetosum italici*, 4-9 = *Juncetum maritmo-acuti*, 10-15 = *Suaedo maritimae-Salicornietum patulae*, 16-19 = *Puccinellio festuciformis-Sarcocornietum fruticosae*, 20-22 = *Tamaricetum dalmaticae*, 23 = *Rubo ulmifolii-Viticetum agni-casti*, 24 = *Paliuro australis-Viticetum agni-casti*, 26-27 = *Loto hirsuti-Dittrichietum viscosae*, 28 = *Dauco majori-Foeniculetum vulgaris*. Vegetation classes: CAK = *Cakiletea maritimae*, CRI = *Crithmo-Staticetea*, JUN = *Juncetea maritimi*, THE = *Thero-salicornietea*, SAL = *Salicornietea fruticosae*, NER = *Nerio-Tamaricetea*, DIT = *Dittrichietea viscosae*.

Tab. 1. Phytosociological table based on the relevés collected in the lower Neretva delta. Code of the vegetation class (EuroVegChecklist) : CAK = *Cakiletea maritimae*, CRI = *Crithmo-Staticetea*, JUN = *Juncetea*

Reelevé No.	1	2	3	4	5	6	7	8	9	10
Code of the vegetation class	CAK	CAK	CRI	JUN	JUN	JUN	JUN	JUN	JUN	THE
Vegetation cover (%)	25	10	5	70	25	70	30	100	100	70
Number of taxa	16	5	7	10	10	10	11	11	10	11
Cakilo-Xanthietum strumarii										
Salsola kali aggr.	1	.	.	.	.	.	.	.	.	.
Cakile maritima Scop.	2	.	.	.	.	.	.	.	.	.
Xanthium orientale subsp. *italicum* (Moretti) *Greuter*	3	.	.	.	.	.	.	.	.	.
Euphorbio-Glaucietum flavi										
Glaucium flavum Crantz	+	1	.	.	.	.	.	.	.	.
Euphorbia peplis L.	+	1	.	.	.	.	.	.	.	.
Euphorbia segetalis var. *pinea* (L.) Lange	.	+	.	.	.	.	.	.	.	.
Limonietum anfracti helichrysetosum italici		.	.	.	.	.	.	.	.	.
Limonium dictyophorum (Tausch) Degen	.	.	1	.	.	.	.	.	.	.
Helichrysum italicum (Roth) G. Don	.	.	r	.	.	.	.	.	.	.
Juncetum maritmo-acuti										
Juncus acutus L.	.	.	.	4	2	4	2	4	2	.
Suaedo maritimae-Salicornietum patulae										
Salicornia perennans Willd.	.	.	.	1	+	+	+	1	+	4
Suaeda maritima aggr.	.	.	.	.	.	.	.	.	.	+
Puccinellio festuciformis-Sarcocornietum fruticosae	.	.	.	.	.	.	.	.	.	.
Sarcocornia fruticosa (L.) A. J. Scott (L.) Moq.	.	.	.	.	.	.	.	.	.	+
Puccinellia festuciformis (Host) Parl.	1	.	.	.	.	.	.	.	.	+
Tamaricetum dalmaticae										
Tamarix dalmatica B. R. Baum	.	.	.	.	.	.	.	.	.	.
Rubo ulmifolii-Viticetum agni-casti, Paliuro australis-Viticetum agni-casti										
Vitex agnus-castus L.	.	r	.	.	.	.	.	.	.	.
Paliurus spina-christi Mill.	.	.	.	.	.	.	.	.	.	.
Rubus ulmifolius Schott	.	.	.	.	.	.	.	.	.	.
Phragmitetum australis										
Phragmites australis (Cav.) Steud.	2	.	.	.	+	.	+	.	+	+
Loto hirsuti-Dittrichietum viscosae										
Dittrichia viscosa (L.) Greuter	.	.	+	.	.	.	.	.	.	.
Dorycnium hirsutum (L.) Ser. (=*Lotus h.* L.)	.	.	.	.	.	.	.	.	.	.
Dauco majori-Foeniculetum vulgaris										
Foeniculum vulgare Mill.	.	.	.	.	.	.	.	.	.	.
Daucus carota subsp. *major* (Vis.) Arcang.	.	.	.	.	.	.	.	.	.	.
Cakiletea maritimae										
Atriplex prostrata DC.	1	+	+	.	.	.	.	+	.	.
Crithmo-Staticetea										
Crithmum maritimum L.	.	.	+	.	.	.	.	.	.	.
Carex extensa Good.	.	.	.	.	.	.	.	.	.	.
Therosalicornietea										

maritimi, THE = *Therosalicornietea*, SAL = *Salicornietea fruticosae*, NER = *Nerio-Tamaricetea*, PHR = *Phragmito-Magnocaricetea*, DIT = *Dittrichietea viscosae*.

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
THE	THE	THE	THE	THE	SAL	SAL	SAL	SAL	NER	NER	NER	NER	NER	PHR	DIT	DIT	DIT
50	70	25	75	75	25	50	60	80	100	100	100	80	90	100	80	100	90
4	10	4	14	13	5	9	7	14	17	14	18	4	16	11	9	10	12
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.	.	.	1	1	1	+	.	1	+	2	+	.	.	.	.	.	.
3	2	1	2	1	.	.	.	2	.	.	.	.	.	.	.	.	.
1	1	1	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	2	.	+	+	2	3	4	+	.	.	.	.	.	.	.	.	.
.	.	+	.	.	.	+	+	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	5	5	5	.	.	.	.	.	.
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.	.	.	.	.	.	.	.	.	+	+	+	2	1	+	+	+	.
r	+	.	.	.	.	.	.	.	+	.	+	.	.	5	1	1	r
.	.	.	.	.	.	.	.	.	2	2	2	+	.	.	4	3	2
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.
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.	.	.	+	+	.	.	.	+	.	.	.	.	.	.	.	.	.

Table 1. Continued

Reelevé No.	1	2	3	4	5	6	7	8	9	10
Code of the vegetation class	CAK	CAK	CRI	JUN	JUN	JUN	JUN	JUN	JUN	THE
Vegetation cover (%)	25	10	5	70	25	70	30	100	100	70
Number of taxa	16	5	7	10	10	10	11	11	10	11
Salsola soda L.	.	.	.	.	.	.	.	.	.	+
Juncetea maritimi										
Juncus gerardi Loisel.	.	.	.	+	.	+	+	+	.	+
Juncus maritimus Lam.	1	.	.	1	3	1	3	1	3	.
Scirpoides holoschoenus (L.) Soják	.	.	.	.	.	.	.	.	.	.
Elytrigia atherica (Link) Kerguélen	.	.	.	+	2	+	2	+	2	.
Salicornietea fruticosae										
Arthrocnemum macrostachyum (Moric.) K. Koch	.	.	.	.	.	.	.	.	.	.
Limonium narbonense Mill.	.	.	.	2	+	2	+	2	+	1
Artemisia caerulescens L.	.	.	.	.	.	.	.	.	.	.
Halimione portulacoides (L.) Aellen	.	.	r	1	+	1	+	1	+	3
Limbarda crithmoides (L.) Dumort.	1	.	+	1	2	1	2	1	2	+
Limonium bellidifolium (Gouan) Dumort.	.	.	.	1	2	1	2	1	2	+
Phragmito-Magnocaricetea										
Calystegia sepium (L.) R. Br.	.	.	.	.	.	.	.	.	.	.
Lythrum salicaria L.	.	.	.	.	.	.	.	.	.	.
Typha angustoflia L.	.	.	.	.	.	.	.	.	.	.
Althaea officinalis L.	.	.	.	.	.	.	.	.	.	.
Eleocharis palustris (L.) R. Br.	.	.	.	.	.	.	.	.	.	.
Alno glutinosae-Populetea albae										
Populus alba L.	.	.	.	.	.	.	.	.	.	.
Ulmus minor Mill.	.	.	.	.	.	.	.	.	.	.
Vitis vinifera L.	.	.	.	.	.	.	.	.	.	.
Morus alba L.	.	.	.	.	.	.	.	.	.	.
Nerio-Tamaricetea										
Arundo donax L.	+	.	.	+	1	+	+	+	1	.
Periploca graeca L.	.	.	.	.	.	.	.	.	.	.
Digitario sanguinalis-Eragrostietea minoris										
Sorghum halepense (L.) Pers.	.	.	.	.	.	.	.	.	.	.
Cynodon dactylon (L.) Pers.	1	.	.	.	.	.	.	.	.	.
Artemisietea vulgaris										
Cirsium vulgare (Savi) Ten.	.	.	.	.	.	.	.	.	.	.
Elytrigia repens (L.) Nevski	1	.	.	.	.	.	.	.	.	.
Helminthotheca echioides (L.) Holub	.	.	.	.	.	.	.	.	.	.
Cichorium intybus L.	.	.	.	.	.	.	.	.	.	.
Chenopodietea										
Sonchus asper subsp. *glaucescens* (Jord.) Ball	.	.	.	.	.	.	.	.	.	.
Lygeo sparti-Stipetea tenacissimae										
Dactylis glomerata L. subsp. *hispanica* (Roth) Nyman	.	.	.	.	.	.	.	.	.	.
Ammophiletea										
Elytrigia juncea (L.) Nevski	.	.	.	.	.	.	.	.	.	.
Saginetea maritimae										
Parapholis incurva (L.) C. E. Hubb.	+	.	.	.	.	.	.	.	.	.

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
THE	THE	THE	THE	THE	SAL	SAL	SAL	SAL	NER	NER	NER	NER	NER	PHR	DIT	DIT	DIT
50	70	25	75	75	25	50	60	80	100	100	100	80	90	100	80	100	90
4	10	4	14	13	5	9	7	14	17	14	18	4	16	11	9	10	12
.	+	.	4	3	.	.	.	4	.	.	.	.	.	.	.	.	.
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2	4	3	3	3	2	2	1	3	+	+	+	.	.	.	+	+	.
.	+	.	3	2	1	1	+	3	1	1	1	.	.	.	1	1	.
.	+	.	4	4	.	.	.	4	+	+	+	.	.	.	.	.	.
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Table 1. Continued

Releveé No.	1	2	3	4	5	6	7	8	9	10
Code of the vegetation class	CAK	CAK	CRI	JUN	JUN	JUN	JUN	JUN	JUN	THE
Vegetation cover (%)	25	10	5	70	25	70	30	100	100	70
Number of taxa	16	5	7	10	10	10	11	11	10	11
Bidentetea	.	.	.	.	.	.	.	.	.	.
Pulicaria vulgaris Gaertn.	.	.	.	.	.	.	.	.	.	.
Crataego-Prunetea										
Prunus spinosa L.	.	.	.	.	.	.	.	.	.	.
Pegano harmalae-Salsoletea vermiculatae										
Plumbago europaea L.	.	.	.	.	.	.	.	.	.	.
Trifolio-Geranietea sanguinei										
Hypericum perforatum L.	.	.	.	.	.	.	.	.	.	.
Quercetea pubescentis										
Punica granatum L.	.	.	.	.	.	.	.	.	.	.
Stipo-Trachynietea distachyae										
Lagurus ovatus L.	+	.	.	.	.	.	.	.	.	.
Molinio-Arrhenatheretea										
Plantago lanceolata L.	.	.	.	.	.	.	.	.	.	.
Potentilla reptans L.	.	.	.	.	.	.	.	.	.	.
Lotus corniculatus L.	.	.	.	.	.	.	.	.	.	.
Rumex crispus L.	.	.	.	.	.	.	.	.	.	.
Quercetea ilicis										
Asparagus acutifolius L.	.	.	.	.	.	.	.	.	.	.
Others										
Cuscuta sp.	1	.	.	.	.	.	.	.	.	.
Carex sp.	.	.	.	.	.	.	.	.	.	.

Syntaxonomic scheme

***NERIO-TAMARICETEA* Br.-Bl. et O. de Bolòs 1958**

***Tamaricetalia africanae* Br.-Bl. et O. de Bolòs 1958**

Tamaricion dalmaticae Jasprica in Jasprica et al. 2016

Tamaricetum dalmaticae Jasprica in Jasprica et al. 2016

Rubo ulmifolii-Nerion oleandri O. Bolòs 1985

Rubo ulmifolii-Viticetum agni-casti Paradis 2006

Paliuro australis-Viticetum agni-casti Jasprica, Ruščić et Kovačić 2011

***CRITHMO-STATICETEA* Br.-Bl. in Br.-Bl. et al. 1952**

***Crithmo-Staticetalia* Molinier 1934**

Limonion anfracti-cancellati (Horvatić 1934) Mucina in Mucina et al. 2106

Limonietum anfracti Ilijanić et S. Hećimović 1982 *helichrysetosum italici* Jasprica 2015

***CAKILETEA MARITIMAE* Tx. et Preising in Tx. ex Oberd. 1952**

***Thero-Atriplicetalia* Pignatti 1953**

Euphorbion peplidis Tx. ex Oberd. 1952

Euphorbio pineae-Glaucietum flavi Horvatić 1934

Cakilo-Xanthietum strumarii (Beg. 1941) Pignatti 1958

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
THE	THE	THE	THE	THE	SAL	SAL	SAL	SAL	NER	NER	NER	NER	NER	PHR	DIT	DIT	DIT
50	70	25	75	75	25	50	60	80	100	100	100	80	90	100	80	100	90
4	10	4	14	13	5	9	7	14	17	14	18	4	16	11	9	10	12
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***ZOSTERETEA* Pignatti 1953**

***Zosteretalia* Béguinot ex Pignatti 1953**

Nanozosterion noltii Den Hartog ex Mucina in Mucina et al. 2016

Nanozosteretum noltii Harmsen 1936

***Posidonietalia oceanicae* Den Hartog ex Mucina in Mucina et al. 2016**

Posidonion oceanicae Br.-Bl. ex Molinier 1960

Posidonietum oceanicae (Funk 1927) Molinier 1958

***HALODULO WRIGHTII-THALASSIETEA TESTUDINUM* Rivas-Mart. et al. 1999**

***Thalassio-Syringodetalia filiformis* Knapp ex Borhidi et al. 1979**

Cymodoceion nodosae Den Hartog ex Mucina in Mucina et al. 2016

Cymodoceetum nodosae Feldman 1937

***THEROSALICORNIETEA* Tx. in Tx. et Oberd. 1958**

***Therosalicornietalia* Pignatti 1952**

Therosalicornion Br.-Bl. 1933

Suaedo maritimae-Salicornietum patulae Brullo et Furnari 1976 ex Géhu et Géhu-Franck 1984

***JUNCETEA MARITIMI* Br.-Bl. in Br.-Bl. et al. 1952**
***Juncetalia maritimi* Br.-Bl. ex Horvatić 1934**
Juncion maritimi Br.-Bl. ex Horvatić 1934
Juncetum maritmo-acuti Horvatić 1934

***SALICORNIETEA FRUTICOSAE* Br.-Bl. et Tx. ex A. Bolòs y Vayreda et O. de Bolòs in A. Bolòs y Vayreda 1950**
***Salicornietalia fruticosae* Br.-Bl. 1933**
Salicornion fruticosae Br.-Bl. 1933
Puccinellio festuciformis-Sarcocornietum fruticosae (Br.-Bl. 1928) Géhu 1976

***PHRAGMITO-MAGNOCARICETEA* Klika in Klika et Novák 1941**
***Phragmitetalia* Koch 1926**
Phragmition communis Koch 1926
Phragmitetum australis Savič 1926

***ARTEMISIETEA VULGARIS* Lohmeyer et al. in Tx. ex von Rochow 1951**
***Elytrigio repentis-Dittrichietalia viscosae* Mucina 2016**
Inulo viscosae-Agropyrion repentis Biondi et Allegrezza 1996
Arundinetum micranthae Jasprica, Bogdanović et Dolina 2014

***DITTRICHIETEA VISCOSAE* Trinajstić, B.Foucault et Jasprica 2019**
***Dittrichietalia viscosa*e Trinajstić, B.Foucault et Jasprica 2019**
*Dittrichion viscosa*e Trinajstić, B.Foucault et Jasprica 2019
Loto hirsuti-Dittrichietum viscosae Trinajstić, B.Foucault et Jasprica 2019
Dauco majori-Foeniculetum vulgaris Trinajstić 2008

The alliances were assigned to EUNIS habitat types: (1) *Limonion anfracti-cancellati* [EUNIS2020 habitat code: N32, habitat type name: Mediterranean and Black Sea rocky sea cliff and shore]; (2) *Euphorbion peplidis* [N22, Mediterranean and Black Sea coastal shingle beach]; (3) *Juncion maritimi* [MA252, Mediterranean upper-mid saltmarsh and saline and brackish reed, rush and sedge bed]; (4-5) *Salicornion fruticosae*, *Thero-Salicornion* [MA 253, Mediterranean mid-low saltmarsh]; (6) *Phragmition communis* [Q51, Tall-helophyte bed], (7-8) *Rubo ulmifolii-Nerion oleandri*, *Tamaricion dalmaticae* [S 93, Mediterranean riparian scrub]; (9) *Inulo viscosae-Agropyrion repentis* [V33, Dry Mediterranean lands with unpalatable non-vernal herbaceous vegetation; the vegetation of the *Inulo viscosae-Agropyrion repentis* has more recently been attributed to the *Dittrichion viscosa*e alliance (Foucault & Jasprica 2019)]. The alliances *Nanozosterion noltii*, *Posidonion oceanicae* and *Cymodoceion nodosae* are related to EUNIS habitat type A2.6: Littoral sediments dominated by aquatic angiosperms (https://eunis.eea.europa.eu/habitats/).

The above communities, including some other habitats found in this study, are also associated with the next Annex I habitat types (Habitats Directive 92/43/EEC): (1) sandbanks lightly covered by seawater at all times [habitat code 1110]; (2) *Posidonia* banks (*Posidonion oceanicae*), priority habitat [1120]; estuaries [1130]; (3) mud and sand flats not covered by seawater at low tide [1140]; (4) coastal lagoons, priority habitat [1150]; large shallow inlets and bays [1160]; (7) annual vegetation of dunes [1210]; (8) Overgrown

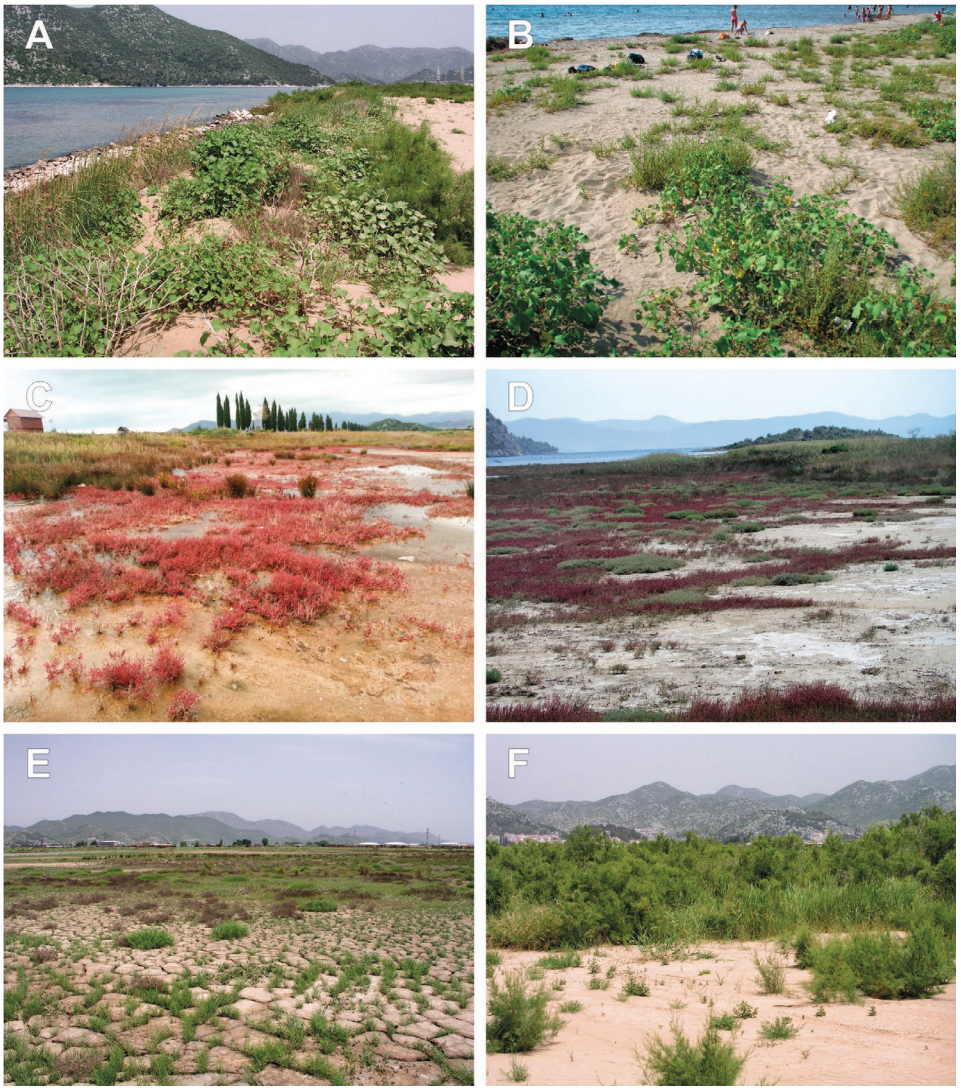

Fig. 3. Phigsionomy of the plant associations in the lower Neretva river delta. A–B = halo-therophytic plant community of the *Cakilo-Xanthietum strumarii* association occurs on nutrient rich sandy beaches (photo taken on 20th June 2006), C–D = pioneer vegetation of annual succulent halophytes of tidal mud flats of the *Suaedo maritimae-Salicornietum patulae* association on 1st October 2021, E = summer aspect of halophilous intertidal succulent dwarf chenopod shrubs of the *Puccinellio festuciformis-Sarcocornietum fruticosae* association in the supralittoral belt on 20th June 2006, F = tamarisk scrub of the *Tamaricetum dalmaticae* association on 20th June, 2006 (Photo: N. Jasprica).

sea cliffs of Mediterranean coasts with endemic *Limonium* spp. [1240]; (9) *Salicornia* and other annuals colonizing mud and sand [1310]; (10) Mediterranean salt meadows (*Juncetalia maritimi*) [1410]; (11) Mediterranean and thermo-Atlantic halophilous shrubs (*Sarcocornetea fruticosi*) [1420]; and (12) southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*) [92D0].

DISCUSSION

In this study, 15 associations and one subassociation were identified using the EuroVegChecklist syntaxonomic framework (EVC, Mucina *et al*., 2016). Among them, five associations (*Paliuro australis-Viticetum agni-casti*, *Euphorbio pineae-Glaucietum flavi*, *Cakilo-Xanthietum strumarii*, *Suaedo maritimae-Salicornietum patulae*, *Dauco majori-Foeniculetum vulgaris*) and one subassociation (*Limonietum anfracti helichrysetosum italici*) are new to the delta region (cf. Jasprica & Kovačić, 2005; Jasprica, 2007). Other associations studied here have already been described in the delta over the last decade (e.g., *Arundinetum micranthae*), while some of them are either in fact synonyms for plant associations in earlier classifications or have had their syntaxonomic status and/or names (e.g., *Loto hirsuti-Dittrichietum viscosae*) changed.

The vegetation of saline and brackish waters and swamps i.e. communities with *Posidonia oceanica*, *Zostera noltii* and *Cymodocea nodosa* develop on the sandy-muddy substrates more or less in the shallow waters at the mouth of the Neretva delta, but also common in other parts of the Neretva Channel (Jasprica *et al*., 2015). Stands of the *Posidonietum oceanicae* association are climatogenic infralittoral meadows common in the western Mediterranean and central Adriatic, while in the northern Adriatic this community has edaphic extrazonal importance, moving away from the open sea into warm and calm bays (Boudouresque *et al*., 2006).

Stands of the *Nanozosteretum noltii* association are edaphically conditioned meadows, significant for brackish and somewhat polluted waters, lagoons and estuaries on the Atlantic, Mediterranean and Adriatic coasts, and are also widespread in continental brackish waters (Baltic, Pannonian lakes, Black and Caspian seas, etc.). The association *Cymodoceetum nodosae* is a thermophilic community that replaces *Posidonietum* in suitable biotopes under various extreme conditions (eutrophic ecosystems, strong currents, coral fossilisation of the substrate, etc.) and is therefore common on detrital and sandy bottoms in exposed shoals (Jasprica *et al*., 2015; Jasprica, 2022). Although the phytosociological descriptions of all associations are based on the angiosperms present, these species represent only a part of the communities. The associations show great local and regional variation in terms of associated algae, fauna and microorganisms, depending on salinity, substrate, exposure to currents and waves, and the nature of the adjacent communities (Den Hartog, 2016).

The vegetation of the sandy and low rocky coasts includes two associations (*Euphorbio-Glaucietum flavi*, *Cakilo-Xanthietum strumarii*) and the subassociation (*Limonietum anfracti helichrysetosum italici*). Pebbly shores are the habitat for the stands of the *Euphorbio-Glaucietum flavi* association. These stands develop on the slopes exposed to the influence of the waves, so on their surface there is a more or less thick layer of sediments, under which a more or less humus, nitrogen-rich soiloften develops. It occurs quite rarely in the village of Blace. The stands of the association *Cakilo-Xanthietum strumarii* are best developed in the port of Ploče on a thicker sandy substrate. This halo-therophytic plant community develops on nutrient-rich substrates and it is first in the zonation of vegetation from the sea towards the inland (Šilc *et al*., 2016). Since low rocky coasts at the delta are extremely rare and the influence of waves is weak, the endemic southern Adriatic subassociation *Limonietum anfracti helichrysetosum italici* is only fragmentarily developed (cf. Jasprica *et al*., 2015).

Three types of vegetation develop on the muddy coast, ecologically differentiated according to the flooding regime of the seawater. The first, coastal saline rush vegetation, develops during prolonged inundation on shallow mud substrates reached at high tide, while at low tide they are beyond the reach of seawater (the *Juncetum maritmo-acuti* association). Dítě *et al.* (2019) outlined the importance of revision of recent phytosociological data of vegetation regarded as *Juncetum maritimo-acuti*.

The second, community of halophilous intertidal succulent dwarf chenopod shrubs (the *Puccinellio festuciformis-Sarcocornietum fruticosae* association), occurring in the supralittoral belt (regularly splashed by seawater but not flooded) at the mouth, on silty, gravelly, and salty soils. The associations *Juncetum maritmo-acuti* and *Puccinellio festuciformis-Sarcocornietum fruticosae* were previously studied at the mouth of the Neretva river and in Mali Ston Bay, as well as in other parts of the eastern (Janković & Stevanović, 1983; Pandža *et al*., 2007) and western (Tomaselli *et al*., 2011) coasts of the Adriatic Sea.

The third, pioneer vegetation of annual succulent halophytes of tidal mud flats (*Therosalicornietea*) is represented by a low therophytic stand made up of a small number of species dominated by *Salicornia perennans* subsp. *perennans* (see Šajna *et al*., 2013). Stands with *S. perennans* subsp. *perennans* are referred to here as the *Suaedo maritimae-Salicornietum patulae* association. This association is one of the most widespread in the Mediterranean (Frondoni & Iberite, 2002; Šajna *et al*., 2013), but its composition has not yet been studied in detail on the eastern Adriatic coast. Monitoring of the state of terrestrial communities at the mouth of the Neretva river also revealed the *Suaedo maritimae-Salsoletum sodae* association (Nikolić *et al*., 2009, 2012). This community with a small number of therophytes is dominated by *Suaeda maritima* and *Salsola soda*, alongside *Halimione portulacoides*, *Salicornia perennans* subsp. *perennans* and *Atriplex hastata*. It develops on muddy substrates without any tidal influence. In Croatia, this community generally occupies only small areas and is often only fragmentarily developed (Trinajstić, 2008). However, the floristic compositions of *Suaedo maritimae-Salsoletum sodae* and *Suaedo maritimae-Salicornietum patulae* show a high similarity.

In the delta, circum-Mediterranean and Macaronesian riparian scrub vegetation (*Nerio-Tamaricetea*) includes two types of communities: (i) tamarisk scrub of the Balkan Adriatic seaboards (*Tamaricion dalmaticae*) and (ii) oleander scrub of the western Mediterranean (*Rubo ulmifolii-Nerion oleandri*). They often occur along the upper edge of the adlittoral (epilittoral) along semi-saline lagoons, permanent and temporary watercourses (channels). This vegetation type, including ruderal vegetation of the class *Artemisietea vulgaris* (i.e. *Arundinetum micranthae*), has already been extensively described in the literature (Jasprica & Kovačić, 2011; Jasprica, 2016; Jasprica *et al*., 2016, etc.). Species of the *Loto hirsuti-Dittrichietum viscosae* and *Dauco majori-Foeniculetum vulgaris* (*Dittrichietea viscosae*) and other ruderal species abundant in anthropically modified areas occupy larger areas in the delta, exclusively on habitats that are never inundated by seawater (Foucault & Jasprica, 2019). Sladonja *et al*. (2021) summarized current knowledge on the invasion potential of *Dittrichia viscosa* and effective management of the species in changing habitats.

The results presented here refer only to the lower delta. The plant communities of halo-nitrophilous pioneer vegetation on sandy and gravelly coasts (*Cakiletea maritimae*) and salt marsh vegetation (*Therosalicornietea*, *Salicornietea fruticosae*) are restricted to relatively small areas, but still show a preserved structure. Anthropogenic impacts on

the lower delta remain pronounced, and the diversity of flora and vegetation is threatened by habitat degradation and loss, unsustainable use of natural resources, and pollution. However, a more complete understanding of this complex system will require similar studies in other parts of the delta. In practical terms, identification and quantitative analysis of community structure will be useful for rational management of this important regional resource.

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Appendix 1

Syntaxa quoted in the text and tables (in alphabetical order), but not in scheme

Alno glutinosae-Populetea albae P. Fukarek et Fabijanić 1968
Ammophiletea Br.-Bl. et Tx. ex Westhoff et al. 1946
Bidentetea Tx. et al. ex von Rochow 1951
Chenopodietea Br.-Bl. in Br.-Bl. et al. 1952
Crataego-Prunetea Tx. 1962
Digitario sanguinalis-Eragrostietea minoris Mucina, Lososová et Šilc in Mucina et al. 2016
Isoëto-Nanojuncetea Br.-Bl. et Tx. in Br.-Bl. et al. 1952
Lygeo sparti-Stipetea tenacissimae Rivas-Mart. 1978 nom. conserv. propos.
(=*Thero-Brachypodietea* Br.-Bl. in Br.- Bl. et al. 1947)
Molinio-Arrhenatheretea Tx. 1937
Pegano harmalae-Salsoletea vermiculatae Br.-Bl. et O. de Bolòs 1958
Potamogetonion Libbert 1931 (=*Magnopotamion* (Vollmar 1947) Den Hartog et Segal 1964)
Quercetea ilicis Br.-Bl. ex A. Bolós et O. de Bolòs in A. Bolòs y Vayreda 1950
Quercetea pubescentis Doing-Kraft ex Scamoni et Passarge 1959
Saginetea maritimae Westhoff et al. 1962
Scorzoneretalia villosae Kovačević 1959
Stipo-Trachynietea distachyae S. Brullo in S. Brullo et al. 2001
Stratiotion Den Hartog et Segal 1964
(=*Hydrocharition morsus-ranae* (Passarge 1964) Westhoff et Den Held 1969)
Suaedo maritimae-Salsoletum sodae Br.-Bl. 1931
Trifolio-Geranietea sanguinei T. Müller 1962

Appendix 2

Place and date of relevés.

Rel. 1, 43.033014 N, 17.422111 E (20.6.2006.); rel. 2, 42.998164 N, 17.478654 E (1.10.2021.); rel. 3, 43.000887 N, 17.467596 E (1.10.2021.); rels. 4-9, 43.010628 N, 17.469649 E (27.4.2009., 31.8.2009., 3.12.2012.); rels. 10-12, 43.004853 N, 17.472396 E (1.10.2021.), rels. 13-15, 43.016088 N, 17.467117 E (1.10.2021.); rels. 16-19, 43.039523 N, 17.425489 E (20.6.2006.); rel. 20, 43.036919 N, 17.424609 E (20.6.2006.); rels. 21-22, 43.010879 N, 17.470293 E (31.8.2009.); rel. 23, 43.024324 N, 17.461474 E (20.6.2006.); rel. 24, 43.022551 N, 17.462289 E (20.6.2006.); rel. 25, 43.024308 N, 17.455294 E (20.6.2006.); rels. 26-28, 43.009828 N, 17.470421 E (31.8.2009., 3.12.2012.).