Research Article

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Mapping of the ecosystems of the littoral ecotone in the Ural River Delta and in the Caspian Sea

Liliya A. Dimeyeva, Gulnara T. Sitpayeva, Kapar Ussen, Bakhytzhamal M. Sultanova, Veleriya N. Permitina, Ravil E. Sadvokasov, Satpay B. Nurashov, Elmira S. Sametova

Institute of Botany & Phytointroduction, 36-D Timiryazev Str., Almaty 050040, Republic of Kazakhstan;
dimeyeva@mail.ru, sitpaeva@mail.ru, ussen.kapar@mail.ru, sultanovab@mail.ru, v.permitina@mail.ru, sadvokasov@sed.kz, nurashs@mail.ru, elyasam@mail.ru

Abstract: The purpose of the present study was to map and describe the ecosystems of the Ural River Delta and the adjacent Caspian Sea for evaluation of current state and spatial distribution of the phytobiota. Block structure of water-terrestrial ecotone system was used for classification of the ecosystems. Mapping of the ecosystems was based on the integrated approach which takes into account the distribution patterns of the phytobiota depending on environments. For each block the list of ecosystems was identified on the basis of evaluation of the species (algae and vascular plants), phytocoenotic diversity and environmental conditions. The mapping unit was a group of ecosystems. There were 20 groups of ecosystems in the studied area. In each ecosystem the species composition, dominant and characteristic plants were identified. The Map produced in this study could serve as a baseline for further ecological studies and biodiversity monitoring. Assessment of the structure and dynamics of the ecosystems allows us to define the role of natural and anthropogenic factors, to develop recommendations for botanical diversity conservation in conditions of exploitation of oil fields in the shelf of the Caspian Sea.

Key words: algae**,** biodiversity, block structure, phytobiota, species composition, vascular plants

Introduction

The reference point for the Caspian Sea level since 2000 is as low as 27 m below the Baltic Sea level (b.s.l.). The coastal area has experienced oscillations in the level of the Caspian Sea due to interrelationship among the sea level, climate, and runoff from rivers in its catchment basin, which all varied during the alternations between glacial and interglacial periods. The Caspian Depression represents an ancient ecotone of the first order (Lazareva et al. 2011). Over the past 18–20 thousand years during the fluctuations of the level of the Caspian Sea there have been formed three ancient Caspian terraces: early Khvalynian, late Khvalynian and New Caspian, which form the ecotones of the second order. The transitional zones between them are the ecotones of the third order.

Ecotones of the coastal area of the Caspian zone are the transitional zones between ground and aquatic natural complexes, the contemporary and ancient topographic forms, created as a result of the impact of the sea waves (Glushko 1995). The use of the term *littoral* broadly varies and there is no single definition but most commonly it is used for the coastal area, strongly influenced by the sea. When sea regression occurs, there is a withdraw with release of land and enlargement in the areas of solonchaks and halophytes, while during the transgression there is flooding and marsh formation with enlargement of the areas of flooded swamp soils and of the saline meadow-swamp soils (Svitoch & Kuleshova 1994). Therefore, the *littoral ecotone* is defined as the strip of periodical flooding and drying, oriented towards the sea (Krasnova et al. 2013).

In regard to the Caspian Sea, the main expectation of Kazakhstan is associated with the

development of the North Caspian Kashagan oil field located in the offshore area with estimated reserves of 8 billion barrels. According to the forecasts, the development of this field will increase the volume of oil extraction from 82 million tons in 2013 to 102 million tons in 2017. However, parallel with the growth of oil production increases the risk of disturbance of the ecological state of the environment. Therefore, it becomes important to identify the botanical diversity and the structure of the Caspian littoral ecotone, and the natural and anthropogenic dynamics of its vegetation as well. The species richness and the structure of the phytobiota are important indicators of the state of the environment and of the pollution. They are necessary in the planning of ecological monitoring and in the development of nature protection activities related with the solving of the problems of the conservation of biological diversity in conditions of developing oilfields in the Caspian Sea shelf. Therefore, the purpose of the study was to map and describe the ecosystems of the Ural River Delta and the adjacent Caspian Sea for evaluation of the current state and spatial distribution of its phytobiota.

Material and methods

The studied area was in the "Ak Zhayik" natural reserve, located in the delta of the Ural River (111.5 000 ha) and adjacent to the Caspian Sea coast. The block structure of the water-terrestrial ecotone system was accepted as the main theoretical approach and methodology of the research, which allows to examine both direct and indirect impacts of the aquatic factor on the ecosystems of the adjacent land (Zaletayev 1997, Novikova 2011). According to this approach, the littoral ecotone consists of three blocks: *Aquatic block* with the sea water of 0.5–3.5 m depth (from –31 to –27.5 m b.s.l.), *Amphibian block,* which expanded from the sea shore to the shallow water of 0.5 m depth (from –27.5 to –27 m b.s.l.) and a *Fluctuational block,* which covers the "surges area" (from –27 to –25.5 m b.s.l.). In addition, the *Distant block* (higher than –25.5 m b.s.l.) connected with the ground water changes is recognized in the same methodology.

During the study, the borders of the littoral ecotone were mapped on the basis of the space image LandsatTM and its overlapping with topographical map. Mapping of the ecosystems was based on comprehensive approach which takes into account the distribution patterns of phytobiota depending on the environments, the relationships between the components within and between the ecosystems, their anthropogenic modifications, etc. Topography, soil conditions and vegetation cover were recognized as the most important indicators of the ecosystem typology (Ogar 2006, Erokhov 2007). The GIS technologies and remote sensing methods were used for the development of the map. The combination of traditional methods of geobotanical field studies and utilizing the automatic and semi-automatic classification of satellite data allowed us to cover the inaccessible areas.

For each block the list of ecosystems was identified on the basis of the evaluation of species (algae and vascular plants), their phytocoenotic diversity and environmental conditions. In the paper, the Latin names of algae followed the Algaebase (Guiry & Guiry 2017) and for the vascular plants the taxonomic revision of species names developed by Cherepanov (1995) was used.

Results

The map of the littoral ecotone ecosystems was made in a medium scale, where the group of ecosystems was the mapping unit (Fig. 1). During the study we identified 20 groups of ecosystems: two in the Aquatic block, two in the Amphibian block, eleven in the Fluctuational block, and two natural and three anthropogenically disturbed (agricultural, technogenic, urban ecosystems) in the Distant block. They are briefly described with their most representative species and are numbered consecutively in the text below, as well as and on Fig. 2.

Ecosystems of the Aquatic block

1. Marine brackish-water ecosystems with a predominance of submersed-aquatic macrophytes (*Potamogeton pectinatus* L.*, Ceratophyllum demersum* L.*, Najas marina* L.*, Myriophyllum spicatum* L.) on underwater soils with algae from Bacillariophyta (*Fragilaria capucina* Desm., *Nitzschia* spp., *Surirella linearis* W. Smith*, Campylodiscus clypeus* (Ehrenberg) Ehrenberg ex Kützing), Chlorophyta (*Scenedesmus* spp., *Ulothrix zonata* (F. Weber & Mohr) Kützing) and Cyanophyta (*Merismopedia tenuissima* Lemmermann, *Oscillatoria* spp., *Dolichospermum spiroides* (Klebahn) Wacklin, L. Hoffmann & Komárek, *Anabaena caspica* Ostenfeld, *Nodularia spumigena* Mertens ex Bornet & Flahault).

2. River freshwater flowing ecosystems with sparse communities of submersed-aquatic macrophytes (*Potamogeton perfoliatus* L.*, P. natans* L.) on the underwater soil with algae from Bacillariophyta (*Fragilaria capucina, Ulnaria ulna* (Nitzsch) Compère*, Navicula cincta* (Ehrenberg)

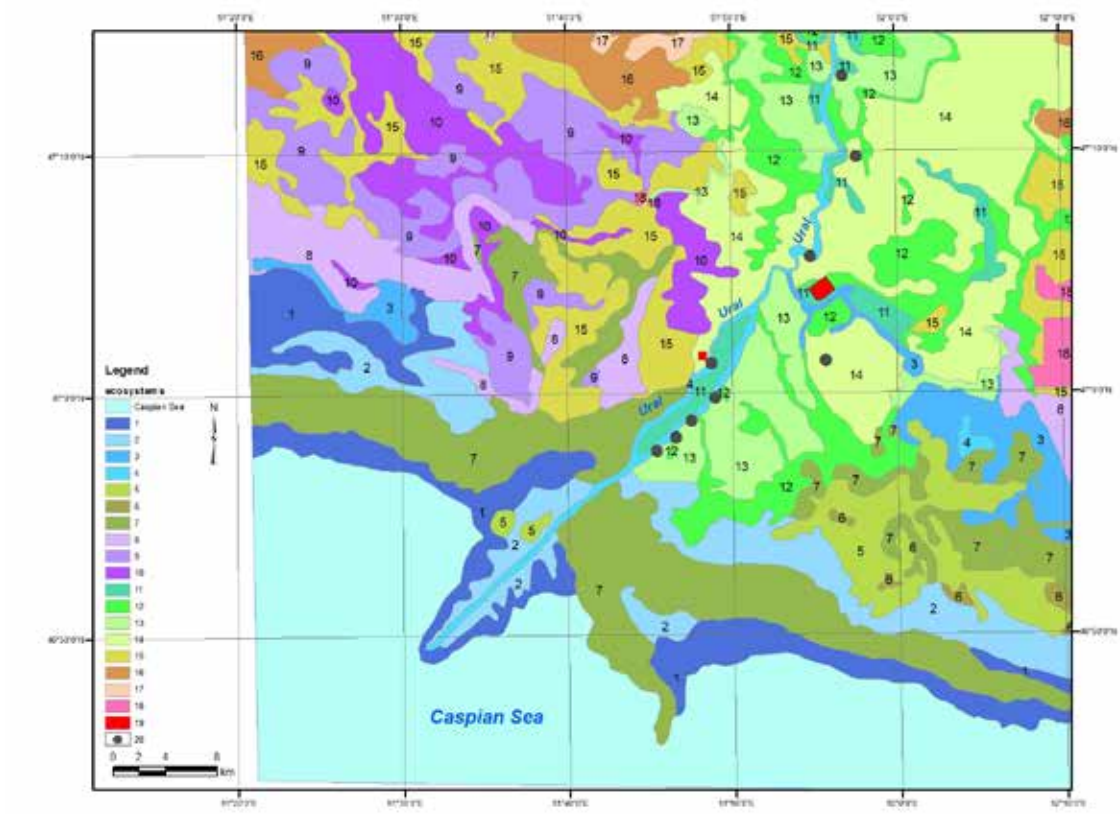

Fig. 1. Map of the ecosystems of the littoral ecotone in the Ural River Delta and the Caspian Sea. The numbers of the map represent groups of ecosystems in the four studied blocks: 1-2 - ecosystems of the Aquatic block; 3-4 - ecosystems of the Amphibian block; 5-15 – ecosystems of the Fluctuational block; 16-17 – ecosystems of the Distant block; 18-20 – anthropogenically disturbed ecosystems. For details see the text of the paper.

Ralfs, *Gyrosigma acuminatum* (Kützing) Rabenhorst, *Bacillaria paxillifera* (O. F. Müller) T. Marsson), Cyanophyta (*Dolichospermum spiroides, Anabaenopsis circularis* (G. S. West) Woloszynska & V. Miller, *Aphanothece stagnina* (Sprengel) A. Braun, *Oscillatoria princeps* Vaucher ex Gomont), Chlorophyta (*Tetradesmus obliquus* (Turpin) M. J. Wynne, *Scenedesmus communis* E. Hegewald, *Ulothrix zonata*).

Ecosysems of the Amphibian block

3. Marine brackish-water ecosystems with a predominance of submersed-aquatic macrophytes (*Potamogeton natans, P. perfoliatus, Ceratophyllum submersum* L., *C. demersum, Zannichellia pedunculata* Rchb., *Myriophyllum spicatum, M. verticillatum* L., *Najas marina*) on underwater soils with algae from Bacillariophyta (*Fragilaria capucina*, *Ulnaria ulna*, *Gyrosigma acuminatum, Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot), Cyanophyta (*Oscillatoria princeps, Dolichospermum spiroides*) and Chlorophyta *(Tetradesmus obliquus, Scenedesmus communis, Ulothrix zonata*).

4. River freshwater stagnant ecosystems with reed (*Phragmites australis* (Cav.) Trin. ex Steud.), hygrophitic herbs (*Scirpus lacustris* L., *S. tabernaemontani* C.C. Gmel., *Bolboschoenus maritimus* (L.) Palla, *Sparganium stoloniferum* (Graebn.) Buch.-Ham. ex Juz.) on the flooded swamp soils, with free-floating macrophytes (*Trapa natans* L., *Salvinia natans* (L.) All., *Lemna trisulca* L.), fern (*Telypteris palustris* Schott) and algae from Bacillariophyta (*Navicula cincta, Bacillaria paxillifera*), Cyanophyta (*Aphanothece stagnina, Anabaenopsis circularis*) and Chlorophyta (*Ulothrix zonata, Pediastrum duplex* Meyen).

Ecosystems of the Fluctuational block

5. Ecosystems of sandy islands with single plants of *Argusia sibirica* (L.) Dandy, *Cynanchum sibiricum* Willd. on sandy sediments.

6. Ecosystems of marine terraces with reed (*Phragmites australis*) and cattail (*Typha angustifolia* L.) communities on flooded swamp and marsh soils.

7. Ecosystems of marine terraces with reed (*Phragmites australis*) and cattail-reed (*Typha angustifolia*) communities on swamp and meadow-swamp soils.

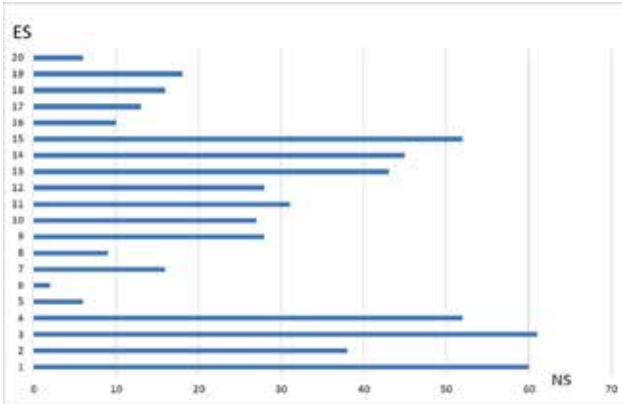

Fig. 2. Plant diversity (expressed in number of species - NS) of the ecosystems of the littoral ecotone in the Ural River Delta and the Caspian Sea (ecosystems are presented by their numbers – ES, relevant to the descriptions in the text).

8. Ecosystems of marine terraces and depressions with annual glasswort and seepweed (*Salicornia europaea* L. and *Suaeda prostrata* Pall.) communities on marshy solonchaks.

9. Ecosystems of shores with annual saltwort-grass (*Aeluropus littoralis* (Gouan) Parl., *Puccunellia distans* (Jacq.) Parl., *Limonium gmelinii* (Willd.) O. Kuntze, *L. caspium* (Willd.) Gams, *Salsola foliosa* (L.) Schrad., *Climacoptera crassa* (M. Bieb.) Botsch., *Petrosimonia brachiata* (Pall.) Bunge) communities in combination with primary aggregations of *Xanthium strumarium* L., *Atriplex aucheri* Moq. and *Argusia sibirica* on sand dunes.

10. Ecosystems of low marine plain with halophytic shrubs and semishrubs (*Halocnemum strobilaceum* (Pall.) M. Bieb., *Kalidium caspicum* (L.) Ung.-Sternb., *Suaeda physophora* Pall., *Halostachys belangeriana* (Moq.) Botsch., *Nitraria schoberi* L.) on coastal solonchaks.

11. Ecosystems of river valleys and canals with tree-shrub (*Elaeagnus oxycarpa* Schltdl., *Salix caspica* Pall., *S. alba* L., *Populus diversifolia* Schrenk) vegetation on forest-meadow floodplain soils.

12. Ecosystems of the Ural River valley with forb-grass meadows (*Calamagrostis epigeios* (L.) Roth, *Beckmannia eruciformis* (L.) Host, *Bromopsis inermis* (Leyss.) Holub, *Elytrigia repens* (L.) Nevski, *Glycyrrhiza glabra* L., *Limonium gmelinii, Cynanchum sibiricum*) on meadow soils.

13. Ecosystems of the floodplain terrace of the Ural river with halophytic forb-shrub meadows (*Karelinia caspia* (Pall.) Less., *Leymus multicaulis* (Kar. & Kir.) Tzvel., *Aeluropus littoralis, Tamarix hispida* Willd., *T. ramosissima* Ledeb., T. *laxa* Willd.) on drying meadow soils and meadow solonchaks.

14. Ecosystems of river terraces with annual saltworts and halophytic forb and grass meadows (*Petrosimonia brachiata, Leymus multicaulis*, *Alhagi pseudalhagi* (M. Bieb.) Fisch., *Karelinia caspia, Glycyrrhiza glabra, G. uralensis* Fisch., *G. echinata* L., *Achnatherum splendens* (Trin.) Nevski, *Leymus angustus* (Trin.) Pilg., *Puccinellia distans* (Jacq.) Parl.) on meadow saline soils.

15. Ecosystems of river valleys and the Ural river delta with sagebrush (*Artemisia schrenkiana* Ledeb., *A. nitrosa* Weber) and halophytic forbs (*Aeluropus littoralis, Limonium gmelinii, Saussurea salsa* (Pall. ex Bieb.) Spreng.) on meadow solonchaks.

Ecosystems of the Distant block

16. Ecosystems of undulating plains with sagebrush (*Artemisia lerchiana* Web., *A. terrae-albae* Krasch.) communities on brown desert solonetz soils.

17. Ecosystems of undulating plains with perennial saltwort (*Anabasis salsa* (C.A. Mey.) Benth. ex Volkens) communities on desert solonetz.

Anthropogenically disturbed ecosystems

18. Agroecosystems (fields, abandoned fields).

19. Technogenic ecosystems (dams, carriers, oil fields).

20. Urban ecosystems (populated areas).

There are projects to connect the studied area with the Ural River delta. In this way it shall include both aquatic and terrestrial ecosystems. Based on the aquatic regime, the terrestrial ecosystems shall be divided into automorphic (ground waters at the depth of more than 5–6 m), semi-hydromorphic (ground waters at the depth of 3.5–5 m) and hydromorphic (ground waters at the depth 1.5–3 m). In this case the littoral ecotone shall comprise of aquatic, hydromorphic and semi-hydromorphic ecosystems, while the automorphic ecosystems shall be referred to the distant block.

Two classes of ecosystems were identified within the limits of the automorphic category: semi-shrub sagebrush deserts and perennial saltwort deserts. Four intrazonal classes of ecosystems were identified within the limits of the semi-hydromorphic and hydromorphic categories: island and coastal systems; saltwort, halophyte grass and halophyte shrub classes of the late new Caspian plain; the tree-shrub, and the meadow classes of the alluvial-deltaic valley. The anthropogenically disturbed ecosystems were represented with three classes: agricultural, technogenic and urban ecosystems.

The ecosystems of the Aquatic block were characteristic of the Ural River Delta front and the adjacent area of the Caspian Sea, and were characterized by sand and sand-muddy soils. The species diversity

of the marine brackish water ecosystems (1) comprised of six species of vascular plants and 54 species of algae. Among the last group four species are known as rare in such ecosystems (*Tropidoneis lepidoptera* (Gregory) Cleve*, Plagiotropis lepidoptera* var. *intermedia* (Kisselev) Lilitska & P. M. Tsarenko*, Ankyra lanceolata* (Korshikov) Fott, *Topaczevskiella nautococcoides* Massjuk). The species diversity of the river freshwater flowing ecosystems (2) contained two species of vascular plants and of 36 species of algae, one of which (*Aphanothece stagnina*) was considered as rare.

The ecosystems of the Amphibian block occupied shallow waters. The species diversity of the marine brackish water ecosystems (3) was represented by eight species of vascular plants and 53 species of algae, one of which was rare for this ecosystem (*Tropidoneis lepidoptera*). The River freshwater stagnant ecosystems (4) were represented with twelve species of vascular plants, three of which were rare (*Trapa natans, Salvinia natans, Thelypteris palustris*) and with 40 algal species.

The terrestrial ecosystems were located within the limits of the Fluctuational and Distant blocks. The Fluctuational block, as a seasonal flooding area (above the water level), was characterized by semi-hydromorphic and hydromorphic ecosystems. The hydromorphic ecosystems were located in the post-aquatic primary marine plain (5-10). The species diversity of the ecosystems varied from 2 to 16 plants. Semi-hydromorphic ecosystems occupied alluvial-deltaic valley (11-15) and included meadows, halophytic shrub and tree-shrub ecosystems. In the riparian forest (11) grew the rare species *Populus diversifolia* and the plant diversity included 31 species. The halophytic grass (12) and halophytic shrub communities (13) prevailed on the Ural river terraces. The floristic diversity of plant communities comprised from 15 to 28 species. The annual saltwort-grass and grass meadows on saline meadow soils were also distributed on the river terraces. The distinctive property of the soils there was the presence of dark humus horizon. The floristic diversity within the limits of the 14th ecosystem consists of 45 plant species. The halophytic sagebrush ecosystem (15) with about 52 plant species was allocated to the meadow solonchaks.

The automorphic ecosystems of the Distant block (16-17) were subordinated to the latitudinal-zonal patterns. The automorphous zonal ecosystems occupied small areas in the north-western part of the project territory. They included a group of ecosystems of the gently undulating plains with the development of the sagebrush and perennial saltwort desert communities. The community composition of sagebrush deserts included 10-15 species of plants with some ephemerals among them (*Lepidium perfoliatum* L.*, Eremopyrum orientale* (L.) Jaub. & Spach., *Rheum tataricum* L. fil.*, Ferula caspica* Bieb.). The ecosystems of perennial saltwort deserts occupied depressions of varying relative height. The vegetation cover was characterized with the development of *Anabasis salsa* communities. The annual saltworts were to a small extent abundant in communities (*Climacoptera brachiata, C. lanata* (Pall.) Botsch.*, Petrosimonia triandra* (Pall.) Simonk.), the species composition of which did not exceed ten plants.

The anthropogenically disturbed ecosystems (18-20) were connected with rangeland and road digression, as well as with technogenic factors. The species composition of these communities comprised from 6 to 18 species. In the degraded rangelands the weed communities with the participation of *Peganum harmala* L.*, Anabasis aphylla* L.*, Atriplex tatarica* L. were common. In the technogenically violated plots and areas adjacent to the settlements the aggregations with the participation of *Ceratocarpus arenarius* L.*, Peganum harmala, Descurainia sophia* (L.) Webb ex Prantl. were formed.

Discussion

The aquatic ecosystems, especially marine brackish-water were with the greatest diversity, mostly due to the high taxonomic richness of algae (Fig. 2). According to the species diversity, the ecosystems 13-15 of the Ural River valley occupied the second place. As it could be expected, the lowest was the diversity on the narrow ecological niches of the sandy islands and marine terraces (5-6), the automorphic distant block systems and the anthropogenically disturbed ecosystems (15-20) – Fig. 2. The results obtained clearly show the effects of the anthropogenic impact towards declining of the biodiversity and proved the possibility to use the Map produced during the present study as a baseline for further ecological studies and biodiversity monitoring. Assessment of structure and dynamics of ecosystems allows to define the role of natural and anthropogenic factors, to develop recommendations for botanical diversity conservation in conditions of exploitation of oil fields in the shelf of the Caspian Sea.

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