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Assessment of the vegetation state of the coastal ecosystems of the Caspian Sea northern part (within Azerbaijan) and their transformation

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ABSTRACT This article provides the results of monitoring the flora and vegetation of the northern part of the Caspian Sea in modern conditions, analyzes the species composition and vegetation cover of the coastal strip, compiles the succession series of vegetation depending on the coastal zonation, and also considers factors such as anthropogenic activity and the impact of lichens. On the basis of the obtained materials, possible options for the further development of vegetation are predicted with possible fluctuations in the level of the Caspian Sea in the future.

KEY WORDS transgression; coastal vegetation; communities; successions; anthropogenic factors.

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INTRODUCTION

The Caspian Sea, with a total area of about 386,400 km^2, surrounded by five countries (Azerbaijan, Iran, Kazakhstan, the Russian Federation and Turkmenistan), is the largest saline lake in the world (Kotlyakov, 2004). Historical and paleogeographic data show that the characteristic feature of the Caspian is periodic changes in its level, and over the past 8 thousand years the water level in the Caspian has fluctuated within the range of 15 m (Dobrovolsky & Zalogin, 1982). Since the mid-1970s, a long-term drop in the level of the Caspian was replaced by its rapid and significant increase (Nesterov, 2016; Losada, 2014). However, the transgression that began actively in 1978 (from -29 m at 15 cm/year), in 1995 suddenly stabilized at level -26 m (Dobrovolsky & Zalogin, 1982; Dumont, 1998), and from 2010 the Caspian regression began to be observed (Fig. 1). There is no consensus on the reasons for such fluctuations. Climate change has an even more negative impact on the region, because due to the increase in temperature, the evaporation of the pool surface progresses and volume of water flow decreases. Predicting the time and scale of the next sea level fluctuation is very difficult because at present, it can be due to various factors (including geological) causing the corresponding consequences (Chen et al., 2017).

Thus, the main problems of the Caspian Sea are associated with changes in its level, assessment of the intensity of chemical pollution, as well as its impact on marine biota and coastal ecosystems (Kostyanoy & Kosarev, 2005; Massager et al., 2016; Budagov et al., 2002).

The Azerbaijani part of the Caspian Sea is 380 thousand km². The total length of the coastline (along the perimeter) is 6380 km, and the length of the longest part is 1205 km, width is 554 km, the deepest part is 1025 meters (Ismayılov, 2005). Periodic floods of the Caspian Sea, numerous fresh

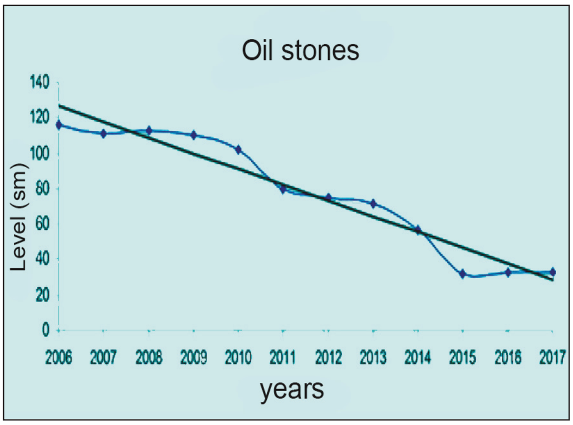


Figure 1. Dynamics of fluctuations in the level of the Caspian Sea, 2006–2017 years (http://eco.gov.az/az/fealiyyet-istiqametleri/xezer-denizi/xezer-denizinin-seviyyesi).

river flows that cross the coast and flow into the sea, and the uneven distribution of wet salt marshes, stagnant waters, sandstones and wetlands, as well as human activities, inevitably lead to the transformation of its coastal ecosystems (Alizade et al., 2019).

The studies of the coastal vegetation of the coast of Azerbaijan in the western part of the Caspian Sea were carried out both during the period of the rise of its level by Grossheim (1926), Agadzhanov (1971), and during the period of its relative stabilization by Shakhsuvarov et al. (1993), Kakhramanova (2001). An analysis of this information and our observations show that many patterns of development of phytocenoses with an increase in sea level (up to the 1970s) and its subsequent decrease (2010 and later) have undergone a number of significant changes. At the same time, over the past almost two decades, the transformation of coastal vegetation in the changing conditions created by the Caspian Sea has been neglected. However, in a recent review by Zadereev et al. (2020), past, current and future trends of ecosystem and biodiversity due to the influence of natural and anthropogenic factors of the Caspian Sea are analyzed. Identifying the driving forces of these changes and building scenarios based on the monitoring activities of researchers seems to be extremely relevant and promising. Due to these pre-requisites, the purpose of this study was to study the current state of the vegetation cover of coastal ecosystems.

MATERIAL AND METHODS

The study was carried out by the route method in 2016-2019 in the middle part of the Western Caspian (41°49’50.6”N - 048° 36’ 36.4°E; 41°42’04.2”N - 048°45’10.4”E). The object of the study was the vegetation of the coastline within a radius of 0–300 m. From a physical and geographical point of view, the study area belongs to the region of the Eastern tip of the Greater Caucasus (Azerbaijan Republic Ecological atlas, 2010). Climatically it is characterized by an arid, moderately warm and dry steppe climate. The coldest month is January (minimum -1.5 ºC, average monthly +2 ºC). The hottest month is August (absolute 43.3 ºC, average monthly 30.8 ºC) (Madatzade, Shikhlinsky, 1968). The soils are diverse - from lowland forest, meadow, to gray-brown, chestnut, sandy and wet salt marshes (Azerbaijan Republic Ecological atlas, 2014). Salt marshes, especially wet ones, occupy vast areas in the study area. High salinity is due to the presence of groundwater, saline rocks and periodic flooding of the coastline (Museyibov, 2000).

The length of the route was 68 km. The collection of material was carried out over several field seasons from April to November. Species names are given considering regional (Grossheim, 1939–1945; Flora of Azerbaijan, 1950–1961) and world floristic sources (worldfloraonline.org). Biomorphological analysis was based on the ecological and morphological classification of Serebryakov (1964) and Raunkier (1934). The distribution of species into ecological groups was carried out taking into account the degree of water availability and salinity of their habitats (Shennikov, 1964). To study the distribution of vegetation depending on marine zonality, the method of ecological profiling was used (Pedrotti, 2013). The generally accepted phytocenotic approaches were used in the study of plant communities (Mirkin et al., 2001; Odum, 1986; Whittaker, 1975). Within each plant community, model areas of 100 m^2 were selected, on which standard descriptions were performed with the identification of the species composition, tiers, and the determination of the projective cover (%) (Braun-Blanquet, 1964). Based on the data obtained in each type of vegetation, an assessment of species diversity was carried out using alpha-diversity indices (Whittaker, 1972; Magurran, 1988). The locations of the key communities were recorded by means of geolocation (GPS) and then included into the ArcGIS10.6 program, after which a vegetation map of the coastal strip was compiled.

RESULTS AND DISCUSSION

Comparative analysis of the floristic data collected by us, combined with the data of previous researchers (Agadzhanov, 1971; Grossheim, 1926; Kakhramanova, 2001; Karyagin,1952; Shakhsuvarov et al., 1993), showed that at present change in the dominant composition of communities and ecological groups of plants, a decrease in the number of previously dominant species and the emergence of species not characteristic of the coast are observed in coastal ecosystems.

Flora and vegetation

The flora of the coastal strip of the middle part of the western Caspian currently numbers 195 species belonging to 156 genera and 59 families. We have found that the largest number of genera and species in the families Asteraceae (accordingly, 20 and 26), Poaceae (16 and 17), Fabaceae (11 and 15); somewhat less Rosaceae (7 and 11), Chenopodiaceae (7 and 11), Apiaceae (8 and 9), Boraginaceae (6 and 6), Lamiaceae (5 and 6), Cyperaceae (4 and 5) and Malvaceae (4 and 4). The rest of the families include from 1 to 3 species.

Life forms are distributed as follows. The largest number is represented by herbaceous plants, of which perennials are 91 species and annuals 45 species, biennials 11 species. Trees have 18 species, and the rest of life forms from 3 to 7 species (Fig. 2).

According to the classification of life forms Raunkier (1937) this environment is dominated by hemicryptophytes (85 species), therophytes (62) and phanerophytes (33). Chamaephytes, cryptophytes-hydrophytes, and cryptophytes-hygrophytes are represented by an insignificant number of species (9, 5, and 1, respectively) (Fig. 3).

Of the 195 species growing in the coastal part, 177 (90.77%) are useful plants, and most of them (56.41%) have a number of properties. So, 157 species are medicinal (*Artemisia annua* Pall., *Pulicaria dysenterica* Gaertn., *Acer campestre* L., *Apium graveolens* L., *Daucus carota* L., *Nasturtium officinale* R.Br., *Sphaerophysa salsula* (Pall.) DC. and etc.), 66 - decorative (*Achillea filipendulina* Lam., *Senecio vernalis* Waldst. & Kit., *Hedera pastuchovii* Woronow, *Convolvulus persicus* L., *Juncus acutus* L., *Ailanthus altissima* Mill. Swingle etc.), 42 - food (*Morus alba* L., *Polygonum aviculare* L., *Mespilus germanica* L., *Rubus anatolicus* Focke etc.), 26 - feed (*Aeluropus litoralis, Elymus repens* (L.) Gould, *Avena fatua* L., *Cynodon dacty-*

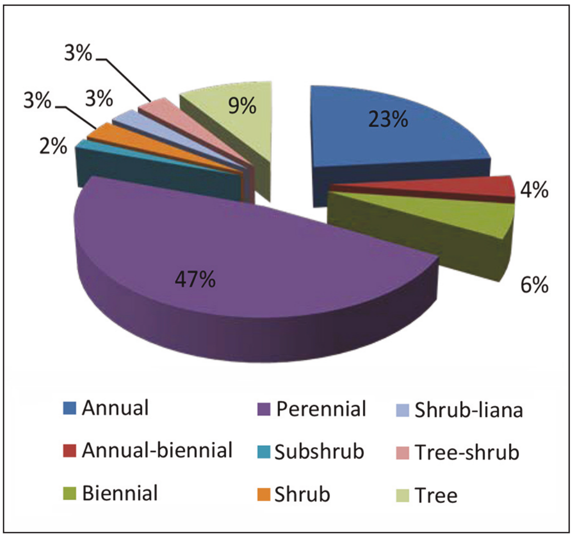


Figure 2. The ratio of life forms of plants according to Serebryakov (1964).

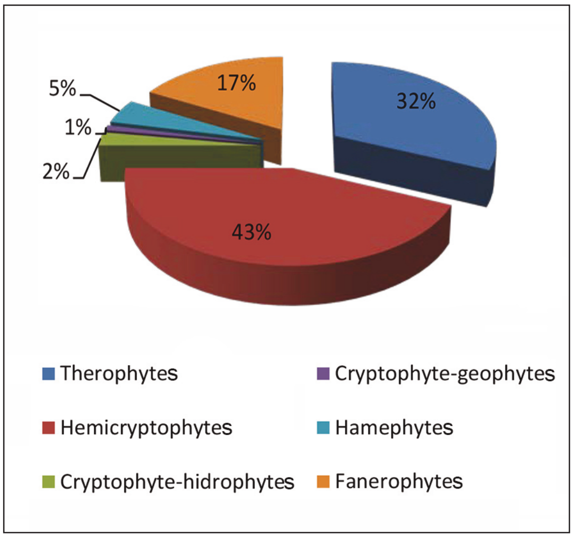


Figure 3. The ratio of life forms of plants according to Raunkier (1934).

lon (L.) Pers, *Lolium rigidium*, *Medicago lessingii* Fisch. & C.A. Mey. ex Kar., *Trifolium arvense* L.), 24 - melliferous (*Eupatorium cannabinum* L., *Periploca graeca* L., *Alnus glutinosa* subsp. *barbata* (C.A.Mey.) Yalt., *Capparis spinosa* var. *herbacea* (Willd.) Fici, *Diospyros loureiroana* G. Donetc.), 18 - technical (*Populus canescens* (Aiton) Sm., *Paliurus spina-christi* Mill., *Phragmites australis* (Cav.) Steud., *Juncus litoralis, Quercus robur* subsp. *pedunculiflora* (K. Koch) Menitsky etc.), 11 - dyeing (*Chelidonium majus* L., *Sambucus ebulus* L. and etc.), 5 - aromatic (*Pimpinella affinis* Ledeb., *Froriepia subpinnata* Baill., *Mentha aquatica* L., *Sium sisaloideum* etc.). Also species of poisonous plants were registered (*Xanthium spinosum* L., *Cynanchum acutum* L., *Conium maculatum*L., *Cynoglossum officinale* Willk., *Echium italicum* Sieber ex Decketc).

Forty-one (41) Azerbaijan endemics are distributed in coastal areas in the territory of Azerbaijan (Flora of Azerbaijan, 1950–1961). Eleven (11) of them were recorded in the Samur-Devachi lowland and the Caspian coast lowland. These are *Alcea kusariensis* (Iljin ex Grossh.) Iljin, *Astragalus albanicus* Grossh., *Bellevalia zygomorpha* Woronow, *Dianthus schemachensis* Schisck., *Ficaria Ledebourii* Grossh. & Schisck., *Iris acutiloba* C.A. Mey., *Onobrychis vaginalis* C.A. Mey., *Quercus longipes* Hu, *Thesium maritimum* C.A. Mey., *Torularia Ledebourii* (Boiss.) Grossh., *Tulipa eichleri* Regel. We have monitored the species in the study areas. It is known that these species are found in very small numbers and their populations are already aging. As a result of climate and anthropogenic effects, there is a sharp decrease in their number. Only the species *Alcea kusariensis* and *Tulipa eichleri* are in satisfactory condition compared to others. The rest are in danger of extinction.

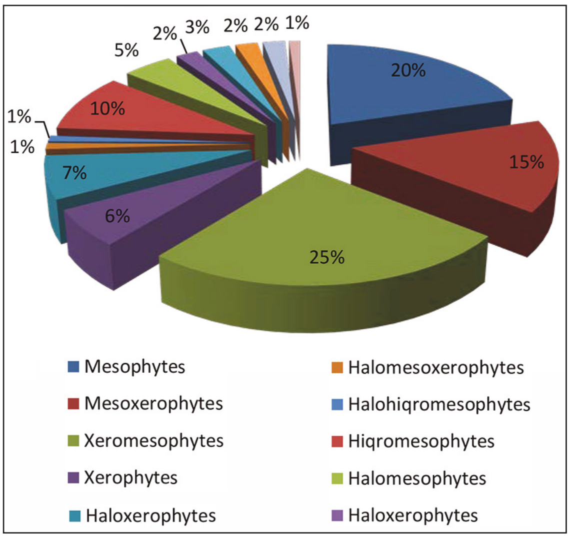


Figure 4. Distribution of plants by ecological groups.

The diversity of soils in combination with the hydrological regime promotes the wide development of various ecological groups of plants from xerophytes and mesophytes to hygrophytes and hydrophytes (Fig. 4). The largest number is distinguished by xeromesophytes (50 species), mesophytes (40) and mesoxerophytes (30), the rest are from 1 to 19 species.

As can be seen from Fig. 4, mesoxerophytes are one of the predominant ecological groups (15%). This is typical for sandy littorals and deserts. However, the dominance of mesophytes (20%) and xeromesophytes (25%) indicates the occurrence of mesophilization of the coastal strip as a result of transgression. On the territory we surveyed, we report desert (*Suaedeta, Salsoleta*), psammophytic-littoral (*Convolvuleta*, *Tourneforteta*), boggy (*Phragmiseta*, *Calamagrostiseta*), saline meadow (*Juncuseta, Limonieta, Herbosa*), forest (*Quercuseta*) and shrub (*Rubuseta*) environments (Figs. 5–7).

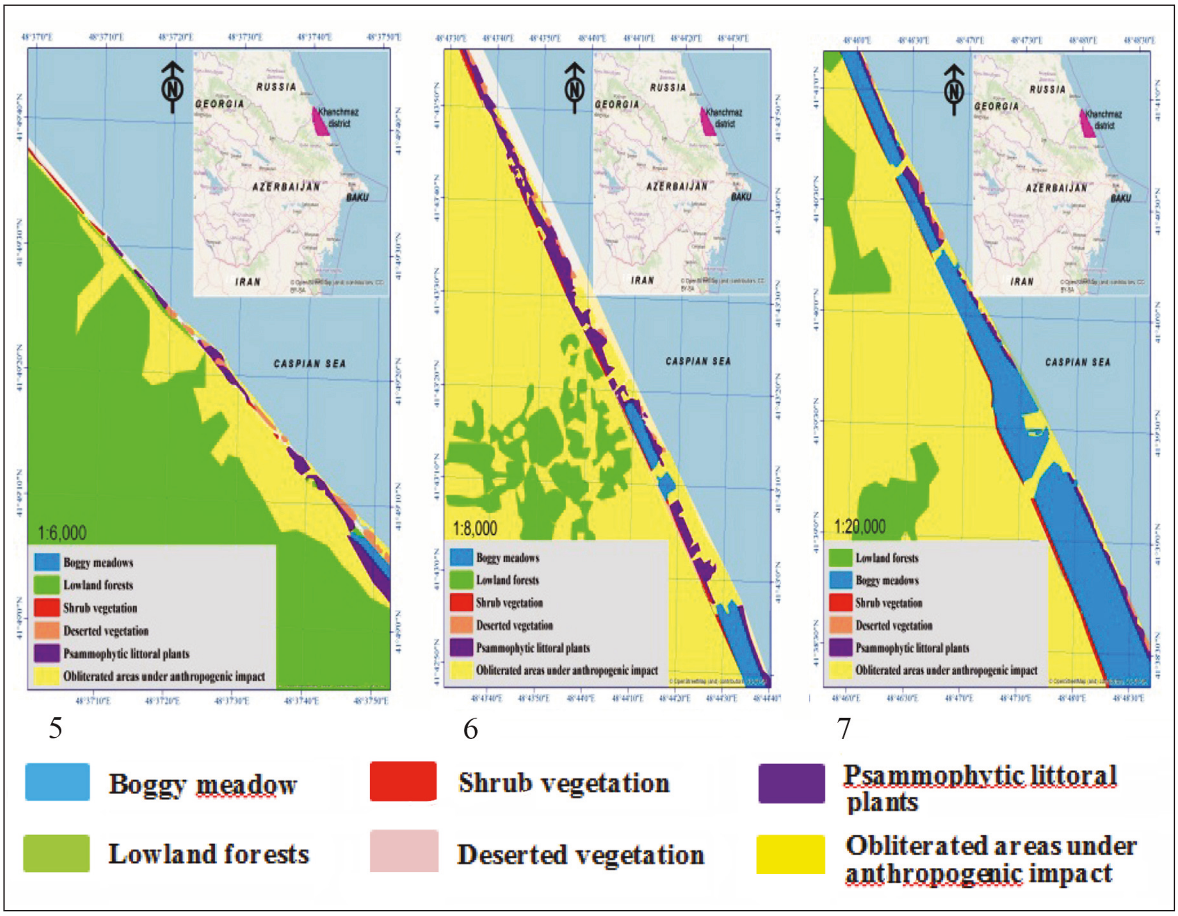
An assessment of the species diversity of these types of communities (Table 1) showed that the greatest species diversity is characteristic of forest and shrub communities, which is due to the diversity of soils, low salinity or its absence, and a positive hydrological regime at the locations. Low indices of diversity are observed in annual saltwort and herb psammophytic-littoral communities. The reason for this is the growth of these plants in the zone of intensive exploitation (beach areas). As for wetland vegetation, here the limiting factors of species diversity are the hydrological regime and interspecific competition. The high abundance of *Ph. australis* and *C. gigantea* makes it difficult for other species to enter these areas.

On the territory of the surveyed forest, we found two rare species *Tulipa sylvestris* subsp. *australis* (Link) Pamp.and *Crocus specious* M. Bieb. (Red book of Azerbaijan, 2013).

Clarification of the state of the species was carried out taking into account the ontogenetic struc-

Community	Number of species	Number of specimens	Index Menchenik (Mn)	Index Margalef (Mg)
Annual saltwart	30	384	1.53	4.87
Wetland	40	355	1.79	6.28
Herb (psammophytic-littoral)	42	393	2.17	7.03
Shrub	85	1172	2.48	11.90
Meadow	66	721	2.46	9.88
Forest	73	845	2.55	10.83

Table 1. Indicators of species α-diversity of the coastal strip.



Figures 5–7. Vegetation map of the coastal strip of the middle part of the western Caspian. Fig. 5: part of this forest area, which is under protection, has a length of 1.5 km, is located 50-500 m from the coastline (vicinity of the village of Samurchay on the border with Dagestan (Russia) and is separated from the sea by a narrow highway. Fig. 6: the central part of the coast 27 km long, most of all exposed to anthropogenic impact. Fig. 7: the last part, 30 km long, has an average anthropogenic load and is most exposed to the transgression of the Caspian.

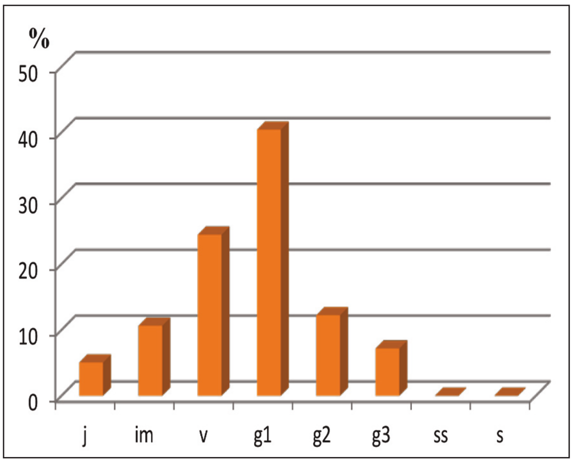


Figure 8. Ontogenetic structure of *Tulipa sylvestris* subsp. *australis* (Link) Pamp.

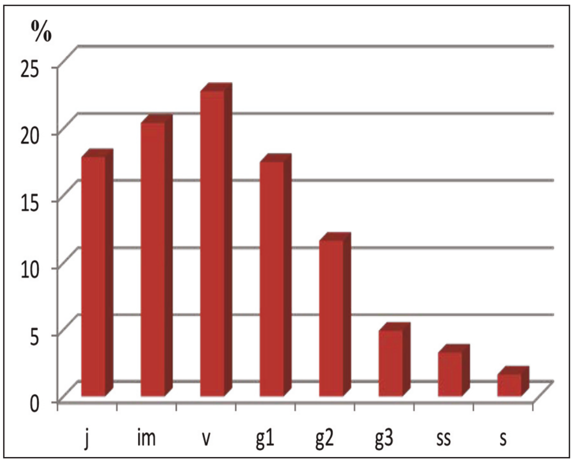
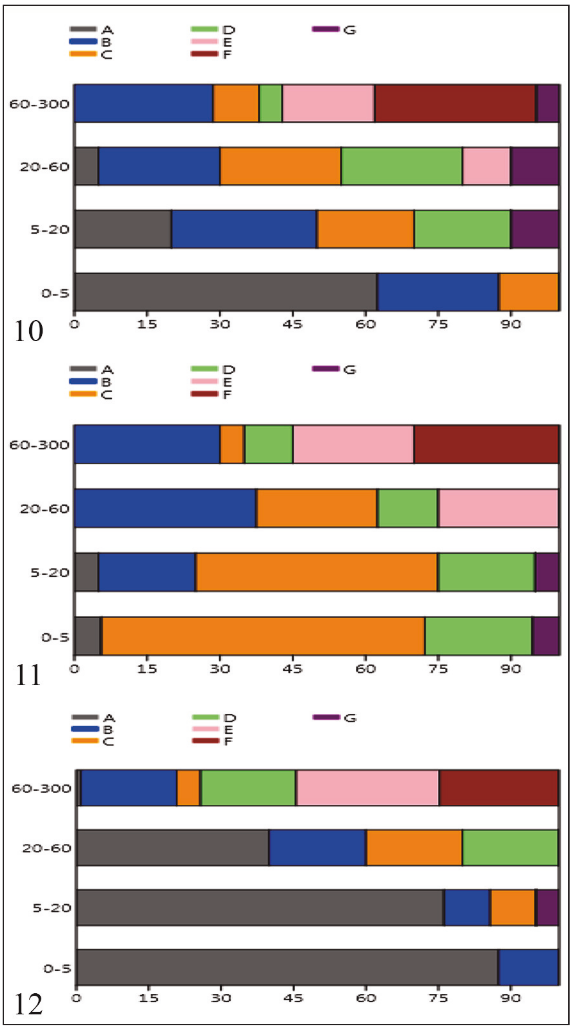


Figure 9. Ontogenetic structure of *Crocus speciosus* M. Bieb.

ture (Figs. 8, 9). On the occupied area, which was 200 m^2, 376 specimens of *Tulipa sylvestris* subsp. *australis* were counted, among which specimens of the generative period prevailed (225 specimens), the number of pregenerative individuals was somewhat less (151), individuals of the post-generative period were not observed. In the same area, the number of *C. speciosus* was 549 individuals, of which the largest number were individuals of the pre-generative (335); generative (187) periods. The post-generative specimens were significantly less (27). The predominance of young individuals in both studied species indicates their satisfactory condition. However, there is still the threat of a decrease in their number due to natural (mudflows and landslides) and anthropogenic (collection by tourists for bouquets and grazing) factors.

Transformation of vegetation cover due to the dynamics of level of the Caspian Sea and climatic conditions at present

In view of the intensively occurring processes of transgression – regression of the Caspian Sea, the eolian-accumulative processes of the formation of the coastline since the '90s. gave way to abrasive ones, because of what, even then, uncharacteristic phytocenoses began to form here (Shakhsuvarov et al., 1993). As you move away from the coastline towards the mainland, the water-salt regime of the soil and its quality change: salt marsh, replaced by mobile sands, then semi-mobile and mobile sands follow, then low-lying forest soils. This sequence is decisive in the horizontal structure of the vegetation cover. To clarify the pattern of distribution of plant communities under the present conditions, we described the modern ecological-succession series. As it can be seen from Fig. 10, in the 0–5 m distance zone, there are annual saltwort communities dominated by the succulent haloxeromesophyte *Suaeda confusa* and haloxerophyte *Salsola kali* subsp. *tragus* (L.) Čelak. Dominance of xerophyte *Salsola kali* subsp. *tragus* in the wet salt marsh zone is a confirmation of the ongoing Caspian regression process. Here, alien xeromesophytes *Xanthium strumarium* L. and species *Erigeron* L. which form communities and are not typical for these coastal areas, are also encountered. Sandy forb halomesophytes dominate at a distance of 5–20 m from the sea with transition to semi-mobile sands (*Convolvulus persica, Tournefortia sibirica*, *Cakileeuxina*, *Melilotus polonicus*and etc.). In some places, there are swampy areas with a predominance of *Phragmitesaustralis*, an indicator of increased moisture. Zone 20–60 m from the sea, is characterized by an increase of swampy areas dominated by *Phragmites australis*, *Calamagrostis gigantea* and halomesophilous meadows with *Limonium meyeri*, *Juncus acutus, J. littoralis*, *Typha laxmannii* (*T. minima*), *Typha latifolia* L. (*T. angustifolia* var. *sonderi*), *Spergularia media, Apium graveolens*, *Juncus acutus*in which fresh herb species *Equisetum arvense*, *E. palustre* L., *E. ramosissimum*, *E. majus*, *Mentha aquatica*, *Mentha longifolia* and etc. appear. In the area 60–300 m from the sea coast, there are shrub and forest communities with the presence of *Quercus pedunculiflora*, *Acer campestre*, *Carpinus betulus*, *Elaeagnus caspica*, *Alnus barbata*, *Populus hybrida*, *Rubus anatolica*, *Tamarix ramosissima*, *Clematis orientalis*, *Smilax excelsa*. Actively spreading invasive species *Ailanthus altissima* also appears here.



Figures 10–12. Distribution of typical plant communities of the coastal strip of the middle part of the western Caspian: (A: annual saltwort, B: forb; C: boggy, D: cereal, E: shrub, F: forest, G: sedge): x - projective cover of plant communities in percent (%), y - distance from the sea to the mainland 0–5 m, 5–20 m, 20–60 m, 60–300 m; a) in the present conditions. в) probability of distribution of communities in case of progressive transgression. c) probability of distribution of communities in case of progressive regression.

Along with this, the average annual surface temperature over the Caspian Sea in the period 1979-1995, 1996–2015, 2015–2017 years increased by about 1 °C (1.8 degrees on Fahrenheit) (Chen et al., 2017), given the global warming, this process is likely to continue and as the planet warms up (Losada et al., 2014; Cocquempot et al., 2019; Orejarena-Rondonet al., 2019), the level of the Caspian will decline. Obviously, this will inevitably affect the vegetation cover of coastal ecosystems. Therefore, we combined the research data of the authors who studied the distribution of vegetation of the coastal strip in different periods of the Caspian Sea level (Agadzhanov, 1971; Grossheim, 1926; Kakhramanova, 2001; Karyagin, 1952; Shahsuvarov et al., 1993) with our modern observations and developed a preliminary forecast of the ecological-successional distribution of vegetation in the coastline zone according to three options: in the present conditions (Fig. 10), in the conditions of a catastrophic transgression (Fig. 11) and in the case of a catastrophic regression of the sea (Fig. 12). With a decline in the level of the Caspian, the dominance of saltwort, mesoxerophytic herb communities is obvious. At the same time, representatives of wetland vegetation (reeds, cereals, sedges) and halomesophilic meadows will reduce their area. The distribution of shrub and forest communities in all variants is likely to remain relatively stable, but in the event of global warming, the mesophilic species composition will significantly decrease. In case of significant flooding of the coast, the vegetation of the coastline will move towards the shrub and forest zone (5–60 m). Wetland communities will become predominant, forbs mesophilization will also occur, annual saltwort vegetation will reduce its range.

Transformation due to exposure to lichens and human activities

The climatic factor is not the only one causing the transformation of vegetation. Human activities, fungal infections of plants and interspecific competition pose a serious threat in our region. At the beginning of the 20th century, the forest zone occupied the entire coastline. However, the expansion of infrastructure, which began in the '90s, led to a significant reduction in the territory of the forest zone and the degradation of coastal vegetation.

As a result, a small part of the forest has been preserved, which is now under the protection of the Samurchay-Yalama National Park. The forest is represented here by the variants *Quercusetum euphorbosum* and *Quercusetum fruticosum*.The restoration of the tree layer is ensured by the active restoration of *Q. pedunculiflora* and *Acer campestre*. Since the forest is under protection, no significant anthropogenic impacts have been found here. However, the state of tree species is under the threat of mass destruction by lichens of *Ramalina pollinaria* (Westr.) Ach. and *Evernia prunastri* (L.) Ach. Three-year observations of the state of the forest have shown that the distribution of lichens on trees and shrubs is very active. Apparently, a favorable ecological regime for their development is being created here. If in 2016 only 15 cultivated trees of *Pinus eldarica* were affected on the vicinity of the forest, and in the natural forest itself single specimens of trees and shrubs were covered with lichens, then in 2018, all individuals of *P. eldarica* were completely covered with lichens, which led to shrinkage of trunks, and the number of trees and shrubs affected by lichens has doubled.

Against the background of these transformations, alien plants are spreading here. Currently, in the Azerbaijani part of the Caspian Sea there are 17 species of alien species from the Amaranthaceae Juss. family (6 species), Asteraceae Dumort. (5 species), Euphorbiaceae Juss. (1 species), Elaeagnaceae Adans. (1 species), Fabaceae Lindl. (1 species), Poaceae Barnhart (1 species), Phytolaccaceae R.Br. (1 species), Simarubaceae Lindl. (1 species). Of the 17 species, 5 are transformers (*Amaranthus retroflexus* L., *Erigeron canadensis* L., *Phytolacca americana* L., *Xanthium strumarium* L., *X. spinosum* L., *Ailanthus altissima* (Mill.) Swingle.

CONCLUSIONS

The dominants of plant communities in the middle part of the western Caspian Sea characteristic for the coastal strip are revealed - *Salsola kali* subsp. *tragus, Suaeda confusa, Salicornia europea*, *Convolvulus persica, Tournifortia sibirica*, *Elagnus angustifolia, Populus hybrida*, *Rubus caesius*, *R. anatolicus, Phragmitis australis, Calamagrostis giganthea, Nasturtia oficinale, Thypha angustifolia, Melilotus polonicus* and *Mentha aquatica*. It has been established that under modern conditions in the vegetation cover of the coastal strip, the communities of succulent halophytes *Suaeda confusa* and *S. altissima* are replaced by communities of the ruderal annual *Salsola kali* subsp. *tragus* and invasive species *Xanthium strumarium*, *Conyza canadensis* and *Ailanthus altissima.* As a result of the earlier transgression of the Caspian Sea, vast areas of the coastal strip are occupied by wetland and meadow vegetation, which has recently begun to decline due to global warming. Thus, the presence of active dynamic processes in the vegetation cover has been established.

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