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Research Article

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Vegetation cover of the Kulaly Islands in the Kazakhstan region of the Caspian Sea

This study presents a comprehensive analysis of the floristic and ecological diversity of vascular plants on Kulaly Island, located in the Kazakhstani sector of the Caspian Sea. Field surveys documented 149 species, predominantly annual therophytes (47.0%) and perennial xerophytes, reflecting adaptations to arid climates, high soil salinity, and unstable substrates. Most taxa are associated with sandy and solonchak habitats, while wetland and aquatic ecosystems support comparatively fewer species. A quantitative assessment of alpha diversity using the Shannon (H′ = 1.55), Simpson (D = 0.71), and Pielou (J = 0.79) indices revealed a relatively high level of structural heterogeneity, with a balanced distribution of ecological groups. Canonical Correspondence Analysis (CCA) identified salinity, moisture, and substrate mobility as the primary environmental gradients structuring vegetation, with clear separation of halophytic, psammophytic, and hydrophilic communities. These findings demonstrate both the ecological plasticity of the flora and the vulnerability of rare and localised taxa to hydrological fluctuations of the Caspian Sea and anthropogenic pressures. The results provide a crucial scientific foundation for biodiversity monitoring, the conservation of genetic resources, and the sustainable management of fragile arid ecosystems in western Kazakhstan.

Keywords: Kulaly Island, Caspian Sea; vascular plants; biodiversity; halophytes; psammophytes; Shannon index; Jacquard index; arid ecosystems; gene pool conservation

Introduction

The Kazakhstan sector of the Caspian Sea occupies the northeastern and eastern parts of the planet's largest enclosed body of water and is of high ecological significance. It encompasses several islands and island groups, the largest of which is the Tyuleniy Islands archipelago, administratively part of the Mangystau region. The archipelago spans approximately 130 square kilometres and comprises five islands: Kulaly, Morskoy, Podkovka, Rakushechny, and Zhilany. These islands form unique natural complexes where, despite the harsh climate and unique geomorphology, distinctive floral and faunal communities have been preserved [1].

The islands' geological structure is dominated by sand, shell, and clay deposits, the surface of which is subject to wind erosion and abrasion. The terrain is low-lying and flat, with absolute elevations not exceeding 5-6 meters above sea level. These conditions make the island ecosystems vulnerable to fluctuations in the Caspian Sea level and the impact of ice masses. The climate is sharply continental with pronounced seasonal contrasts: in summer, air temperatures reach 40°C, and soil warms up to 65–70°C; in winter, temperatures drop to –10°C. High humidity, frequent fog, and soil salinity create a stressful environment that limits the growth of vegetation [2].

The islands of the Tyuleniy Archipelago are critical biodiversity hotspots in the Kazakhstan sector of the Caspian Sea. They are designated as Important Bird Areas (IBAs) because they provide crucial habitats for nesting and migratory stopovers for numerous bird species. Rare and endemic species inhabit the area, including the Caspian seal (*Pusa caspica*), which is listed in the Red Data Book of Kazakhstan and the IUCN Red List of Threatened Species. The islands' flora serves as a biogeocenotic framework, preventing deflation and erosion, stabilising loose substrates, forming microbiotopes, and acting as an indicator of climate change.

Of particular importance in the archipelago is Kulaly Island—the largest in area (approximately 38 km²) and the longest (34 km long, 2–4 km wide). It is distinguished by its crescent-shaped form and mosaic landscapes: dunes, salt marshes, lagoons, and coastal shoals. Kulaly is the only island where a permanent human

presence remains, associated with fishing. This makes the island's ecosystems more vulnerable to anthropogenic impact, but simultaneously opens up opportunities for observation and regular monitoring. The most diverse floristic complexes of desert vegetation are represented here, including halophytes (*Halocnemum strobilaceum, Salicornia europaea*), psammophytes (*Agriophyllum squarrosum, Carex physodes*), xerophytes and salt-tolerant shrubs (*Tamarix ramosissima, Kalidium caspicum*) [3].

Despite the importance of the island ecosystems, the level of knowledge of Kulala's flora and fauna remains extremely low. The main problems can be summarised as follows: Systematic floristic surveys have been conducted only sporadically; the most notable expedition took place in 2013, with the participation of the Mangyshlak Experimental Botanical Garden and scientific organisations from Dagestan. However, the obtained data are of a general nature and do not encompass the full diversity of the island's vascular plants [4].

Inaccessibility and extreme conditions. The harsh climate, high humidity, isolation, and complex transport logistics limit the possibility of conducting long-term and regular expeditions. This leads to a shortage of herbarium materials, complicating the creation of a comprehensive flora inventory. Fishing, military outposts, and uncontrolled human impacts (such as waste disposal and trampling of vegetation) have a localised but significant effect on biodiversity. Fluctuations in the Caspian Sea level, increased frequency of extreme weather events, and changes in the hydrological regime directly affect the composition and structure of vegetation.

The flora of the mainland part of the Mangystau region has been relatively well studied, comprising 770 species of vascular plants from 73 families and 333 genera [5, 6]. The Chenopodiaceae, Asteraceae, Brassicaceae, Poaceae, Fabaceae, and other families play a significant role, which is typical of the Irano-Turanian floristic province. However, the flora of island ecosystems remains poorly studied, with no comprehensive reports and limited data on the dynamics of plant communities and their role in ecosystem processes. This significantly complicates the development of conservation and monitoring programs [7].

Studying the flora of Kulaly Island helps fill gaps in our knowledge of the island ecosystems of the Caspian region. The data obtained will contribute to: Identifying plant adaptation strategies to extreme conditions (salinity, aridity, wind load, ice processes); Creating indicator species groups for monitoring climate change; Assessing the conservation potential of island biocenoses; and Developing scientifically based measures for the conservation of biodiversity and sustainable use of the region's natural resources. The objective of this study is to analyse the vascular plants of Kulaly Island, identify their floristic composition, and assess the role of vegetation in maintaining the stability of island ecosystems in the Kazakhstan sector of the Caspian Sea.

Experimental

Field studies of the vegetation cover of Kulaly Island were conducted during the summer of 2013 as part of a comprehensive expedition by the Mangyshlak Experimental Botanical Garden. The work covered the central, northeastern, and coastal parts of the island, allowing for the spatial heterogeneity of plant communities to be taken into account. Floristic data were collected using a route-reconnaissance method across the main habitat types, including dune sands, salt marshes, coastal lagoons, and lowland meadows. Along each route, vascular plant species encountered were recorded, linked to the biotope, moisture level, and substrate mobility. Their life form, ecological-coenotic role, and relative frequency were also noted. The collected specimens were herbarized using standard botanical methods and are stored in the herbarium of the Mangyshlak Experimental Botanical Garden (MEBG). Each plant was accompanied by a label indicating the coordinates, collection date, ecotope type, and the name of the collector. Species were identified using the "Flora of Kazakhstan" (1956–1966) and regional identification guides, such as "Identification Guide to Plants of Central Asia" (1968). An international database, Plants of the World Online (POWO, 2021), was also utilised to update the nomenclature. Standard biostatistical approaches were used to quantify biodiversity and the ecological-cenotic structure of the flora: analysis of species distribution by life form according to Raunkiaer's classification, grouping by salt tolerance, moisture availability, and substrate types (sand, silt, clay, gravel, and salt marshes), and calculation of the Shannon, Simpson, Margalef, and Pilou indices to characterize alpha diversity. Data processing and graphic creation were performed using PAST 4.0 and Microsoft Excel 2019 [8].

Canonical correspondence analysis (CCA) was employed to investigate the impact of abiotic factors on the distribution of vascular plants. This multivariate statistical approach enables the simultaneous analysis of a matrix of species composition and environmental parameters, identifying the primary ecological gradients

that govern the spatial structure of the flora. The study was conducted in R (version 4. x) using the vegan package. The input data included a species occurrence matrix (comprising 149 taxa) and a matrix of environmental factors (including salinity, humidity, substrate mobility, and life form). The results are visualised as biordination diagrams, where the CCA axes reflect the contribution of environmental factors, and the position of each species indicates its ecological preferences [9].

Results and discussion

A study of the flora of Kulaly Island revealed a significant diversity of vascular plants, reflecting the adaptation of communities to arid conditions and high soil salinity. A total of 149 species representing various life forms and ecological strategies were recorded. The most significant number of taxa are represented by annual therophytes and perennial xerophytes, indicating the dominance of short-lived forms capable of quickly completing their life cycles under conditions of moisture deficiency. Most of the identified species are associated with sandy and saline habitats, emphasising the leading role of these biotopes in maintaining the island's floristic diversity. Fewer species characterise wetland and meadow areas, but their importance for the overall flora structure is demonstrated by the formation of specific communities that serve as indicators of increased humidity.

To clearly present the floristic composition and its ecological characteristics, a summary table was compiled, including information on the life form of each species, its salt tolerance, humidity requirements, type of substrate, and its central role in the community (Tab. 1).

Table 1

Ecological structure and floristic composition of vascular plants of Kulaly Island

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
	Equisetaceae					
1	***Equisetum ramosissimum***	Perennial. Hemicryptophyte.	Saline and sandy soils	Dry to moderately humid conditions	Mobile sandy and rocky substrates	Soil-strengthening, participant in xerophytic communities
	Ephedraceae					
2	***Ephedra distachya***	Perennial. Chamaephyte	Sandy soils, slightly saline	Dry conditions	Shifting sands	Forms sparse communities, a food source for animals
	Typhaceae					
3	***Typha angustifolia***	Perennial. Hemicryptophyte, geocryptophyte	Fresh and slightly brackish waters	High humidity (shores of reservoirs)	Stable, silty substrates	Forms coastal thickets and acts as a filter feeder
4	***Typha latifolia***	Hemicryptophyte, helocryptophyte	Fresh water	High humidity	Stable shores	Strengthening the banks, creating habitats
	Potamogetonaceae					
5	***Stuckenia filiformis***	Perennial. Hydrocryptophyte.	Fresh and brackish water (up to 11%)	Aquatic environment	Silts, sandy bottom sediments	Forms underwater communities and stabilises bottom soils
6	***Stuckenia pectinata***	Perennial. Hydrocryptophyte.	Sea bays (slightly salty)	Aquatic environment	Sandy and silty soils	An essential component of underwater communities
7	***Zannichellia palustris subsp. major***	Perennial. Hydrocryptophyte.	Fresh and brackish waters	Aquatic environment	Ily	Forms underwater thickets, an indicator of brackish biotopes
8	***Zannichellia palustris***	Perennial. Hydrocryptophyte.	Fresh and brackish waters	Aquatic environment	Silts, soft soils	Participant in underwater phytocenoses
	Ruppiaceae					
9	***Ruppia maritima***	Perennial. Hydrocryptophyte.	Brackish waters	Aquatic environment	Sandy and Shelly's bottom soils	The primary component of underwater vegetation serves as a food source for waterfowl.

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
10	***Ruppia cirrhosa***	Perennial. Hydrocryptophyte.	Brackish and salt waters	Aquatic environment	Sandy and shell-sandy soils	Forms dense underwater thickets, an indicator of salty biotopes
	Juncaginaceae					
11	***Triglochin palustris***	Perennial. Helocryptophyte	Lightly saline meadows	Wet, damp conditions	Stable silt and meadow substrates	Forms coastal and meadow communities, an indicator of dampness
	Poaceae					
12	***Aeluropus littoralis***	Perennial. Hemicryptophyte.	Salt marshes, salted sands	Dry conditions	Mobile sandy and saline soils	Soil conditioner, dominant in solonchak communities
13	***Alopecurus arundinaceus***	Perennial. Geocryptophyte.	Saline meadows	Wet, coastal conditions	Stable floodplain and meadow substrates	Forms dense turf, fodder value
14	***Aristida adscensionis***	Annual. Therophyte	Non-saline dry sands	Dry conditions	Mobile sandy and rocky substrates	Ephemeral of desert communities, it fixes the sands
15	***Bromus tectorum***	Annual. Therophyte	Non-saline sands	Dry conditions	Light, sandy, and gravelly soils	Ephemeral component of desert communities
16	***Bromus squarrosus***	Annual. Therophyte	Non-saline sands	Dry conditions	Shifting sands	Participant in ephemeral deserts
17	***Sporobolus aculeatus***	Annual. Therophyte	Saline and salt marshes	Wet, damp habitats	Silts, damp sands	Forms thickets on salt marshes, with food value
18	***Sporobolus alopecuroides***	Annual. Therophyte	Solonetzic soils	Wet, damp conditions	Sandy-clayey substrates	Member of meadow-saline communities
19	***Digitaria sanguinalis***	Annual. Therophyte	Non-saline soils	Moderately humid (along the ditches)	Sandy and alluvial soils	A weed species in agrocenoses, a soil fixer
20	***Eremopyrum bonaepartis***	Annual. Therophyte	Non-saline soils	Dry conditions	Sands, clayey substrates	Ephemeral desert communities
21	***Eremopyrum triticeum***	Annual. Therophyte	Solonetzic, gravelly soils	Dry conditions	Dry substrates (sand, crushed stone)	Xerophytic ephemeral, an indicator of desert conditions
22	***Lolium arundinaceum***	Perennial. Hemicryptophyte.	Solonetzic and slightly saline soils	Wet conditions (shores, meadows)	Clayey, meadow substrates	Forms turf, valuable forage species
23	***Leymus racemosus***	Perennial. Hemicryptophyte.	Non-saline sands, sea coasts	Moderately humid (shores)	Shifting sands	Strengthening sandy banks, forming turf
24	***Leymus ramosus***	Perennial. Hemicryptophyte.	Solonetzic steppes, river banks	Moderately humid	Sandy-clayey, solonetzic	Soil strengthener, weed species in agrocenoses
25	***Stipa caucasica***	Perennial. Hemicryptophyte.	Non-saline sands and gravelly slopes	Dry conditions	Shifting sands, rocky substrates	Xerophyte forms feather grass communities
26	***Stipa capillata***	Perennial. Hemicryptophyte.	Non-saline gravelly and sandy soils	Arid	Slopes, scree	Indicator of dry steppes and deserts
27	***Stipa sareptana***	Perennial. Hemicryptophyte.	Clayey saline depressions, sands	Arid	Rocky, clayey, sandy	Member of feather grass-wormwood communities
28	***Stipa hohenackeriana***	Perennial. Hemicryptophyte.	Non-saline soils	Dry	Loess, gravelly slopes	Forms feather grass in the foothills
29	***Puccinellia distans***	Perennial. Hemicryptophyte/helocryptophyte	Slightly saline meadows	Wet, swampy	Sandy-clayey, pebble	Dominant of wet meadows, an indicator of salinity

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
30	***Puccinellia poecilantha***	Perennial. Hemicryptophyte/helocryptophyte	Slightly salty waters, wet salt marshes	Raw conditions	Sandy-loamy, grussy	Forms a grass stand, an indicator of water-logged soils
31	***Phalaris arundinacea***	Perennial. Geocryptophyte.	Non-saline floodplains	Raw conditions	Stable floodplain soils	Creates dense turf and strengthens banks
32	***Phragmites australis***	Perennial. Hemicryptophyte/geocryptophyte	Slightly saline and non-saline waters	Raw conditions	Coastal and silty soils	Forms thickets and stabilises banks
33	***Polypogon monspeliensis***	Annual. Therophyte	Solonetzic soils	Raw conditions	Moist soils	Fast-growing, ephemeral, waterlogging indicator
34	***Tragus racemosus***	Annual. Therophyte	Non-saline sands	Dry conditions	Shifting sands	A weedy species, a member of sandy communities
	Cyperaceae					
35	***Carex physodes***	Perennial. Hemicryptophyte.	Non-saline sands	Dry conditions	Mobile and fixed sands	The primarystabiliser of sands fixes dunes
36	***Bolboschoenus maritimus***	Perennial. Geocryptophyte.	Salt meadows, swamps	Raw	Silts, wet sands	Forms coastal thickets and filters water
	Asparagaceae					
37	***Asparagus breslerianus***	Perennial. Hemicryptophyte.	Salt marshes, salt lakes	Arid	Clayey, chalky soils	A semi-desert species, an element of xerophytic communities
	Polygonaceae					
38	***Atraphaxis spinosa***	Shrub. Phanerophyte.	Non-saline soils	Dry	Clay and gravel substrates	Forms sparse forests and shrub communities
	Amaranthaceae					
39	***Agriophyllum pungens***	Annual. Therophyte	Non-saline sands	Arid	Dune and hummocky sands	Psammophyte, sand fixer
40	***Anabasis eriopoda***	Perennial. Hemicryptophyte.	Sandy-clay deserts	Arid	Clay and gravel substrates	Dominant of desert communities
41	***Anabasis aphylla***	Subshrub. Chamaephyte	Salt marshes, solonetz	Moderately humid (with close groundwater)	Clay and sandy substrates	Member of salt marsh communities
42	***Atriplex aucheri***	Annual. Therophyte	Salt marshes	Moderately humid	Clay and sandy substrates	An inhabitant of salt marshes, a weed species
43	***Atriplex dimorphostegia***	Annual. Therophyte	Hilly sands, outskirts of Takyrs	Arid	Rubble and sandy soils	Ephemer, a member of desert communities
44	***Atriplex patens***	Annual. Therophyte	Wet salt marshes	Wet	Coastal solonetzic soils	Member of salt marsh communities
45	***Atriplex tatarica***	Annual. Therophyte	Salt marshes, solonetz	Moderately humid	Floodplain and meadow soils	A weedy species, an indicator of salt marshes
46	***Bassia hyssopifolia***	Annual. Therophyte	Salt marshes, salted sands	Arid	Sandy and loamy substrates	An inhabitant of salt marshes, a weed species
47	***Bassia odontoptera***	Annual. Therophyte	Salt marshes, clay slopes	Arid	Rocky and clayey substrates	A desert species, an indicator of saline habitats
48	***Bassia prostrata***	Perennial. Hemicryptophyte.	Salt marshes, solonetz	Arid	Rocky and sandy substrates	Forage species, soil fixer
49	***Bienertia cycloptera***	Annual. Therophyte	Gypsum-bearing salt marshes, shores of salt lakes	Moderately moist (occasionally damp)	Clayey and saline substrates	An indicator of salt marsh habitats, an ephemeral of desert communities

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
50	***Corispermum laxiflorum***	Annual. Therophyte	Non-saline sands	Arid	Shifting sands, dunes	Psammophyte, a member of desert communities, a sand fixer
51	***Corispermum aralocaspicum***	Annual. Therophyte	Saline sands, saline coasts	Moderately wet/dry	Hilly sands, clayey and pebble soils	Psammophyte and halophyte species areindicators of arid habitats
52	***Corispermum squarrosum***	Annual. Therophyte	No data for the region	—	—	A rare alien species, a weed (in the flora of Kulala)
53	***Ceratocarpus arenarius***	Annual. Therophyte	Non-saline sands and sandy loams	Arid	Sandy and rocky-gravelly substrates	Ephemeral desert and steppe communities
54	***Chenopodium album***	Annual. Therophyte	Weedy, non-saline places	Moderately humid	Various substrates (sand, loam)	A weed species, an indicator of anthropogenic habitats
55	***Climacoptera kasakorum***	Annual. Therophyte	Clayey salt marshes	Wet (occasionally damp)	Plump clay substrates	Halophyte, a member of salt marsh communities
56	***Climacoptera lanata***	Annual. Therophyte	Salt marshes, shores of salt lakes	Damp, salty conditions	Clay and saline substrates	Halophyte, dominant in saline communities
57	***Caroxylon scleranthum***	Annual. Chamaephyte	Non-saline sands, less often, gravelly places	Arid	Sandy and rocky substrates	Psammophyte, indicator of dry habitats
58	***Caroxylon nitrarium***	Annual. Therophyte	Takyrs, salt marshes, salted sands	Moderately humid (salt marshes) and dry	Clayey-gravelly and gypsum-bearing substrates	Halophytes, which are indicators of saline soils, are integral to semi-desert communities
59	***Grubovia sedoides***	Annual. Therophyte	Solonchaks, solonetz, solonetzic steppes	Moderately dry	Clayey and compacted soils	A member of halophytic communities, a weed species
60	***Halanthium kulpianum***	Annual. Therophyte	No data (absent in the KM flora)	—	—	A rare alien species
61	***Halimocnemis sclerosperma***	Annual. Therophyte	Takyrs, salt marshes, serozems	Arid and semi-humid	Clayey and compacted soils	Halophyte, a member of salt marsh communities
62	***Halocnemum strobilaceum***	Shrub. Chamaephyte	Salt marshes, wet and puffy salt marshes, and the shores of salt lakes	Wet	Clay and silt substrates	Dominant of solonchak communities, an indicator of saline depressions
63	***Halogeton glomeratus***	Annual. Therophyte	Salt marshes, gravelly desert slopes	Arid	Crushed rock and clay soils	Obligate halophyte, indicator of desert salt marshes
64	***Halostachys caspica***	Shrub. Phanerophyte.	Wet and puffy salt marshes, sea coasts	Wet	Clay and silt soils	Dominant of coastal and salt marsh communities
65	***Halothamnus turcomanicus***	Shrub. Chamaephyte	No data (absent in the KM flora)	—	—	Rare species
66	***Kalidium caspicum***	Shrub. Chamaephyte	Salt marshes, salt marshes, banks of salt lakes and rivers	Wet and semi-wet	Clay substrates	Halophyte, coastal stabiliser

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
67	***Caviria gossypina***	Annual. Therophyte	Chalk outcrops, gypsum-bearing clays, salt marshes	Arid	Chalk and clay substrates	Indicator of saline and gypsum-bearing soils
68	***Lipandra polysperma***	Annual. Therophyte	Sandy shores, cliffs, estuaries, and garbage dumps	Moderately humid	Sandy and loose soils	A weed species, an inhabitant of anthropogenic habitats
69	***Oxybasis glauca***	Annual. Therophyte	Salt marshes, river and lake banks, and vegetable gardens	Wet and semi-wet	Sandy and clayey substrates	A weedy species, an indicator of saline habitats
70	***Pyankovia affinis***	Annual. Therophyte	Clayey solonchaks, takyrs, rubble-clayey trails	Arid and semi-humid	Clay and gravel substrates	Halophyte, a member of desert communities
71	***Pyankovia brachiata***	Annual. Therophyte	Solonetz, highly solonetzic soils	Arid	Clayey-gravelly substrates	Member of halophytic communities
72	***Petrosimonia brachiata***	Annual. Therophyte	Salt marshes, less commonly solonetz	Moderately humid	Clay and silt soils	Forms clumps on salt marshes, an indicator of wet halophytic habitats
73	***Petrosimonia glaucescens***	Annual. Therophyte	Salt marshes, solonetz	Moderately dry	Clay compacted soils	Member of halophytic communities
74	***Salicornia europaea***	Annual. Therophyte	Wet salt marshes, sors, sea coasts, and shores of salt lakes	Wet	Silty and saline substrates	Halophyte, an indicator of waterlogged salt marshes
75	***Salsola australis***	Annual. Therophyte	Sandy areas of river valleys, saline places	Dry and moderately dry	Sandy and sandy loam substrates	A weed species, an indicator of anthropogenic disturbances
76	***Salsola paulsenii***	Annual. Therophyte	Solonetzic sandy soils, desert steppes	Arid	Sandy and sandy loam	Member of halophytic desert communities
77	***Salsola foliosa***	Annual. Chamaephyte	Salt marshes, salt licks, takyrs	Dry and moderately dry	Clay and saline	Weed and halophytic species
78	***Suaeda acuminata***	Annual. Therophyte	Salt marshes, salt marsh meadows, wastelands	Semi-moist and moist	Clayey and saline	Halophyte, an indicator of salt marsh habitats
79	***Suaeda kossinskyi***	Annual. Therophyte	Salt marshes, sors in sandy areas	Semi-moist	Saline sandy substrates	Member of salt marsh communities
80	***Suaeda salsa***	Annual. Therophyte	Coastal and continental salt marshes	Wet	Silt and salt marshes	Halophyte, an indicator of coastal habitats
	Caryophyllaceae					
81	***Holosteum umbellatum subsp. glutinosum***	Annual. Therophyte	Non-saline clay and rocky slopes	Dry	Clayey and stony	Ephemeral, a member of xerophytic communities
82	***Psammophiliella muralis***	Annual. Therophyte	Weedy areas, arable land, wastelands, salt marshes	Moderately humid	Various substrates	A weed species that occurs in disturbed habitats

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
83	***Gypsophila paniculata***	Perennial. Hemicryptophyte.	Meadow and sandy steppes, salt marshes	Moderately dry and semi-moist	Sandy loam and sierozem soils	Forms clumps, an indicator of steppe habitats
84	***Gypsophila perfoliata***	Perennial. Hemicryptophyte.	Sands, pebbles, salt meadows	Semi-moist	Sandy and pebble substrates	Member of meadow and floodplain communities
85	***Silene wolgensis***	Biennial. Therophyte	Meadow and grassy slopes	Moderately humid	A variety of grassy soils	Member of the meadow and forest edge communities
86	***Silene cyri***	Biennial. Therophyte	Non-saline rocky slopes	Arid	Rocky and gravelly substrates	An element of xerophytic communities, an indicator of the foothills
87	***Spergularia diandra***	Annual. Therophyte	Solonetzic meadows, salt marshes	Moderately humid	Clay and silt substrates	Halophyte, an indicator of wet habitats
88	***Spergularia mediasubsp. media***	Perennial. Hemicryptophyte.	Saline soils	Wet	Saline substrates	Coastal halophyte
89	***Spergularia rubra***	Annual. Therophyte/hemicryptophyte	Saline and sandy soils, weedy areas	Moderately dry	Sandy and clayey soils	Weed and halophytic species
	Ceratophyllaceae					
90	***Ceratophyllum demersum***	Perennial. Hydrocryptophyte.	Fresh and slightly salty water bodies	Aquatic environment	Silty bottom sediments	Forms underwater communities and stabilizes the bottom soils
	Ranunculaceae					
91	***Adonis scrobiculata subsp. scrobiculata***	Annual. Therophyte	Saline and wet sands, shrub thickets	Wet and semi-wet	Sandy and sandy loam substrates	Ephemeral, an indicator of disturbed habitats
92	***Ranunculus falcatus***	Annual. Therophyte	Steppes and deserts, clay and sandy soils	Dry	Clay, sand and pebble substrates	Ephemer, a member of desert communities
93	***Ranunculus testiculatus***	Annual. Therophyte	Deserts, clayey and sandy soils	Arid	Sandy and clayey soils	Ephemeral desert habitats
94	***Delphinium camptocarpum***	Annual. Therophyte	Fixed and semi-fixed sands	Dry	Sandy substrates	Member of ephemeral communities on the sands
	Papaveraceae					
95	***Papaver laevigatum***	Annual. Therophyte	Rocky and gravelly slopes, pebbles	Arid	Crushed rock and variegated rocks	Ephemeral, an indicator of rocky habitats
	Brassicaceae					
96	***Alyssum turkestanicum***	Annual. Therophyte	Rubbly, stony and slightly saline soils	Arid	Loamy and sandy loam substrates	Ephemeral, a member of xerophytic communities
97	***Kakile maritimasubsp. euxina***	Annual. Therophyte	Sea coasts (presumably)	Wet	Coastal sands	Coastal halophyte, rare alien species
98	***Chorispora tenella***	Annual. Therophyte	Steppe slopes, banks of reservoirs	Moderately humid	Clay and sandy loam substrates	Ephemeral, an indicator of disturbed habitats
99	***Descurainia sophia***	Annual. Therophyte	Salted areas	Moderately dry	Clayey and sandy loam	A weedy species, an indicator of saline areas
100	***Goldbachia laevigata***	Annual. Therophyte	Hilly sands, sandy-rocky and clayey substrates	Arid and semi-humid	Shifting sands, sandy loams	Ephemer, a member of desert communities

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
101	***Meniocus linifolius***	Annual. Therophyte	Sands and outcrops of Tertiary clays	Arid	Sandy and clayey substrates	Ephemeral indicator of clay outcrops
102	***Strigosella brevipes***	Annual. Therophyte	Sands (often saline), gypsum clays, pebbles	Arid	Sandy and gravelly	Ephemeral, a member of halophytic and desert communities
103	***Strigosella circinata***	Biennial. Therophyte	Sands, alluvial deposits, sandy loams	Arid	Sandy and sandy loam	Ephemeral, a rare species on the plain
104	***Syrenia siliculosa***	Biennial. Therophyte	Steppe meadows on sandy soils	Moderately humid	Sandy and sandy loam	Member of meadow communities
	Fabaceae					
105	***Alhagi pseudalhagisubsp. persarum***	Perennial. Hemicryptophyte.	Slightly saline clay soils, sands	Moderately humid	Clayey and sandy	Halophyte, a depression indicator
106	***Alhagi pseudalhagi***	Perennial. Hemicryptophyte.	Slightly saline sandy soils, edges of fixed sands	Moderately dry	Sandy	Weed species, forage shrub
107	***Astragalus karakugensis***	Subshrub. Chamaephyte	Semi-fixed sands	Arid	Shifting sands	Psammophyte, sand fixer
108	***Astragalus ammodendron***	Subshrub. Chamaephyte	Sandy soils	Arid	Shifting sands	Forage and soil-strengthening species
	Geraniaceae					
109	***Erodium ciconium***	Annual. Therophyte	Loamy soils, variegated flowers	Moderately dry	Loams and stony soils	Ephemeral, an indicator of disturbed habitats
	Nitrariaceae					
110	***Tetradiclis tenella***	Annual. Therophyte	Wet saline soils	Wet	Clayey and saline	Halophyte, an indicator of damp salt marshes
111	***Peganum harmala***	Perennial. Hemicryptophyte.	Sands, weedy places	Arid	Sandy	Weed species, medicinal plant
	Zygophyllaceae					
112	***Zygophyllum fabago***	Perennial. Hemicryptophyte.	Sands, salt marshes	Arid	Loamy and sandy	Halophyte, weed species
	Rutaceae					
113	***Haplophyllum obtusifolium***	Subshrub. Chamaephyte	Sand and gravel deposits, rocky ridges	Arid	Pebbles and sand	Elements of xerophytic communities
114	***Haplophyllum bungei***	Perennial. Hemicryptophyte.	Margins and depressions of hummocky sands	Arid	Sandy	Desert habitat indicator
	Euphorbiaceae					
115	***Euphorbia helioscopia***	Annual. Therophyte	Weedy and fallow areas	Moderately humid	Loamy and garden soils	Weed, an indicator of disturbed habitats
	Malvaceae					
116	***Malva pusilla***	Annual/biennial. Therophyte	Fine-grained and gravelly slopes, pebbles	Moderately dry	Rubble and sandy soils	
	Frankeniaceae					
117	***Frankenia hirsuta***	Subshrub. Chamaephyte	Wet banks, clay and rocky deserts	Wet	Clay and stony soils	Halophyte, an indicator of wet habitats

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
	Tamaricaceae					
118	***Tamarix gracilis***	Shrub, phanerophyte	Saline soils (solonetz, solonchaks)	High (groundwater close)	Sandy, clayey	Forms coastal thickets and strengthens banks
119	***Tamarix ramosissima***	Shrub, phanerophyte	Solonetz, salt marshes	Average	Sands, chalk hills	Substrate stabilisation, habitat for birds
120	***Tamarix laxa***	Shrub, phanerophyte	Solonetzes, solonchaks, takyrs	Variable	Sands	Dominant of solonetz communities
	Elaeagnaceae					
121	***Elaeagnus angustifolia***	Shrub/low tree, phanerophyte	Slightly saline sands	Low	Hummocky sands	
	Apiaceae					
122	***Ferula nuda***	Perennial, hemicryptophyte	Slightly saline sands	Average	Semi-fixed sands	Elements of psammophytic groups
123	***Ferula foetida***	Perennial, hemicryptophyte	Arid habitats	Low	Sandy hills	Dominant of dry communities, medicinal value
124	***Zosima absinthiifolia***	Perennial/biennial, hemicryptophyte/therophyte	Not salted	Dry	Rocky slopes	Member of xerophytic communities
	Primulaceae					
125	***Androsace maxima***	Annual, therophyte	Slightly saline	Low	Rocky, gravelly slopes	Episodic component of rock and steppe phytocenoses
	Plumbaginaceae					
126	***Limonium gmelinii***	Perennial, hemicryptophyte	Salt marshes, salt marsh meadows	High	Salt-laden depressions, river valleys	A weed species, an element of anthropogenic habitats
127	***Limonium caspium***	Perennial, hemicryptophyte	Salt marshes	High	Damp meadows, depressions	Indicator of saline and wetland habitats
	Gentianaceae					
128	***Centaurium pulchellum***	Annual, therophyte	Saline substrates	Average	Sands, stream banks	Indicator medicinal plant
	Apocynaceae					
129	***Cynanchum acutum subsp. sibiricum***	Perennial, hemicryptophyte	Slightly saline	Average	Rubble-rocky slopes, variegated flowers	Weedy appearance
	Convolvulaceae					
130	***Convolvulus persicus***	Perennial, hemicryptophyte	Salt-laden sands	Average	Coastal sands (200 m from the sea)	A rare protected species, an indicator of coastal communities
131	***Convolvulus erinaceus***	Subshrub, chamaephyte	Slightly saline	Low	Hilly and flat sands	Sand stabilizer
132	***Convolvulus arvensis***	Perennial, hemicryptophyte	Wide range	From dry to wet	Miscellaneous (vegetable gardens, wastelands, fields)	A weed species with a broad ecological range
	Boraginaceae					
133	***Tournefortia sibirica***	Perennial, hemicryptophyte	Lightly saline coasts	Average	Shell rocks, boulders, pebbles, storm surges	Coastal stabiliser forms protective communities
134	***Heliotropium ellipticum***	Perennial, hemicryptophyte	Non-salted or slightly salted	Average	Rocky shores, mountain trails	A common component of coastal communities

Continuation of Table 1

№	View	Life form	Habitat salinity	Humidity	Substrate mobility	Primary role in the community
135	***Lappula barbata***	Annual or biennial, therophyte	Unsalted	Low	Rocky and gravelly slopes	Ephemeral desert and mountain communities
136	***Lappula patula***	Annual, therophyte	Unsalted	Low	Sands, sandy loams, pebbles	A weedy and ephemeral species of desert steppes
	Lamiaceae					
137	***Lamium amplexicaule***	Annual or biennial, therophyte	Unsalted	Average	Rocky and gravelly slopes, forest edges, fields, and vegetable gardens	A weed species, an indicator of disturbed habitats
	Orobanchaceae					
138	***Orobanche amoena***	Perennial, hemicryptophyte	Solonetzic steppes	Average	Clay and sandy substrates	A parasitic plant affects the structure of communities
	Asteraceae					
139	***Artemisia arenaria***	Subshrub, chamaephyte	Salted coasts, sands	Low	Sandy substrates	Dominant desert vegetation
140	***Artemisia austriaca***	Perennial, chamaephyte	Steppe and solonetzic meadows	Average	Sandy and sandy loam soils	A widespread species, it grows as a weed.
141	***Artemisia lercheana***	Subshrub, chamaephyte	Light chestnut soils, chalk outcrops	Low	Rocky, gravelly, sandy substrates	Member of cereal-wormwood communities
142	***Artemisia abrotanum***	Hamephyte, hemicryptophyte	Saline and moist meadows	Medium-high	Banks of rivers, lakes, and ravines	Medicinal species, found in agrocenoses
143	***Artemisia scoparia***	Annual, therophyte	Weed and steppe communities	Average	Sandy loam, sandy, loess slopes	A weedy species that quickly colonises disturbed lands.
144	***Artemisia marschalliana var. marschalliana***	Subshrub, chamaephyte	Sands, salted coasts	Low	Sandy soils	Dominant of local desert communities
145	***Cicerbita macrophylla***	Perennial, hemicryptophyte	Not salted	Moderate	Forest and meadow habitats	Potential component of wetland communities
146	***Lactuca serriola***	Annual/biennial, therophyte	Slightly saline soils, anthropogenic places	Average	Sands, vegetable gardens, roads	A common weed species
147	***Lactuca tatarica***	Perennial, hemicryptophyte	Salt marshes, saline clays and sands	Average	Pebbles, sandstone outcrops	Indicator of saline habitats
148	***Microcephala lamellata***	Annual, therophyte	Solonchaks, clayey, takyr-like soils	Average	Sandy and gravelly substrates	Ephemeral desert communities
149	***Senecio glaucus subsp. coronopifolius***	Annual, therophyte	Salt marshes, solonetzic meadows	Medium-high	Salt meadows	An ephemeral species in salt marsh communities

Floristic composition analysis revealed a diverse range of life forms and ecological strategies among the plants represented in the studied sample (149 species). The most significant proportion is made up of annual therophytes (70 species, 47.0%), which form the basis of ephemeral and ephemeroid communities characteristic of desert and semi-desert habitats. Perennial hemicryptophytes (30 species, 20.1%), represented by steppe and meadow species that form dense sods and ensure the stability of the vegetation cover, are of significant importance. Hydrocryptophytes (10 species, 6.7%), confined to aquatic and coastal biotopes, chamaephytes (10 species, 6.7%), and geocryptophytes (5 species, 3.4%) were also noted. Phanerophytes (7 species, 4.7%) are represented by shrubs and small trees that play a key role in stabilising the substrate (e.g., Tamarix, Halostachys). Mixed life forms comprise 11.4% of the flora.

In terms of habitat salinity, non-saline biotope species predominate, comprising 40 species (26.8%). However, a significant portion of the flora is formed by halophytes: solonchaks (30 species, 20.1%), solonetzic (20 species, 13.4%), and slightly saline habitats (20 species, 13.4%). Another 15 species (10.1%) are associated with brackish and saline water bodies, while 12 species (8.1%) inhabit freshwater environments. Thus, almost half of the flora is represented by halophytes, emphasising the adaptation of the vegetation to the extreme conditions of saline and arid ecosystems.

The calculation of diversity indices revealed that the flora is characterised by a relatively high level of species and structural diversity (Tab. 2).

Table 2

Biodiversity indices

Index	Meaning
Shannon H'	1.55
Simpson D	0.71
Saw J	0.79

The Shannon index was H' = 1.55, reflecting the presence of several major life-form groups dominated by therophytes. The Simpson index was D = 0.71, indicating a relatively high probability of encountering different groups if randomly selected. The Pilou evenness index (J = 0.79) indicates a relatively balanced distribution of species among the various life forms.

Overall, the results of the analysis confirm that the flora of the studied area is ephemeral and ephemeroid in nature, but is also distinguished by a pronounced mosaic: along with ephemerals, perennial halophytes, shrubs, and hydrophytes play a significant role, forming a stable and diverse vegetation cover adapted to sharp fluctuations in humidity and salinity of habitats.

Canonical correspondence analysis (CCA) of the Kulaly Island flora revealed key ecological gradients that determine the spatial distribution and structural organisation of plant communities. Factors such as substrate salinity, moisture level, and soil mobility were included as key predictors in the analysis, allowing for a comprehensive characterisation of the ecological niche of each species (Fig.).

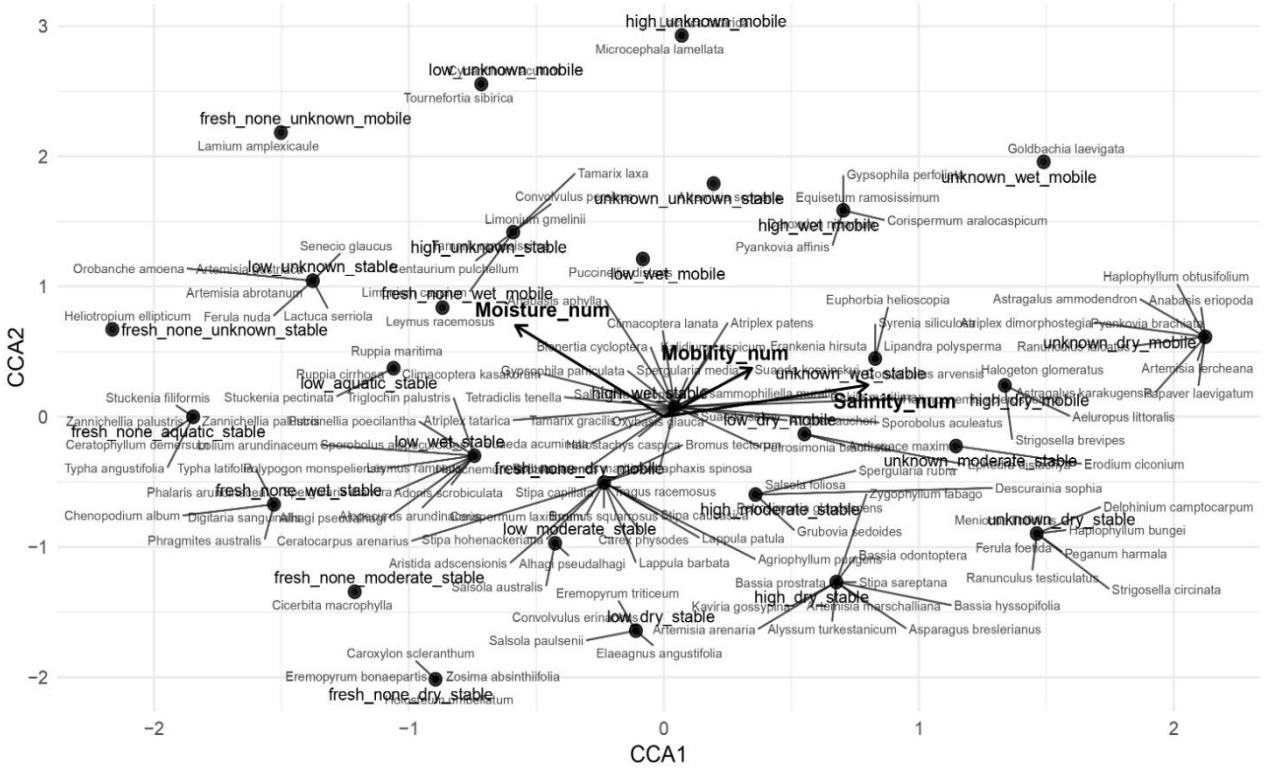

Figure. Canonical analysis of the environment and biodiversity flora of Kulaly Island

The distribution of objects on the diagram showed that the CCA1 axis best reflects the salinity gradient, which is closely related to moisture conditions. Typical halophytes from the Chenopodiaceae and Amaranthaceae families are located at the positive pole of the axis. *Suaeda salsa, Halocnemum strobilaceum, Kalidium caspicum, Halogeton glomeratus, Atriplex dimorphostegia, Salsola paulsenii, and* others. These species are confined to salt marshes and areas with high salt concentrations, forming distinct communities that are resistant to the extreme conditions of mineralised soils. On the opposite side of the axis are hydrophytes and coastal species—*Typha angustifolia, Typha latifolia, Stuckenia filiformis, Zannichellia palustris, Ruppia maritima, Ceratophyllum demersum,* reflecting freshwater aquatic habitats. Thus, the CCA1 axis represents the primary ecological-geochemical contrast in the island's flora, ranging from freshwater to saline ecotopes.

The CCA2 axis broadlycharacterises the influence of substrate mobility and moisture gradients. The upper part of the diagram contains species associated with dune and sand ecotopes characterised by high substrate dynamics—Agriophyllum pungens, Aristida adscensionis, Carex physodes, Corispermum aralocaspicum, and Anabasis eriopoda. Their spatial displacement indicates the significant role of edaphic instability and wind activity in the formation of phytocenoses. Species that prefer more stable substrates, such as Suaeda acuminata, Artemisia arenaria, and Atriplex tatarica, are concentrated closer to the centre of the diagram, demonstrating a broad ecological amplitude range and plasticity in relation to substrate conditions.

Coastal hygrophilous species occupy a special position (*Phragmites australis, Bolboschoenus maritimus, Polypogon monspeliensis*), which form a cluster in the lower left quadrant of the ordination. Their placement confirms that humidity is the second most crucial factor structuring the island's vegetation cover. In contrast, xerophytes (*Astragalus ammodendron, Artemisia scoparia, Ephedra distachya, Haplophyllum*bungei) are shifted to the right pole of the diagram, which reflects their adaptation to arid conditions and moisture-poor substrates.

Thus, the CCA results indicate that the primary ecological determinant of Kulaly Island's vegetation cover is salinity, which shapes the fundamental division of the flora into hydrophilic and halophytic complexes. A secondary, but significant, role is played by the moisture gradient, which creates a contrast between coastal and dry arid communities. Finally, substrate mobility determines the specificity of dune and psammophyte assemblages, increasing their ecological selectivity and limiting species composition. The observed species distribution confirms the high ecological mosaicism of Kulaly Island's flora, where each species or group of species occupies a strictly defined position within the spatial distribution of environmental axes. This spatial structure highlights the adaptive strategies of plants in the extreme conditions of arid-salt marsh landscapes in the northeastern Caspian.

Conclusion

The flora of Kulaly Island is characterised by a significant diversity of vascular plants—149 species—reflecting a wide range of life forms and ecological strategies. The most abundant taxa are annual therophytes (47.0%) and perennial xerophytes, indicating the vegetation's adaptation to the extreme conditions of an arid climate, high salinity, and dynamic substrate. Perennial halophytes and shrubs play a crucial role in stabilising ecosystems, strengthening soil substrates, and forming resilient communities.

Calculation of biodiversity indices confirmed the high structural mosaicity of the flora. The Shannon index (H' = 1.55) and Simpson index (D = 0.71) indicate a relatively high level of alpha diversity. In contrast, the Pilou evenness index (J = 0.79) reflects a balanced distribution of taxa across different ecological groups. This indicates the presence of a stable floristic structure even under conditions of sharp fluctuations in habitat humidity and salinity.

Canonical correspondence analysis (CCA) identified three key ecological gradients determining the spatial distribution of flora: salinity, humidity, and substrate mobility. The primary division of flora is determined by the contrast between freshwater and saline biotopes, while secondary factors structure coastal, arid, and dune communities. This spatial organisation confirms the high ecological flexibility of the Kulala flora and its ability to form stable phytocoenoses in the extreme conditions of the arid-salt marsh landscape.

At the same time, the vulnerability of rare and locally distributed taxa to anthropogenic impacts (fishing, economic use) and fluctuations in the Caspian Sea level was revealed. This highlights the need for systematic monitoring of the island's flora, the implementation of environmental measures, and the develop-

ment of long-term biodiversity conservation programs. Data obtained from a scientific basis for assessing the dynamics of island ecosystems can be used to develop strategies for the sustainable use of the region's natural resources.

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Conflict of Interest

Authors declare no conflict of interest.

Author contribution

The manuscript was prepared with the contributions of all authors, who have given their approval to the final version. **Sagybdykova M.S**. — conceptualisation, project administration, writing, review and editing. **Gassanova G.G**. — investigation, data curation, and collection of plant material; **Imanbaeva A.A**. — methodology, formal analysis, and visualization, **Orazov A.E**. — data curation, statistical analysis, and writing – original draft.

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Каспий теңізінің Қазақстан аймағындағы Құлалы аралдарының өсімдік жамылғысы

Зерттеуде Каспий теңізінің қазақстандық секторында орналасқан Құлалы аралының тамырлы өсімдіктерінің флоралық және экологиялық алуан түрлілігінің кешенді талдауы ұсынылған. Далалық зерттеулер барысында барлығы 149 түр тіркелді, олардың ішінде басым бөлігі біржылдық терофиттер (47,0%) мен көпжылдық ксерофиттер болды. Бұл флораның аридті климатқа, топырақтың жоғары тұздылығына және тұрақсыз субстраттарға бейімделуін көрсетеді. Түрлердің негізгі бөлігі құмды және сор топырақты биотоптармен байланысты, ал сулы-батпақты және су экожүйелерінде салыстырмалы түрде аздаған таксондар ғана кездесті. Альфа-алуантүрлілікті сандық бағалау нәтижесінде Шеннон (H′ = 1,55), Симпсон (D = 0,71) және Пилу (J = 0,79) индекстері флора құрылымының жоғары мозаикалылығын және экологиялық топтардың салыстырмалы түрде теңгерімді таралуын көрсетті. Канондық корреспонденттік талдау (CCA) өсімдік жамылғысын құрылымдайтын негізгі экологиялық градиенттерді — топырақтың тұздылығын, ылғалдылықты және субстраттың қозғалмалылығын анықтады. Бұл факторлар галофиттік, псаммофиттік және гидрофильді қауымдастықтарды айқын ажыратады. Зерттеу нәтижелері флораның жоғары экологиялық икемділігін, сонымен қатар сирек және шектеулі таралған таксондардың Каспий теңізі деңгейінің гидрологиялық ауытқуларына және антропогендік әсерлерге осалдығын көрсетті. Алынған деректер биоалуантүрлілікті мониторингтеу, генетикалық ресурстарды сақтау және Батыс Қазақстанның нәзік аридті экожүйелерін тұрақты басқару үшін маңызды ғылыми негіз болып табылады.

Кілт сөздер: Құлалы аралы, Каспий теңізі, тамырлы өсімдіктер, биоалуантүрлілік, галофиттер, псаммофиттер, Шеннон индексі, Жаккар индексі, аридті экожүйелер, генқорды сақтау

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Растительный покров острова Кулалы в Казахстанском секторе Каспийского моря

В статье представлены результаты комплексного анализа флористического и экологического разнообразия сосудистых растений острова Кулалы, расположенного в казахстанском секторе Каспийского моря. В ходе полевых исследований было выявлено 149 видов, среди которых преобладают однолетние терофиты (47,0%) и многолетние ксерофиты, что отражает адаптацию флоры к аридному климату, высокому уровню засоления почв и подвижным субстратам. Основная часть видов приурочена к песчаным и солончаковым биотопам, тогда как водно-болотные и аквальные экосистемы характеризуются меньшим числом таксонов. Количественная оценка альфа-разнообразия показала следующие значения: индекс Шеннона (H′ = 1,55), индекс Симпсона (D = 0,71) и индекс равномерности Пилу (J = 0,79), что свидетельствует о выраженной структурной мозаичности и сбалансированном распределении экологических групп. Канонический корреспондентный анализ (CCA) выявил три ведущих экологических градиента — засолённость, влажность и подвижность субстрата, которые определяют пространственное распределение флоры и формирование галофитных, псаммофитных и гидрофильных сообществ. Полученные данные демонстрируют высокую экологическую пластичность растительности, а также уязвимость редких и локально распространённых таксонов к гидрологическим колебаниям уровня Каспийского моря и антропогенному воздействию. Результаты исследования служат важной научной основой для мониторинга биоразнообразия, сохранения генетических ресурсов и устойчивого управления аридными экосистемами Западного Казахстана.

Ключевые слова: остров Кулалы, Каспийское море, сосудистые растения, биоразнообразие, галофиты, псаммофиты, индекс Шеннона, индекс Жаккара, аридные экосистемы, сохранение генофонда

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