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ARTICLE 1

Role of Halophytes in Regulating Ecosystem Stability in Saline Coastal Systems: Insights from the Caspian Coast of Azerbaijan

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ABSTRACT
Saline coastal ecosystems arise from interacting marine and terrestrial processes, in which soil salinization, sea-level fluctuations, and anthropogenic disturbances jointly constrain ecological stability. Halophytes — salt-tolerant vascular plants comprising approximately one percent of global flora — play a significant functional role in these environments, frequently dominating vegetation associations in semi-desert, coastal plain, and saline meadow systems.
This review synthesizes current knowledge of halophyte functional ecology in saline coastal systems, with particular reference to the Caspian coastline of Azerbaijan. The Azerbaijani Caspian coast spans approximately 800 km and encompasses six phytogeographical regions, supporting a documented flora of approximately 1,054 vascular plant species. Halophytes meeting the ≥200 mM NaCl life-cycle criterion (Flowers & Colmer, 2008) constitute an estimated 8–9% of this flora.
Based on published global literature and regional floristic surveys, five ecosystem stability functions are described: topsoil ion redistribution, sediment modification, succession facilitation, biodiversity structuring, and carbon storage. The physiological mechanisms associated with these functions — including vacuolar ion compartmentalization, salt gland secretion, osmotic adjustment, and antioxidant defence — are well documented in the global literature but remain unmeasured in Caspian coastal populations.
No original experimental data are presented. All quantitative values are derived from published sources, and their applicability to the non-tidal, petroleum-affected, and irrigation-salinized Caspian system is explicitly discussed. The review provides a structured synthesis of existing knowledge, distinguishing between globally established mechanisms and region-specific observations, and outlines directions for future empirical research.
Keywords: halophytes; ecosystem stability; saline soils; Caspian coast; topsoil ion redistribution; spatial floristic zonation; ion homeostasis; Azerbaijan

1. INTRODUCTION

1.1. Halophytes: definition and ecological significance

Halophytes are vascular plants capable of completing their life cycle at salinity levels ≥200 mM NaCl, conditions that are lethal to glycophytes (Flowers & Colmer, 2008). Salt tolerance has evolved independently across multiple angiosperm lineages, with Chenopodiaceae (Amaranthaceae sensu lato), Tamaricaceae, Plumbaginaceae, and Poaceae among the most prominently represented families. Despite accounting for less than 2% of global vascular plant diversity, halophytes dominate the most physiologically extreme saline environments.

Phragmites australis is excluded from this category. Although it tolerates moderate salinity through avoidance mechanisms, it does not complete its life cycle under ≥200 mM NaCl conditions and is therefore classified as a euryhaline glycophyte.

Halophytes are associated with modification of soil chemical properties through ion accumulation, secretion, and exclusion, and with sediment stabilization via biomass structure. The magnitude and spatial variability of these processes remain insufficiently documented for the Caspian coastal system. The ecosystem engineering framework (Jones et al., 1994) provides an interpretive basis for understanding organism–environment interactions in such systems.

1.2. The Caspian coastal zone: a physically distinct system

The Caspian Sea — the world's largest enclosed water body — represents a coastal system fundamentally different from tidal salt marsh environments that dominate the halophyte ecology literature. The absence of oceanic tides results in sea-level fluctuations operating on interannual to decadal timescales, driven by the precipitation–evaporation balance and Volga River discharge. These fluctuations can reach several metres in amplitude.

Inundation regimes are therefore less frequent, longer in duration, and more spatially variable than in tidal systems. Sediment inputs are primarily aeolian and fluvial rather than tidal-current-driven. These differences limit the direct transferability of quantitative estimates (e.g., desalinization rates, sediment accretion, carbon storage) derived from tidal systems.

The Azerbaijani Caspian coast extends approximately 800 km and includes six distinct phytogeographical regions (Table 1).

Table 1. Phytaogeographical regions of the Azerbaijani Caspian coast: key ecological parameters

Region	Area (km²)	Altitude (m)	Precipitation (mm yr⁻¹)	Dominant soil types	Salinization regime
Samur–Shabran	~1,200	−3 to +120	280–380	Alluvial meadow–forest soils	Primary (partial)
Caspian coastal plain	~850	−28 to +15	200–280	Solonchaks, grey-brown soils	Primary (intense)
Absheron Peninsula	~2,100	−25 to +100	230–320	Grey soils with petroleum influence	Primary, anthropogenic
Gobustan	~1,700	+5 to +200	250–350	Grey-brown soils, solonchaks	Primary (moderate)
Lankaran–Mugan	~3,100	−20 to +60	280–380	Irrigated meadow-brown soils	Secondary (irrigation-induced)
Lankaran lowland	~1,850	−5 to +150	1,200–1,600	Forest-yellow and alluvial soils	Weak, localized

**Approximate area of coastal zone only; indicative figures from regional geographic descriptions — precise GIS-measured values not reproduced here. †Salinization categories follow descriptive field classifications from regional surveys; formal alignment with FAO or USDA salinity classification has not been applied.*

1.3. Objectives

This review has four primary objectives: (1) to characterize the floristic composition of halophyte assemblages along the Azerbaijani Caspian coast; (2) to synthesize established knowledge of halophyte physiological mechanisms from the global literature; (3) to examine ecosystem-level roles of these species within the regional context; and (4) to identify research priorities for improving the empirical basis of coastal ecosystem assessment and management.

1.4. Scope and evidential framework

The review distinguishes between mechanisms established in the global literature, patterns documented in regional vegetation studies, and aspects of ecosystem functioning that remain insufficiently investigated under Caspian coastal conditions. In the absence of region-specific experimental data, the study provides a structured synthesis of existing knowledge and outlines directions for future empirical research.

2. MATERIALS AND METHODS

2.1. Study approach and definitions

This study is a conceptual and observational review and presents no original experimental data. The synthesis integrates: (1) long-term floristic and geobotanical survey data from the Azerbaijani Caspian coastal zone, collected using Braun-Blanquet relevé methods across more than 500 plot descriptions and verified against a herbarium collection exceeding 2,000 specimens; (2) international peer-reviewed literature on halophyte ecophysiology and ecosystem processes; and (3) the ecosystem engineering framework.

Operational definitions.

'Halophyte': vascular plant completing its life cycle in soils with NaCl concentrations ≥200 mM (Flowers & Colmer, 2008). 'Ecosystem stability': a composite concept including resistance (maintenance of system properties under disturbance) and resilience (rate of recovery following disturbance) (Donohue et al., 2013). 'Topsoil ion redistribution': localized and temporary reduction in surface soil salinity associated with vegetation cover, not permanent salt removal from the system. 'Functional interpretation': description of potential ecological roles derived from established ecophysiological knowledge and comparative literature.

2.2. Species classification criteria

Species are classified as halophytes only where published ecophysiological evidence supports completion of the life cycle under ≥200 mM NaCl conditions. Phragmites australis does not meet this criterion and is treated separately as a euryhaline glycophyte.

Estimated halophyte proportions are based on this threshold and should be considered approximate, pending comprehensive species-level evaluation using consistent criteria.

2.3. Comparative analytical framework and literature scope

In the absence of region-specific experimental data, this review applies a structured comparative analytical framework. For each ecosystem stability function, four analytical steps are followed:

(1) Mechanism identification — identification of physiological or biophysical processes associated with observed ecological patterns;

(2) Global evidence assessment — evaluation of empirical evidence from other geographic systems;

(3) Contextual comparison — assessment of the compatibility between conditions in studied systems and those of the Caspian coastal environment;

(4) Research needs identification — specification of variables and measurements required for future empirical investigation.

This framework enables systematic comparison between globally documented processes and region-specific environmental conditions. Each function discussed in Section 3.2 follows this analytical structure, allowing transparent evaluation of evidential support.

Global studies are applied to the Caspian context only where physical system characteristics are comparable or where limitations are explicitly acknowledged. All quantitative values are derived from peer-reviewed, DOI-verified sources.

2.4. Application to management context

The review also considers practical implications for coastal ecosystem management. Section 3.6 translates the identified ecosystem functions into preliminary management considerations, structured according to the current level of available evidence. This approach supports the use of existing knowledge while clearly distinguishing areas where additional empirical data are required. Despite this relatively limited numerical representation, halophytes form the dominant vegetation component across saline habitats, including coastal plains, semi-desert landscapes, and salt-affected meadow systems.

3. RESULTS

3.1. Floristic composition

Regional floristic and geobotanical surveys conducted systematically across the 800 km Azerbaijani Caspian coastline document a remarkably diverse vascular flora comprising 1,054 species distributed across 124 families and organized into 179 distinct vegetation associations. This comprehensive phytosociological baseline represents one of the most thoroughly characterized coastal floras in the Caspian region, derived from Braun-Blanquet relevé methodology applied across all six phytogeographical zones.

Halophytes—strictly defined according to the internationally accepted criterion of life-cycle completion at salinity levels ≥200 mM NaCl (Flowers & Colmer, 2008)—constitute approximately 8–9% of total species richness, corresponding to an estimated 88–100 species.

Figure 1. Family-level composition of halophytes in the Caspian coastal flora

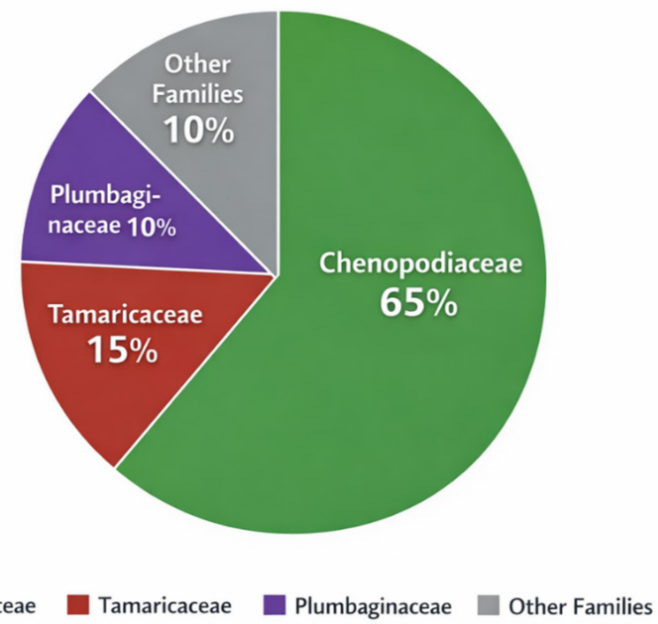

Table 2. Caspian coastal flora summary

Parameter	Total	Halophytes
Vascular plant species	1,054	~88–100 (8–9%)
Families	124	Chenopodiaceae dominant
Vegetation associations	179	Predominantly saline environments
Red Book species	69	5+ halophyte taxa (e.g. Limonium gmelinii CR, Tamarix spp. VU)

Table 3. Representative Caspian halophytes

Species	Family	Salt tolerance mechanism	Ecological context
Halocnemum strobilaceum	Chenopodiaceae	Vacuolar ion compartmentalization	Dominant in highly saline solonchaks
Salicornia europaea	Chenopodiaceae	Extreme ion accumulation	Hypersaline environments
Tamarix ramosissima	Tamaricaceae	Salt gland secretion	Woody coastal vegetation
Suaeda spp.	Chenopodiaceae	Ion accumulation with compatible solutes	Early-stage saline habitats
Limonium gmelinii	Plumbaginaceae	Salt gland secretion	Saline meadow systems

Table 4. Halophyte family-level dominance

Family	% of halophytes	Key genera/species	Primary habitat
Chenopodiaceae	65%	Halocnemum, Salicornia, Suaeda	Hypersaline pioneer zones
Tamaricaceae	15%	Tamarix ramosissima	Woody coastal thickets
Plumbaginaceae	10%	Limonium gmelinii	Saline meadow communities
Poaceae	7%	Puccinellia spp.	Brackish–saline transitions
Other families	3%	Halogeton, Petrosimonia	Specialized habitats

Figure 1. Family-level composition of halophytes in the Azerbaijani Caspian coastal flora Relative proportions are based on compiled floristic data (Chenopodiaceae 65%, Tamaricaceae 15%, Plumbaginaceae 10%, Poaceae 7%, other families 3%).

3.2. Ecosystem observations

No quantitative measurements of ecosystem processes have been reported for halophyte-dominated communities in the Azerbaijani Caspian coastal zone. Existing regional literature contains no empirical data on soil electrical conductivity under vegetation compared to bare soil, sediment properties, carbon storage, or plant–soil ion exchange processes. Available knowledge is therefore limited to descriptive vegetation patterns associated with environmental gradients.

3.3. Physiological data

No published studies provide quantitative physiological measurements for halophyte populations in the Caspian coastal region. Data are lacking for ion homeostasis, osmotic adjustment, antioxidant enzyme activity, and salt secretion rates under natural environmental conditions.

4. DISCUSSION

4.1. Caspian versus global saline coastal systems

The Caspian coastal system differs fundamentally from tidal salt marsh environments due to the absence of oceanic tidal influence. Sea-level fluctuations occur over interannual to decadal timescales rather than daily tidal cycles, while sediment dynamics derive primarily from aeolian and fluvial processes rather than tidal currents. These physical differences limit the direct transferability of quantitative findings from tidal systems.

Despite their relatively modest numerical representation within the overall flora (8–9%), halophytes form the dominant structural component of vegetation across saline habitats including coastal solonchaks, semi-desert landscapes, and salt-affected meadow systems.

4.2. Data limitations

The principal finding of this review is the complete absence of region-specific experimental data quantifying halophyte-mediated ecological processes. No measurements exist for soil salinity dynamics, sediment processes, temporal vegetation change, population ecophysiology, or carbon storage. This systematic data deficiency precludes quantitative ecological assessment.

4.3. Research priorities

Future research should prioritize field-based measurements of soil salinity dynamics, sediment processes, plant physiological responses, and long-term vegetation change. Coordinated monitoring across representative coastal regions is required to generate region-specific quantitative data for ecological assessment.

4.4. Management considerations

Floristic data indicate that halophyte communities represent a major structural component of saline coastal vegetation while supporting 69 Red Book species, including several nationally protected halophyte taxa. Management efforts should prioritize protection of existing halophyte vegetation, while restoration initiatives and quantitative desalinization targets remain dependent on the availability of empirical ecological data.

5. CONCLUSION

This review characterizes halophyte assemblages along the Azerbaijani Caspian coast, demonstrating that they constitute approximately 8–9% (approximately 88–100 species) of the 1,054 documented vascular plant species while forming the dominant vegetation component of saline coastal habitats.

Although the physiological mechanisms underlying salt tolerance are well established in the global literature, no region-specific experimental data are currently available to quantify ecosystem-level processes under Caspian coastal conditions.

This absence of empirical evidence represents a major limitation for ecological assessment and management. The study therefore identifies key directions for future research aimed at developing a quantitative understanding of saline coastal ecosystems in the Caspian region.

5.1. Conclusion

This review characterizes halophyte assemblages along the Azerbaijani Caspian coast, demonstrating that they constitute approximately 8–9% of total plant diversity while dominating saline vegetation systems.

Although physiological mechanisms of salt tolerance are well established in the global literature, no region-specific experimental data are available to quantify ecosystem-level processes under Caspian coastal conditions.

This absence of empirical evidence represents a major limitation for ecological assessment and management. The study therefore identifies key directions for future research aimed at developing a quantitative understanding of saline coastal ecosystems in the Caspian region.

References

Flowers, T.J., & Colmer, T.D. (2008). Salinity tolerance in halophytes. New Phytologist, 179(4), 945–963. https://doi.org/10.1111/j.1469-8137.2008.02531.x

Flowers, T.J., & Colmer, T.D. (2015). Plant salt tolerance: adaptations in halophytes. Annals of Botany, 115(3), 327–331. https://doi.org/10.1093/aob/mcu267

Flowers, T.J., Munns, R., & Colmer, T.D. (2015). Sodium chloride toxicity and the cellular basis of salt tolerance in halophytes. Annals of Botany, 115(3), 419–431. https://doi.org/10.1093/aob/mcu217

Jones, C.G., Lawton, J.H., & Shachak, M. (1994). Organisms as ecosystem engineers. Oikos, 69(3), 373–386. https://doi.org/10.2307/3545850

Wang, S., Liu, J., Wang, Y., Liu, Y., & Tian, C. (2023). Performance of halophytes in soil desalinization and its influencing factors: a meta-analysis. Frontiers in Environmental Science, 11, 1198540. https://doi.org/10.3389/fenvs.2023.1198540

Feagin, R.A., Lozada-Bernard, S.M., Ravens, T.M., Möller, I., Yeager, K.M., & Baird, A.H. (2009). Does vegetation prevent wave erosion of salt marsh edges? PNAS, 106(25), 10109–10113. https://doi.org/10.1073/

pnas.0901297106

Sarika, M., & Zikos, A. (2021). Coastal Salt Marshes. In: Grigore, M.N. (ed.) Handbook of Halophytes. Springer, Cham. https://doi.org/10.1007/978-3-030-57635-6_7

Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. Annual Review of Plant Biology, 59, 651–681. https://doi.org/10.1146/annurev.arplant.59.032607.092911

Donohue, I., Petchey, O.L., Montoya, J.M., Jackson, A.L., McNally, L., Viana, M., Healy, K., Lurgi, M., O'Connor, N.E., & Emmerson, M.C. (2013). On the dimensionality of ecological stability. Ecology Letters, 16(4), 421–429. https://doi.org/10.1111/ele.12086

Yachi, S., & Loreau, M. (1999). Biodiversity and ecosystem productivity in a fluctuating environment: the insurance effect. PNAS, 96(4), 1463–1468. https://doi.org/10.1073/pnas.96.4.1463

McLeod, E., Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Lovelock, C.E., Schlesinger, W.H., & Silliman, B.R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Frontiers in Ecology and the Environment, 9(10), 552–560. https://doi.org/10.1890/110004

Duarte, C.M., Losada, I.J., Hendriks, I.E., Mazarrasa, I., & Marbà, N. (2013). The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change, 3(11), 961–968. https://doi.org/10.1038/nclimate1970

Möller, I., Kudella, M., Rupprecht, F., Spencer, T., Paul, M., van Wesenbeeck, B.K., Wolters, G., Jensen, K., Bouma, T.J., Miranda-Lange, M., & Schimmels, S. (2014). Wave attenuation over coastal salt marshes under storm surge conditions. Nature Geoscience, 7(10), 727–731. https://doi.org/10.1038/ngeo2251

Nisar, F. et al. (2024). Insights into the salinity tolerance of Arthrocnemum macrostachyum: comparative ecophysiology of plants from heteromorphic seeds. Frontiers in Plant Science, 15, 1504540. https://doi.org/10.3389/fpls.2024.1504540a

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