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Modelling habitat suitability and invasion risk of *Erigeron annuus* (L.) Desf. (Asteraceae) in Azerbaijan: current and future potential distribution

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Abstract: Biological invasions of *Erigeron annuus* can impact the biodiversity of many ecosystems worldwide. It is capable of transforming native vegetation through high seed production, rapid growth, and strong ecological adaptability. This study provides detailed analysis of the distribution, phytocoenotic composition, and ecological niche of the species in Azerbaijan. *E. annuus* is found in a different of habitats from lowlands to mountain forests, according to field surveys carried out in the north-western, western, and southern parts of Azerbaijan between 2022 and 2024. The highest abundance and activity of *E. annuus* were recorded in the northwest of Azerbaijan (Balakan, Zagatala, Gakh districs), where the species dominated mainly in meadow and forest edge vegetation. Species distribution modelling (MaxEnt) achieved high predictive accuracy (AUC=0.95) and identified precipitation during the warmest quarter and annual precipitation as the main climatic factors determining the species' distribution. Current suitability maps show that the humid districts of northwestern Azerbaijan are the most suitable habitats, while the lowland and arid districts are mainly unsuitable for the distribution of the species. Future projections (2081-2100) under the SSP1-2.6, SSP2-4.5 and SSP5-8.5 scenarios determined that the humid areas of the southern Greater Caucasus and Lankaran lowland, as well as the protected areas located here, mainly indicate persistently high suitability. These findings suggest that the current distribution areas of *E. annuus* will maintain stable populations and pose a long-term threat to native plant communities. Effective management strategies should therefore focus on early detection and control within these ecologically sensitive areas.

Keywords: *biological invasion, climate change, MaxEnt, phytocoenosis, species distribution modelling*

INTRODUCTION

The increasing variety and abundance of Invasive Alien Species (IAS) are recognized as one of the leading drivers of global environmental changes and biodiversity loss, more detrimentally affecting ecosystem services, economy activities such as agriculture, and human well-being [EEA, 2012]. Significant structural and functional changes, sometimes leading to complete transformation of plant communities can occur from their introduction into natural and semi-natural ecosystems [Lambdon et al., 2008; Sakai et al., 2001]. Pathways of introduction and dispersion [Petitpierre 2012], biological and phytocoenotic characteristics [Dainese et al., 2014], and the ecological and economic effects of IAS [Simberloff, Holle, 1999; Pimentel et al., 2001] have all been the subject of several research.

In recent decades, various methodological approaches have been applied to invasion research, including genetic analyses, allelopathic assessments, and environmental niche modelling [Nix, 1986; Chown et al., 2014]. Ecological niche models, in particular, provide effective tools for predicting the potential distribution of alien plant species under current and future climate scenarios [Abdiyeva et al., 2021]. In Azerbaijan, preliminary inventories of invasive and potentially invasive plants have been compiled [Abdiyeva 2018], and first attempts of species distribution modelling were carried out for *Ambrosia artemisiifolia* [Abdiyeva et al., 2025].

E. annuus is considered to be one of the most aggressive invasive plant species recorded in Azerbaijan [Abdiyeva, 2019]. Its distribution in Azerbaijan was first identified in 2007 [Mehtiyeva et al., 2017]. The species is native to eastern North America [Cronquist, 1994]. In the 17th century, it was introduced to Europe as an ornamental plant [Rothmaler et al., 1994] and is currently included in the list of the most common invasive plant species in Europe [Lambdon et al., 2008]. It is mainly found in disturbed habitats such as roadsides, railways, abandoned fields and meadows [Sennikov, Kurtto, 2019; Trtikova et al., 2011], often entering semi-natural meadows and forest edges. In Europe, it is common in agricultural habitats including

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cereal fields and pastures, where overwintering rosettes provide rapid regeneration in spring [Májeková, Zaliberová, 2008], typically distributed in lowlands up to 1790 m above sea level [Becker et al., 2005]. Its invasiveness is linked to high seed production, wind dispersal capacity, and allelopathic effects inhibiting germination and growth of co-occurring native plants [Liu et al., 2025; Abhilasha, 2008]. Ecological risk assessments in China ranked *E. annuus* among the highest threat categories [Xie et al., 2001], further highlighting its invasive potential under diverse environmental conditions.

In Azerbaijan, *E. annuus* has recently been reported from different regions, but comprehensive studies on its distribution, phytocoenotic characteristics, and invasive potential remain scarce. Therefore, the aim of this study was (i) to document the current distribution of *E. annuus* in Azerbaijan, (ii) to analyze its phytocoenotic characteristics, and (iii) to model its potential distribution under present climatic conditions.

MATERIALS AND METHODS

Study area. The study area divided into six main altitudinal zones: (1) lowland and foothills (up to 400 m a.s.l.), (2) lower mountain zone (500–800 m), (3) middle mountain zone (800–1700 m), (4) upper mountain zone (1700–2000 m), (5) subalpine zone (2200–2400 m), and (6) alpine zone (2400–3200 m) [Museyibov, 1998]. The complex relief and location at the northern margin of the subtropical climate zone create diverse climatic conditions in Azerbaijan [Ibadullayeva, Huseynova, 2021]. Eight out of eleven climate types are represented, ranging from semi-desert and dry steppe to temperate humid and mountain tundra climates. This diversity of environments supports a rich flora with representatives of ancient forest, boreal, steppe, xerophytic, desert, Caucasian, and adventive geographic elements [Grossheim, 1940-1948].

Occurrence data. Occurrence records of *Erigeron annuus* were obtained from field surveys conducted between 2018–2024 across different habitat types: anthropogenic (settlements, gardens, parks, farms, roadsides), semi-natural (ecotones, neglected lands), and natural ecosystems (meadows, forests, riverbanks, ponds). Additional data were derived from the Herbarium Fund (BAK) of the Institute of Botany, MSERA.

Invasion status assessment. During field studies, geobotanical features of phytocoenoses were described following the standard approach [Field geobotany, 1964], and life forms were classified according to C. Raunkiaer [1934]. The invasive status of the species was assessed following the European approaches to invasion biology [Richardson, Pyšek, 2006]. Alien plants were classified into five invasion classes [Yegoshin, 2016], where classes 1–3 represent potentially invasive species and classes 4–5 are considered invasive transformers.

Abundance and community description. The abundance of *E. annuus* was estimated as the proportion of survey points where the species occurred in relation to the total number of surveyed points. The abundance of *E. annuus* was quantified using Drude's scale [Ponyatovskaya, 1964]. Each gradation was assigned a numerical value from 0 to 5: 0 – absence of the species at the survey point; 1 – *sol* (single individuals); 2 – *sp* (sparse occurrence); 3 – *cop1* (moderately abundant); 4 – *cop2* (abundant); 5 – *cop3* (very abundant and dominant). Communities were named according to the dominant plant species co-occurring with *E. annuus.* We determined species activity according to B.F. Sviridenko [Savinov, Nikitin, 2017], who considers activity as a function of two variables – occurrence and abundance – and defines

$$PA = (PP / 100\%) \cdot (B / 100\%)$$

activity as follows:

where PP is the average projective cover of the species in populations (in %), and B is the ecotopic occurrence of populations (%). The maximum value of partial activity can be equal to 1 (at PP = 100%, B = 100). According to B.F. Sviridenko (2000), plant species with $PA < 0.01$ should be considered inactive, while those with $PA > 0.01$ should be considered active, with a subdivision into highly active ($PA > 0.10$), moderately active ($0.05 < PA < 0.10$), and low-active ($0.01 < PA < 0.05$) species.

Species distribution modelling (SDM). Potential distribution was modelled using the Maxent algorithm [Phillips et al., 2006], which is a presence-only modelling approach widely used for predicting species' ecological niches. Maxent estimates the probability distribution of maximum entropy based on occurrence data and environmental variables, making it suitable for species with limited occurrence records.

Environmental predictors included nineteen bioclimatic variables (bio1–bio19) obtained from the WorldClim database, which describe annual trends, seasonality, and extreme environmental factors relevant to species distribution [Fick, Hijmans, 2017]. Occurrence records were derived from field surveys conducted between 2018–2024 and herbarium data (BAK).

Modelling was performed for the current climate and two future time periods: 2041–2060 (mid-century) and 2081–2100 (end of century), under three Shared Socioeconomic Pathways: SSP1-2.6 (low emissions), SSP2-4.5 (intermediate), and SSP5-8.5 (high emissions) using the BCC-CSM2-MR global circulation model from Coupled Model Intercomparison Project Phase 6 (CMIP6).

Maxent modelling was carried out with the following settings: regularization multiplier: 1.0; feature types: linear, quadratic, product, threshold, and hinge; replicates: 10 cross-validated runs; output format: logistic; threshold rule: maximum training sensitivity plus specificity (MTSS); and performance evaluation: area under the curve (AUC) and true skill statistic (TSS).

These settings were chosen to balance model complexity and predictive performance, following best-practice guidelines for species distribution modelling [Merow et al., 2013].

RESULTS AND DISCUSSION

Distribution and abundance. In Azerbaijan, *E. annuus* occurs across lowland, foothill, and mountain ecosystems in the western (Gadabey, Shamkir districts), north-western (Gakh, Balakan, Zagatala, Shaki, Gabala, Oghuz) (Fig. 1), and southern (Lankaran, Astara) parts of the country, according to field surveys conducted between 2018 and 2024. Although these areas generally share similar humid climate conditions for the species' distribution, they also differ in terms of soil types and altitude, indicating the broad ecological tolerance of *E. annuus.*

Assessment of *E. annuus* occurrence frequency and abundance of in both undisturbed natural habitats and anthropogenically modified areas revealed pronounced regional variation. In the northwestern part of Azerbaijan, populations were frequent and abundant, with occurrence rates of approximately 75% and abundance scores ranging between 3–5. In contrast, in the western and southern regions, the species was recorded only sporadically or in small groups, with occurrence frequencies between 10–25% and abundance scores of 1–2. Activity levels of the species across the studied districts form two main clusters – areas with high occurrence (Balakan, Gakh, Zagatala) and areas with medium or low occurrence (Oghuz, Gabala), where plant abundance was inconsistent, occasionally reaching 4 in meadow-type patches but predominantly forming small groups of 2–5 individuals or occurring solitarily (Fig. 2). Other districts show low frequency and low abundance, with populations consisting mainly of small groups (2–5 individuals).

Habitat and community composition. Based on the analysis of 650 geobotanical descriptions of phytocoenoses of *E. annuus* indicated that the species is most abundant in agricultural lands, including farms, gardens, and cultivated areas. Within natural ecosystems, *E. annuus* was primarily recorded in the herbaceous layer of forests and only occasionally in meadow communities close to agricultural areas. Along the Caspian coast, it occurred within 100 m of the shoreline in various ruderal herbaceous communities (Tab. 1).

According to our three-year observations, *E. annuus* significantly increases its abundance in existing habitats, gradually expands its range, and increasingly becomes dominant in meadow communities (*Achilletum*) as well as in the herbaceous layer of forest communities (Carpinuseto-Quercusetum, Carpinuseto-Aceretum) across lower, middle, and higher mountain zones.

Species distribution modelling. Species distribution modelling using MaxEnt demonstrated a high predictive performance with an AUC value of 0.95, indicating excellent model accuracy. Precipitation-related variables played a dominant role among the bioclimatic predictors, in determining the distribution of *E. annuus*. The most influential factor was the precipitation of the warmest

Figure 1. *Erigeron annuus* in an agrocoenosis (hazelnut orchard) in Gakh district.

quarter (BIO18), contributing 49.9% to the model and showing the highest permutation importance (65.7%). The second most important predictor was annual precipitation (BIO12), with a contribution of 27.4% and a permutation importance of 20.1%. Additional variables such as precipitation seasonality (BIO15, 6.1%) and mean temperature of the wettest quarter (BIO8, 6.3%) also influenced to the distribution of species, though to a lesser extent. Other temperature variables, such as BIO9, had minimal impact.

Overall, the results emphasize that the distribution of the species is mainly determined by precipitation patterns, particularly the amount of precipitation during the warmest quarter and the annual precipitation, highlighting the ecological dependence of the species on moisture availability.

Current potential distribution. Based on the model, the current potential distribution of *E. annuus* indicates the highest climatic suitability in the northwestern districts of the Greater Caucasus (Balakan: mean_suitability value = 0.9998; Zagatala: 0.7593; Gakh: 0.6635). The moderate suitability of the species is mainly in Shaki, Gabala, and Oghuz districts (Fig. 3). Although the model predicts very high suitability for Lankaran district

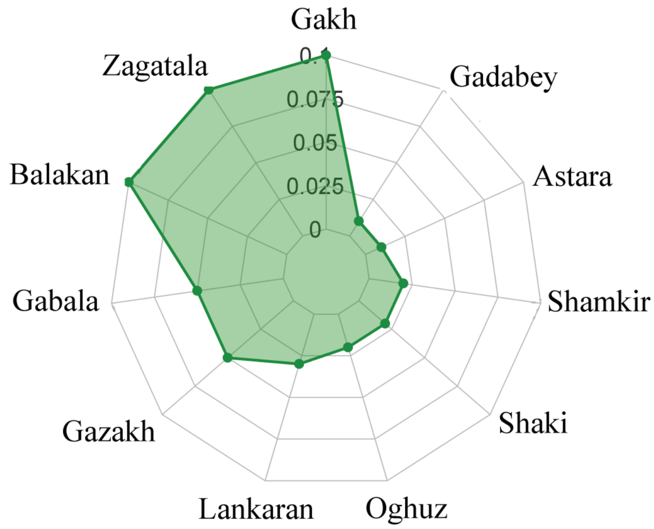

Figure 2. Activity levels of *Erigeron annuus* populations in different regions of Azerbaijan.

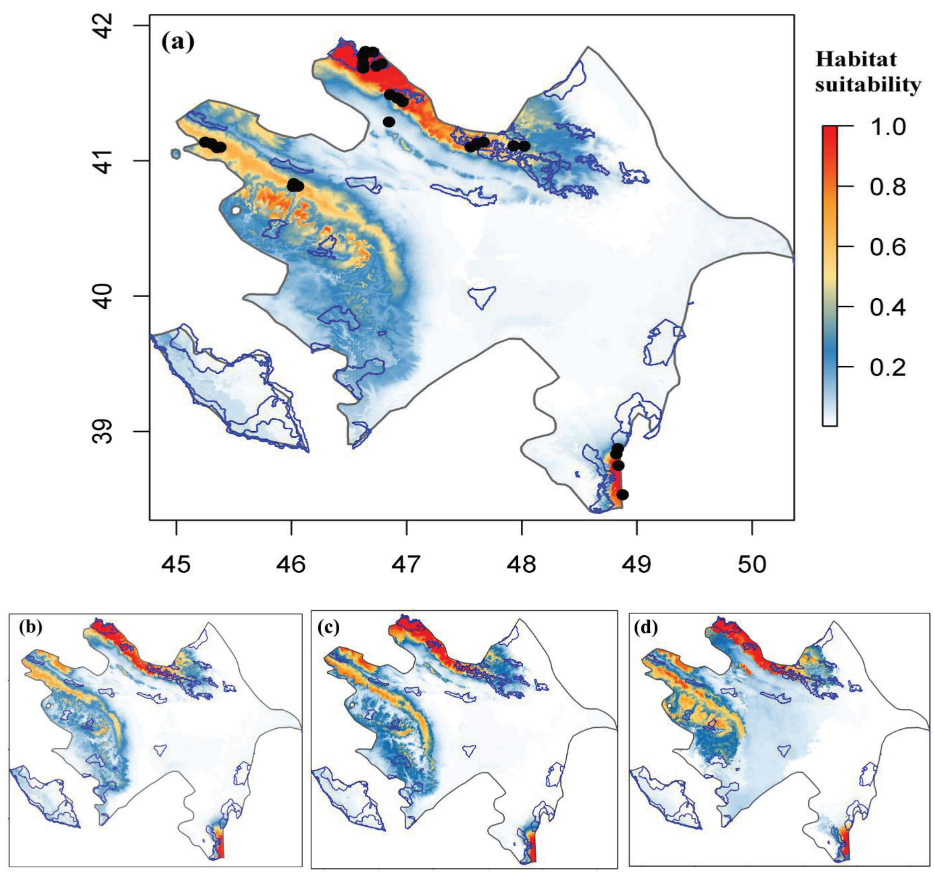

Figure 3. Predicted potential distribution of *Erigeron annuus* in Azerbaijan under current (a) and future (b - SSP1-2.6; c - SSP2-4.5; d - SSP5-8.5) climate scenarios. Field occurrences (2018–2024) are marked as points. Different colors and shades show predicted habitat suitability. Blue frames indicate protected areas.

Table 1. Main plant communities containing *Erigeron annuus* in Azerbaijan.

Natural ecosystem	Community	Herbaceous layer dominant species
Forest	*Carpinus orientalis* + *Acer campestris* (350 m a.s.l.)	*Phytolacca americana*, *Sambucus ebulus*, *Dryopteris filix-mas*, *Plantago major*, *Prunella vulgaris*, *Urtica dioica*, *Equisetum arvense*, *Lythrum salicaria*, *Dactylis glomerata*, *Ajuga genevensis*
	Quercus petraea ssp. *iberica* + *Carpinus orientalis* (653 m a.s.l.)	*Prunella vulgaris*, *Rumex acetosa*, *Arum elongatum*, *Lapsana communis*, *Platanthera chlorantha*, *Poa nemoralis*, *Coronilla varia*
	Corylus avellana + *Fraxinus excelsior* (500 m a.s.l.)	*Equisetum arvense*, *Arum elongatum*, *Asperula odorata*
Meadow	*Daucus carota* + *Plantago major* (680 m a.s.l.)	*Phytolacca americana*, *Lamium album*, *Rumex crispus*, *Urtica dioica*, *Daucus carota*, *Cichorium intybus*, *Plantago major*, *Inula helenium*, *Heracleum pubescens*
	Achillea millefolium + *Trifolium repens* (1200 m a.s.l.)	*Lamium album*, *Rumex crispus*, *Urtica dioica*, *Daucus carota*, *Cichorium intybus*, *Plantago major*, *Hypericum perforatum*, *Mentha longifolia*, *Erigeron canadensis*, *Alopecurus ventricosus*, *Veronica anagalloides*
Caspian coast	*Xanthiumo-Amaranthetum* (-20 m a.s.l.)	*Daucus carota*, *Hordeum leporinum*, *Artemisia vulgaris*, *Persicaria lapathifolia*, *Amaranthus retroflexus*, *Erigeron bonariensis*
	Phytolacca americana + *Artemisia vulgaris* (-23 m a.s.l.)	*Acalypha australis*, *Alcea lencoranica*, *Polygonum nodosum*, *Persicaria lapathifolia*
Agricultural	Potato (*Solanum tuberosum*, 400 m a.s.l.)	*Solanum lycopersicum*, *Amaranthus retroflexus*, *Digitaria sanguineus*
	Nicotiana tabaccum Z. (275 m a.s.l.)	*Solanum nigrum*, *Amaranthus spinosus*
	Corylus avellana Z. (660 m a.s.l.)	*Prunella vulgaris, Trifolium campetre, Inula helenium, Alcea rugosa, Amaranthus retroflexus*

(0.6402), our field works showed that the species is still rare in these districts, suggesting that climatic potential does not yet fully translate into realized distribution, likely due to biotic interactions, dispersal limitations, or local ecological constraints. Kur-Araz lowland and the Nakhchivan Autonomous Republic showed very low suitability (<0.05), consistent with the absence of field records in these areas.

Future potential distribution. According to the model predictions (2081–2100 periods) indicate that the potential distribution of *E. annuus* in the country is expected to be mainly in the districts of the northwestern and southern parts of Azerbaijan with relatively humid climatic conditions. Under all future climate scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5), the highest habitat suitability for *E. annuus* is predicted in Zagatala–Balakan districts and Lankaran lowlands, which represent the most humid parts of the country. These areas are characterized by abundant precipitation and moderate annual temperature variation, which is very close to the ecological requirements of the species.

In the northwest part of the country, areas of high climatic suitability largely overlap with existing protected areas (Shahdag National Park, Zagatala and Ilisu State Nature Reserves). These areas encompass extensive mountain forest ecosystems that are expected to remain suitable habitat for the distribution and long-term survival of *E. annuus* under future climate conditions. At the same time, the Hirkan and Gizilaghaj National Parks in southern Azerbaijan, situated in the humid Lankaran–Astara lowlands, are predicted to retain suitable environmental conditions, providing stable habitat for the species even under high-emission scenarios.

Moderate climatic suitability for the distribution of the species is predicted to be mainly on the western slopes of the Lesser Caucasus, especially in the regions of Gazakh-Tovuz and Ganja-Dashkasan zones. The model results indicate that protected areas in these areas (Goygol National Park, Shamkir State Nature Sanctuary, and others) and surrounding protected forest belts are expected to be prospectively suitable areas for the long-term distribution range of the species. Less suitable habitats are also preserved in the Turyanchay State Nature Reserve, located in the central part of the foothills of the Greater Caucasus, especially under the SSP5-8.5 scenario. These projections indicate a possible gradual expansion of suitable areas towards the foothills and mid-mountain zones, while in the lowland areas, a further decrease in habitat suitability is predicted in SSP1-2.6 and SSP2-4.5.

In contrast, the potential distribution of the species in Absheron, Kur-Araz lowland and the Nakhchivan AR is predicted to remain unfavorable in terms of suitable climatic conditions, with mean suitability values below 0.05. These regions, characterized by high temperatures and limited precipitation, are considered unfavorable for the establishment and spread of *E. annuus*. Even under the most optimal climate scenario (SSP1-2.6), no significant increase in habitat suitability is observed across these areas.

Overall, future projections demonstrate a clear high ecological stability of *E. annuus* in the humid regions of Azerbaijan. Model results show that some of the areas considered most suitable for the species overlap with existing reserves. This highlights the important role these protected areas will play as potential habitats for species to survive in the face of climate changes. From a biodiversity conservation perspective, these results highlight that although *E. annuus* is a widespread invasive plant, its long-term survival in the country will depend on the preservation of humid habitats in the mountainous and coastal forest zones of the country.

Field surveys revealed that *E. annuus* invasive species is distributed in the western, northwestern, and southern regions of Azerbaijan, from the plains to the middle mountain belt. However, as a result of assessment of the frequency, activity and abundance of the species, it was found that the distribution of the species is sparser in the northwestern part in contrast to the southern and western districts (Tab. 1). One of the main reasons for this is that the Greater Caucasus region borders the Russian Federation and Georgia. It is assumed that these plants are introduced into the natural phytocenoses of the region by humans from neighboring countries, either intentionally or accidentally [Abdiyeva, 2019]. Since the Greater Caucasus is the original area of penetration of the species into Azerbaijan, this explains its wider distribution here. The species occurs mainly in agrophytocenoses (roadsides and disturbed lands). However, in recent years its distribution range has expanded and has gradually spread to forest ecosystems of the lower and middle mountain belts, especially forest edges. This pattern is consistent with findings in other temperate regions, where edge habitats serve as corridors for the invasion of invasive species into more natural ecosystems [Dukes, Mooney, 1999; Pyšek et al., 2012].

In the southern part of the country, especially in Lankaran, there is a noticeable discrepancy between the recorded abundance of the species and the climate suitability predicted by the model. Although MaxEnt modeling for these areas indicates high potential suitability for the species, actual populations remain sparse. These differences are quite common in invasion ecology and may be due to limited distribution of the species, resistance of native plants, or small-scale habitat conditions [Gallien et al., 2010]. This suggests that although the humid climatic conditions of the southern part of the country are favorable for the spread of the species, *E. annuus* has not yet fully established itself there and continues to lead the Greater Caucasus in terms of realized distribution.

Future projections under SSP1-2.6 and SSP2-4.5 scenarios also indicate that suitable habitats for *E. annuus* will be concentrated mainly in the northwestern regions and humid zones of the south, while the lowlands (Absheron, Kura-Araz lowland, etc.) and the Nakhchivan Autonomous Republic will have minimal climatic suitability for the species' spread. This highlights the importance of climatic factors in shaping the potential distribution areas of invasive species, while also emphasizing that the invasion is limited by ecological and dispersal factors [Thuiller et al., 2005; Early & Sax, 2014].

The findings from this study have significant implications for management and monitoring of biodiversity of Azerbaijan. This will support the early detection and control of *E. annuus* in southern districts (Lankaran) and continue future monitoring in the Greater Caucasus to assess ecological impacts on native plant communities. Overall, combining field data with species distribution modeling provides a robust framework for understanding both current invasion patterns and potential future expansion of *E. annuus* in Azerbaijan.

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Erigeron annuus **(L.) Desf. (Asteraceae) növünün Azərbaycanda yaşayış mühitinə uyğunluğunun və invaziya riskinin modelləşdirilməsi: cari və gələcək potensial yayılma**

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Erigeron annuus növünün bioloji invaziyaları dünya üzrə bir çox ekosistemlərin biomüxtəlifliyinə təsir göstərə bilər. Bu növ yüksək toxum istehsalı, sürətli böyümə və güclü ekoloji uyğunlaşma qabiliyyəti vasitəsilə yerli bitki örtüyünü tamamilə dəyişdirməyə qadirdir. Bu tədqiqat Azərbaycanda *E. annuus* növünün yayılması, fitosenotik tərkibi və ekoloji mühiti barədə ilk ətraflı elmi tədqiqatları təqdim edir. 2022–2024-cü illərdə Azərbaycan Respublikasının şimal-qərb, qərb və cənub bölgələrində aparılmış çöl tədqiqatlarına əsasən, *E. annuus* düzənlikdən dağ meşələrinə qədər müxtəlif yaşayış mühitlərində rast gəlinir. *E. annuus* növünün ən yüksək bolluğu və aktivliyi şimal-qərb rayonlarında (Balakən, Zaqatala, Qax) qeydə alınmış, burada növ əsasən çəmənlik və meşəkənarı vegetasiyada üstünlük təşkil etmişdir. Növün yayılmasının modelləşdirilməsi (MaxEnt) yüksək proqnoz dəqiqliyi göstərmişdir (AUC = 0.95) və növün yayılmasını müəyyən edən əsas iqlim faktorları kimi ən isti dövr ərzində yağıntı miqdarı və illik yağıntı müəyyən edilmişdir. Cari uyğunluq xəritələri göstərir ki, Azərbaycanın şimal-qərbindəki rütubətli rayonlar ən əlverişli yaşayış mühitləridir, aşağı ərazilər və quraq rayonlar isə növün yayılması üçün əsasən əlverişsizdir. Gələcək proqnozlar (2081–2100) göstərir ki, SSP1-2.6, SSP2-4.5 və SSP5-8.5 ssenarilərinə əsasən Böyük Qafqazın cənub hissəsindəki rütubətli ərazilər və Lənkəran düzənliyi, eləcə də orada yerləşən qorunan ərazilər əsasən davamlı yüksək uyğunluğu nümayiş etdirir. Nəticələr göstərir ki, *E. annuus* növünün indiki yayılma ərazilərində sabit populyasiyalar qorunacaq və bu, yerli bitki qruplaşmaları üçün uzunmüddətli təhlükə

yarada bilər. Bunu nəzərə alaraq, effektiv idarəetmə strategiyaları ekoloji cəhətdən həssas ərazilərdə erkən aşkarlama və nəzarət üzərində cəmlənməlidir.
Açar sözlər: *bioloji invaziya, iqlim dəyişiklikləri, MaxEnt, fitosenoziya, növün yayılmasının modelləşdirilməsi*

Моделирование потенциального распространения и риска инвазии *Erigeron annuus* (L.) Desf. (Asteraceae) в Азербайджане

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Биологическая инвазия *Erigeron annuus* оказывает влияние на биоразнообразие многих экосистем мира. Этот вид способен трансформировать местную растительность за счёт высокой семенной продуктивности, быстрого роста и высокой экологической адаптивности. Данное исследование представляет собой первое подробное изучение распространения, фитосоциологического состава и экологической ниши вида в Азербайджане. По данным полевых исследований, проведённых в 2022–2024 гг. в северо-западной, западной и южной частях страны, *E. annuus* встречается в разнообразных местообитаниях – от низменностей до горных лесов. Наибольшая плотность и активность *E. annuus* зафиксированы в северо-западных районах Азербайджана (Балаканский, Загатальский, Гахский), где вид доминирует преимущественно в луговой и лесостепной растительности. Моделирование распределения видов (MaxEnt) показало высокую точность прогнозов (AUC = 0.95) и определило основные климатические факторы, влияющие на распространение вида: осадки в самый тёплый квартал и годовое количество осадков. Карты текущей пригодности среды показали, что наиболее подходящими местообитаниями являются влажные районы северо-западного Азербайджана, тогда как низменные и засушливые районы в основном непригодны для распространения вида. Прогнозы на будущее (2081–2100 гг.) по сценариям SSP1-2.6, SSP2-4.5 и SSP5-8.5 показали, что влажные районы южного Большого Кавказа и Лянкяранской низменности, а также расположенные здесь охраняемые территории, сохраняют высокую пригодность для вида. Эти результаты свидетельствуют о том, что текущие районы распространения *E. annuus* будут поддерживать стабильные популяции и представляют долгосрочную угрозу для местных растительных сообществ. Эффективные стратегии управления должны, таким образом, сосредоточиться на раннем выявлении и контроле в этих экологически чувствительных зонах.
Ключевые слова: *биологическая инвазия, изменение климата, MaxEnt, фитосоциология, моделирование распространения видов*