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DISTRIBUTION OF *AMBROSIA ARTEMISIIFOLIA* (ASTERACEAE) INVASIVE PLANT SPECIES IN AZERBAIJAN (SOUTH CAUCASUS)

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Abstract

Plants with an alien native range are today a serious problem for local floras. Invasive plants pose a threat not only of an ecological nature; also many of them hybridize with native plants and also cause allergic reactions in humans. In recent years, an increase in the activity of invasive plants has been observed in the world flora, including the flora of Azerbaijan. Researchers emphasize that climate change is one of the factors in this process. In comparison with previous years, an increase in the activity of the invasive species *Ambrosia artemisiifolia* L. (Asteraceae) in Azerbaijan has been established. In this study, the modern habitats of *A. artemisiifolia* in the country were studied, plant communities with the participation of the species were identified, and ecological niche models were created to represent the potential distribution of this species in the territory of Azerbaijan. These results indicate that predictive modeling can be an important resource for early detection of the aggressiveness of potentially invasive species, which will play a positive role in preventing their undesirable spread and conserving biodiversity. Future predictions were made based on the MRI-CGCM3 (MG) scenario for four representative concentration pathways (RCPs) based on Intergovernmental Panel on Climate Change (IPCC). The main findings of the study are that *A. artemisiifolia* is now beginning to invade the forest and grassland ecosystems of Azerbaijan.

Key words: Plant invasion, Ecological niche modelling, Natural ecosystems, Conservation.

Introduction

Invasive alien species (IAS) are known to be one of the main causes of the decline in the biodiversity and floristic and faunistic gene pool of local ecosystems, as well as having a negative impact on sectors of the economy (agricultural, etc.) and human health (Barrett & Husband, 1989; Froud-Williams, 1997; Pimental *et al*., 2001; Richardson & Pysek, 2006; Palmer & Nursey-Bray, 2007). Introduction of IAS into natural and semi-natural communities can lead to significant changes in ecosystems or their complete transformation (Elton, 1958; Reichard & Hamilton, 1997; Simberloff, 2011; Sax & Brown, 2000; Meekins & McCarthy, 2001; Réjmánek *et al*., 2000). In the world practice of effective prevention of the spread of IAS, first of all, it includes the creation of various databases (Global Naturalized Alien Flora (GloNAF); Global Invasive Species Database, (GISD); Hulme *et al*., 2009; Lambdon *et al*., 2008), as well as ecological and geographical modeling of niches, which allows the potential distribution of biological objects to be determined with high accuracy (Nix, 1986; Solano & Feria, 2007; Suárez-Mota *et al*., 2016).

The ecological niche model (ENM) is currently one of the most widely used methods for predicting the potential spread of IAS (Guisan & Thuiller, 2005; Barve, 2011). The Maxent (maximum entropy) approach of the ENM is commonly used by scientists in conservation biology, ecology, and evolution research (Kurpis, 2019; Kariyawasam *et al*., 2019). Various mathematical and statistical aspects make the MaxEnt modeling approach well-suited for ENM. In recent years, researchers have begun to predict the distribution of invasive species in the Caucasus region (Pshegusov, 2020). For Georgia, in the South Caucasus, predictions have been made for several invasive species in the country (Slodowicz *et al*., 2018; Thalmann *et al*., 2014). The study on plant invasions started in Azerbaijan a few years ago, and currently the focus is on identifying and studying the phytocenotic role in the areas of discovery (Abdiyeva, 2019; Abdiyeva *et al*., 2023). Along with the research of phytocenotic features of invasions, we also aim to use ENM to predict the potential distribution of IAS in Azerbaijan in order to control the spread of IAS in the country (Abdiyeva *et al*., 2021).

Ambrosia artemisiifolia L. (Asteraceae) is an annual herb with a North American native range (Lambdon *et al*., 2008). In Europe, this plant species was accidentally introducedin the 18th century, along with soil and seed agricultural material delivered from North America (Brandes & Nitzsche 2006; Bullock *et al*., 2012). Researchers who studied the biological and phytocenotic characteristics of the species in the local floras of Western and Eastern Europe noted that the activity of *A. artemisiifolia* in Europe began to increase significantly in the middle of the 20th century, and one of the main reasons for this was climate change (Brandes & Nitzsche, 2006; Bullock *et al*., 2012). The first outbreaks of *A. artemisiifolia* appeared in 1918 in Russia; in the North Caucasus, the species was discovered in 1930 (Vinogradova *et al*., 2010). From the North Caucasus the plant migrated to Transcaucasia. In Azerbaijan, *A. artemisiifolia* was discovered in the middle of the 20th century in areas located on the border with Georgia (Akhundov, 1961). Therefore, the introduction of *A. artemisiifolia* into Azerbaijan most likely originated in Georgia, a neighboring country situated in the South Caucasus contact zone. Transference of *A. artemisiifolia* from Georgia occurred with fruits, which could have been brought with seed, and food material, on the wheels of vehicles, on the fur/wool of transported livestocks, with water flows and wind from the territory. In local ecosystems, *A. artemisiifolia* spread naturally - by water flows (mudflows, river network), wind flows, with littered waste and on animal fur.

A. artemisiifolia has established itself in recent years and transformed the ecosystems of Azerbaijan. It was regarded as a common weed in the gardens and orchards of rural residents. Additionally, the species has become a malicious biological pollutant of agro-phytocenoses resulting in the decrease of the quality of the crop. The range of *A. artemisiifolia* was limited to the Steppe plateau botanical-geographical region in northwest Azerbaijan by the middle of the 20th century (Akhundov, 1961). It started to expand to the neighboring regions (the Greater Caucasus Mountains) around the beginning of the 21st century, where some of them came in touch with protected areas (Abdiyeva 2019; Abdiyeva, Litvinskaya 2023). Over the past ten years, this plant has started to spread to other districts of the country. Therefore, the objectives of our research were to study the phytocenotic role of *A. artemisiifolia* in local natural ecosystems, as well as the possible distribution of the species in Azerbaijan under current and future climatic conditions. This will give an idea of which areas of Azerbaijan, as well as which protected areas, are at particular risk of invasion.

Material and Method

Study area: Azerbaijan is one of the countries of the Caucasus region, which is located in the east of the South Caucasus, at the crossroads of Eastern Europe and Southwestern Asia, between latitudes 38°–42° N, and longitudes 44°–52° E. It is area is 86,600 km^2. The area is situated between the Caspian and Black seas. It is bounded by the Caspian Sea to the east, Russia to the north, Georgia to the northwest, Armenia to the west, Iran to the south and has a short border with Turkey to the northwest through the Nakhchivan. The great geopolitical significance of Azerbaijan's position once derived from caravan routes connecting distant countries of the West in ancient times, as well as the famous Silk Road stretching from China to Europe. Azerbaijan is mainly mountainous country, and it is surrounded by the Greater Caucasus (Bazarduzu mountain peak, 4466 m above sea level (asl)), Lesser Caucasus (Qamishdag, 3724 m asl), and Talysh Mountains (Komurkoy, 2492 m asl). The Kur-Araz lowland, with plains and low mountainous reefs, is situated between the Greater and Lesser Caucasus and stretches to the Caspian Sea in the central-southern part of the country. Gobustan lies in the eastern part with its numerous mud volcanoes. Lankaran lowland is situated in the south-eastern part, stretching along the seacoast. The elevation changes over a relatively short distance from lowlands to highlands, between –27 meters below sea level up to 4466 (Museyibov, 1998). The complex natural conditions of the country form 11 landscapes. There are representatives of the ancient forest, boreal, steppe, xerophilic, desert, caucasian, as well as adventitious (alien) geographic types in the flora (Grossheim, 1940-1948). The climate of Azerbaijan is the Northern borders of subtropical climate zone. The high mountain plays an important role in preventing cold air masses coming from the north, making the air condition colder in the northern slopes and relatively mild in the southern slopes. Eight out of 11 main climate types are represented in the country (Museyibov, 1998). These are semidesert and dry steppe, moderately warm climate with dry winters, moderately warm climate with dry summers, cold climate with dry winters, cold climate with dry winters, temperate warm climate with equal precipitation, cold climate with rains in all seasons and mountain tundra climates.

There are 44 Protected Areas (PA) organized on the territory of Azerbaijan to preserve the biodiversity of the country (www.eco.gov.az). The PA covers 8,93km2, which is 10.31% of the country's territory. The main protected areas are concentrated along the Caspian Sea (Samur-Yalama, Absheron, and Gizilagach National Parks), in the Greater Caucasus (Shahdag National Park, Zagatala and Ilisu State Nature Reserves), in the Lesser Caucasus (Goygol National Park and Eldar Pine State Nature Reserve) and in Talysh (Hirkan National Park). The global (Protected Planet, 2014-2024) data sources provide information about 35 of the 45 PA. Since it was not possible to obtain information on the territories covered by the remaining protected areas, we were only able to use 35 PA for the analysis in the study.

Data collection: Data on the past and current distribution of *A. artemisiifolia* were extracted from the literature, herbaria, and our field surveys. To identify current distribution areas of *A. artemisiifolia* monitoring was carried out throughout the territory of Azerbaijan in the period 2012-2021. Field studies were carried out in various types of habitats: anthropogenic (settlement, garden, park, farm, railways, rural roads, highways), semi-natural (abandoned sites connecting anthropogenic and natural areas) and natural (meadow, forest, pond, riverbank, etc.). In total, 277 distribution records were collected and used in our ecological niche modeling. Herbarium entries collected during field works are stored in the Herbarium Foundation (BAK) at the Institute of Botany of the Ministry of Science and Education of the Republic of Azerbaijan. Species abundance is determined using Braun-Blanquet scale (Braun-Blanquet, 1964).

Ecological niche modeling: The ecological niche modeling was performed using the species distribution modeling (SDM) approach with the Maximum Entropy Method (Maxent) (Phillips *et al*., 2006;). We used "dismo" package of "R" software (R Core Team, 2019). The current climate conditions (Fick *et al*., 2017; http://worldclim.org/version2, accessed 2017) and future climate projections (the resolution of 30 seconds of arc) (Hijmans *et al*., 2005; Hijmans *et al*., 2011; Hijmans, 2012; http://www.worldclim.org/cmip5_30s, accessed 2017) were downloaded from the WorldClim database, as a set of 19 bioclimatic variables. Future climate projections were constructed based on Scenario MRI-CGCM3 (MG) (Yukimoto *et al*., 2012) for 4 representative concentration pathways (RCP 2.6; 4.5; 6; 8.5) from the Intergovernmental Panel on Climate Change (IPCC), which is part of simulations in the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Meinshausen, 2011; IPCC, 2014). First, we analyzed the importance of all bioclimatic variables for the probability of species occurrence and selected the most sensitive climate conditions to variation in the distribution. Ultimately, 11 climatic variables (Bio 1; 6; 7; 9; 11; 12; 14; 15; 17; 18; 19) were used as input data. To evaluate the predictive accuracy of the model, we selected the receiver operator characteristic (ROC) by the area under the curve (AUC) statistical test (Hirzel *et al*., 2006; Lobo *et al*., 2008). Finally, we overlaid the shapefile of Azerbaijan and its protected areas. Shapefiles of protected areas were downloaded from the Protected Planet website (Protected Planet, 2014-2024) and shapefile of the country from DIVA-GIS repository (DIVA-GIS, 2017). The protected areas represented with blue lines on the predicting maps.

Results

Modeling approach: The final model had the AUC value of 0.98, which indicated excellent performance of the model and high reliability of the results.

Before using the model to project the potential distribution of *A. artemisiifolia*, we assessed how well the model could predict occurrence of the species. Firstly, we analyzed all bioclimatic variables in order to select the necessary climate determinants. We then created a model using only the combinations of bioclimatic variables that best predicted the species' occurrence (Table 1). While all variables had corresponding probability percentages, some made more significant contributions to the model.

Phenological observations and habitat studies of *A. artemisiifolia* in the study area indicated that temperature factors and precipitation affected its distribution equally, as indicated by the highest percentage contributions of Bio6 (34.3%), Bio9 (17.1%), Bio14 (23.8%), and Bio19 (13.4%) (Table 1). The estimated relative contributions of environmental variables to the model for IAS were generally consistent with field observations of these species in nature.

Current distribution range: During field surveys (2012-2021) on the territory of Azerbaijan, we discovered new distribution areas of *A. artemisiifolia*. It was more common in the north-west of Azerbaijan (Steppe plateau, Alazan-Ayrichay valley, Greater Caucasus Mountains). Research on the phytocenotic characteristics of plant species in the investigated area indicated that agrophytocenoses had a higher prevalence of *A. artemisiifolia* than natural habitats. It tends to grow more in lowland and foothills agricultural areas (Steppe plateau, Alazan-Ayrichay valley) at a height of 200–400 m above sea level. However, in the northwest part of the country (the Greater Caucasus Mountains), the species had already begun to expand into natural ecosystems such as forests and meadows in the lower and middle mountain belts (800–950 m asl) in recent years. In forest ecosystems, it was found in the herbaceous layer dominated by *Acer campestre*, *Corylus colurna*, *Acer laetum*, and *Quercus iberica* (Table 2).

Over the 7-8 years, the spread of *A. artemisiifolia* has been found in a small area of the southern (Lankaran lowland) and central (Absheron) coast of the Caspian Sea (within Azerbaijan). These new habitats of the species are very different from the habitats found in northwestern Azerbaijan. In all studied natural and anthropogenic territories of the north-west, the species was in satisfactory condition. On the contrary, in the eastern part it was found in the form of single, crushed individuals in summer cottages. We assessed the appearance of the species in these areas as an unintentional introduction of seed material into the soil. The soil was brought from the territory of the Azerbaijani part of the Greater Caucasus in order to enrich the sandy soil of garden plots, which was poor in microelements. However, at present *A. artemisiifolia* does not show activity or high vitality.

Current niche modeling: Current niche modeling showed that, under the current climate conditions, 21.5% of total area across the country was suitable for potential invasion by *A. artemisiifolia*. Within the respective total suitable area, 8.99% was highly suitable for *A. artemisiifolia* (Fig. 1a). The optimal environmental conditions were identified in lowland, foothill, and mountainous areas in the northwest of Azerbaijan.

Future niche modeling: *A. artemisiifolia* will likely continue to spread into the same areas that it has occupied in the past and the present, following the model analysis performed under future climatic conditions (Fig. 1b-e). Furthermore, the suitable habitat area will increase in the future, especially under scenarios RCP 4.5, RCP 6 and RCP 8.5 (Fig. 1c-e). The migration vector is expected to move from the northwest region of Azerbaijan to the central and western regions. According to RCP 2.6 and RCP 8.5, there is a possibility that the species will spread to new regions of the Greater Caucasus in the northeastern part of the country (Fig. 1b, e), and from there to regions that are in contact with the Caspian Sea coast. It is quite possible that this kind of migration will occur as a result of migrating birds and animals carrying achenes or because soil is richer in microelements is being transported from the country's northwest to the coast, where it will be used to introduce ornamental plants and fruit trees. Fertile soil is still being transported to Azerbaijan's lowlands in a similar way. Consequently, isolated individuals of *A. artemisiifolia* have occasionally been discovered in summer cottages along the coast, particularly in Absheron.

Thus, under emission scenarios RCP 2.6, 4.5 and 6.0, the potential geographic distribution of *A. artemisiifolia* will expand into the plains and foothills of the Greater Caucasus. From there, this species will spread into the flat regions of the northern part of the Lesser Caucasus, as well as into the foothill and low-mountain zones of the central part. Under the predicted conditions of RCP 6 and RCP 8., the emergence of *A. artemisiifolia* in the Caspian Sea coast will become possible.

Predicted distribution of target species in protected areas: The distribution of *A. artemisiifolia* in Azerbaijan raises a natural question: what is the threat of this plant intrusion into protected areas? To do this, we overlay maps of the predicted distribution of *A. artemisiifolia* onto a map of protected areas of Azerbaijan. This allowed us to determine protected areas already subjected to colonization by the species, as well as areas with the greatest risk of invasion in the future. The analysis showed that in front of some protected areas there was a high probability of the introduction of *A. artemisiifolia* (Fig. 1b-e). In particular, the analysis of model indicates a high risk (62%) for the Zagatala and Ilisu State Reserves. These protected areas are located in the zone of contact of current habitats of *A. artemisiifolia*. Therefore, the expected invasioncan be considered quite natural. Furthermore, it is quite possible that *A. artemisiifolia* species will spread to six more protected areas around the country. These are the following: Turyanchay and Garayazi State Nature Reserves; Korchay, Shamkir, Ismayilli, and Gabala State Nature Sanctuaries (Fig. 1c-e).

Table 1. Percentage contribution (%) of the most influential climatic factors in the current distribution of *Ambrosia artemisiifolia*.

Code of variables	Bioclimate variable	Percentage contribution (%)
Bio1	the annual mean temperature (°C)	3.3
Bio6	the minimum temperature of the coldest month (°C)	34.3
Bio7	the temperature annual range (the maximum temperature warmest month - the minimum temperature of coldest month) (°C)	2.9
Bio9	the average temperature of the driest quarter (°C)	17.1
Bio11	the average temperature of coldest quarter (°C)	2.4
Bio12	the annual precipitation (mm)	0.5
Bio14	the precipitation of driest month (mm)	23.8
Bio15	the precipitation seasonality (%)	1.7
Bio17	the precipitation of driest quarter (mm)	0.2
Bio18	the precipitation of warmest quarter (mm)	0.4
Bio19	the precipitation of coldest quarter (mm)	13.4

Table 2. The main composition of plant communities with the participation of *Ambrosia artemisiifolia* in the ecosystems of Azerbaijan.

Distribution area	Plant community	Species composition in the community (with Braun-Blankuet scale) on a model plot of 20x20 m
Natural phytocenoses		
The Greater Caucasus Mountains; forest; 850-950 m above sea level	*Acer campestre + Corylus colurna*	**Woody layer:** *Acer campestre* (4), *Acer laetum* (2), *Corylus colurna* (3), *Quercus iberica* (2), **Herbaceous layer:** *Ambrosia artemisiifolia* (3), *Equisetum arvense* (3), *Dryopteris filix-mas* (2), *Phytolacca americana* (2), *Lythrum salicaria* (2) *Plantago major* (2), *Prunella vulgaris* (2), *Urtica dioica* (1),*Sambucus ebulus* (1)
The Greater Caucasus Mountains; meadow; 800-870 m above sea level	*Daucus carota + Plantago major + Achillea millefolium*	*Ambrosia artemisiifolia* (3), *Daucus carota* (3), *Plantago major* (3), *Carum carvi* (2), *Lamium album* (2*), Rumex crispus* (2), *Phytolacca americana* (1), *Urtica dioica* (1), *Cichorium intybus* (1), *Salvia verticillata* (1), *Euphorbia seguiriana* (1)
Lankaran lowland; -20 m above sea level	In the forb groups of the coastal zone *Xanthium strumarium + Amaranthus retroflexus +Juncus acutus*	*Ambrosia artemisiifolia* (1*), Limonium mayeri* (2), *Convolvulus arvensis* (2),*Amaranthus spinosus* (2), *A. retroflexus (3), Juncus acutus* (2), *Xanthium strumarium* (3), *Daucus carota* (1*), Erigeron canadensis* (1), *Hordeum leporinum* (1), *Persicaria lapathifolia* (1), *Verbascum pyramidatum* (1)
Agricultural, semi-disturbed, disturbed phytocenoses		
Alazan-Ayrichay valley; 300-400 m above sea level	In the herbaceous layer of hazelnut orchards *(Coryllus avellana)*	*Ambrosia artemisiifolia* (3*), Trifolium repens* (3), *Alkekengi officinarum* (2), *Plantago major* (2),*Prunella vulgaris* (2), *Asparagus officinalis* (1), *Inula helenium* (1), *Erigeron annuus* (1), *Urtica dioica* (1)
Absheron; 10 m above sea level	In summer cottages, in the herbaceous layer of an orchard	**Woody layer***:* *Ficus carica* (3). **Herbaceous layer***:* *Ambrosia artemisiifolia* (1*), Chenopodium hybridum* (2), *Urtica dioica* (2), *Vitis vinifera* (2)
Steppe plateau; 200-300 m above sea level	In littered and abandoned areas in forb groups	*Ambrosia artemisiifolia* (2*), Urtica dioica* (2), *Amaranthus retroflexus* (2), *Convolvulus arvensis* (3)

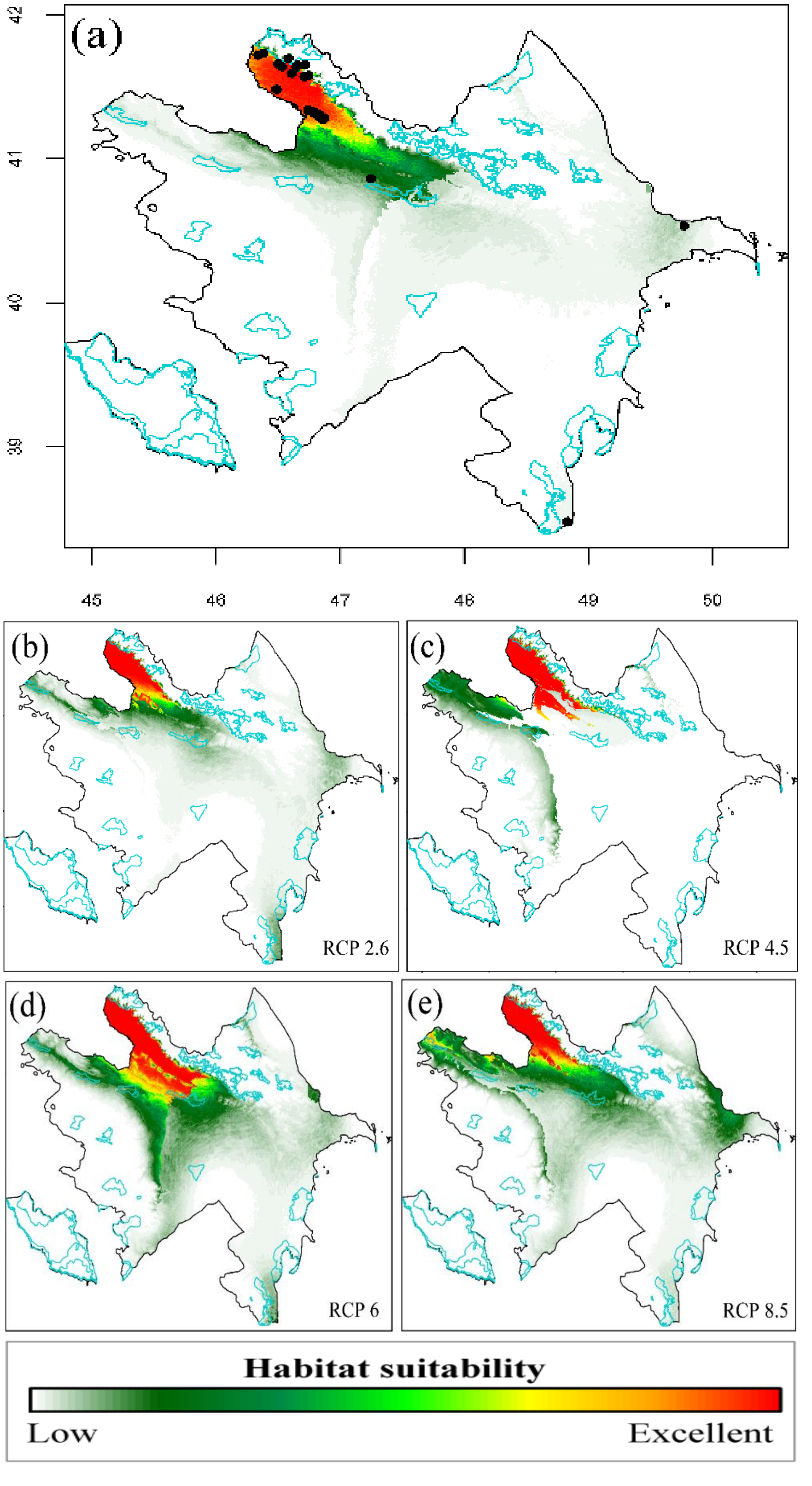

Fig. 1. Predicted potential distribution of *Ambrosia artemisiifolia* in Azerbaijan, based on current (a) and future (b - RCP 2.6; c - RCP 4.5; d - RCP 6; e - RCP 8.5) climate scenarios. The prediction map for current conditions agreed with occurrences recorded in field surveys (2012-2021). Different colors and shades show predicted habitat suitability. Blue frames indicate 35 Protected Areas (ef. text for details).

Discussion

Due to their high adaptability, IAS can occupy new habitats and ecological niches that differ from their natural ranges (Petitpierre *et al*., 2012; Early & Sax, 2014; Wan *et al*., 2016). Climate change can create and expand suitable habitats for IAS (Vicente *et al*., 2013; Thalmann *et al*., 2014; Foxcroft *et al*., 2017). Therefore, modeling approaches that can predict the distribution of IAS in future habitats are of critical importance.

In this study, the current and future distribution of *A. artemisiifolia* in Azerbaijan was modeled for the first time at national scale using the Maximum entropy modeling approach in SDM. Maps of projections of the distribution of species showed that the species will penetrate from the northwest of Azerbaijan.

Mountain forest regions of Azerbaijan will be at the greatest risk of invasion, according to the projections. Most of the protected areas in Azerbaijan are located in mountainous parts of the country, and therefore, the target invasive species will experience stability since their current distribution range is in these areas. *A. artemisiifolia* is the most "unpredictable" species of the other invasive species of Azerbaijan. It is interesting to note that this invasive plant, which was accidentally introduced about 60 years ago, is displaying high aggressiveness in its current narrow area in the foothills region of Azerbaijan (Shaki-Zagatala economic-geographical region), but for some reason, has not yet expanded beyond this area. Habitat predictions under future climate scenarios showed that its distribution will not remain stable in the foothills region as the habitat there will become less suitable, with increasing CO_2 content and air temperature, reducing the range of *A. artemisiifolia*, while its occurrence may rise in the lower and possibly middle mountain belts. However, the prediction maps showed that *A. artemisiifolia* will not have a tendency to expand its range overall in Azerbaijan. This interesting finding makes it necessary to consider the biological and ecological characteristics of *A. artemisiifolia*. In the past, *A. artemisiifolia* was found exclusively as a weed along narrow water channels, on abandoned farms, and in areas with agricultural activities (garden plots, tea, tobacco, and cotton plantations), where it formed stable groups. Over the past three years, we have observed occurrence of *A. artemisiifolia* in native forest and meadow communities, such as *Acer campestre* + *Corylus colurna*+ and *Daucus carota*+ *Plantago major* +*Achillea millefolium*. The model applied in this study revealed how actively the invasive species will spread under current and future climate scenarios. Therefore, potential habitats for IAS should be monitored in both protected and unprotected areas. The work should include field surveys for *A. artemisiifolia*, campaigns to raise awareness of these species among the local population, and studies on the bioecological, phytocenotic and reproductive characteristics of the species. There are already 70 species of IAS in Azerbaijan, 10 of which are the most dangerous form, transformers (Abdiyeva, 2019). The ecological niche and species distribution modelling approach developed here can be applied to other invasive species in Azerbaijan, and to IAS in other countries, in future research to resolve this global issue.

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