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ORIGINAL RESEARCH

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The Ecological Niche of *Pistacia Vera* L. (Anacardiaceae) in Central Asia: A Comprehensive Tool for Agromeliorative Planning

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ABSTRACT

A model of the ecological niche of the nut fruit *Pistacia vera* has been developed based on known locations in Central Asia and an analysis of abiotic environmental variables in order to map out the area of optimal conditions for both the wild and domesticated forms. The model reveals a much larger area of suitability for the species than it presently occupies. The list of key variables and their optimal ranges are compared with the known values of those which have been gathered from experiments on the ground and which are described in the available literature. Most of the optimal values modeled for the key variables appear to resemble the known experimental ranges. The meaning and impact of most of the key variables in relation to the species' life cycle are found in the physiological and ecological peculiarities of *P. vera*'s development at different stages as described in the literature. Unexplained variables may imply a gap in our knowledge of the pistachio and its interrelations with the environment; and point the direction of further study of the biology of the pistachio. The value of the model is the potential application of the results along with existing practical recommendations regarding pistachio cultivation in order to establish guidelines regarding the conservation and commercial cultivation of *P. vera* in Kazakhstan.

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Introduction

The genus *Pistacia* L., of the family Anacardiaceae, includes from 10 to 20 species depending on the taxonomic study. The genus is distributed mainly across the tropical and subtropical regions of the northern hemisphere and consists of both evergreen and deciduous species with shrub and/or tree-like growth habits (Khanazarov et al., 2009). The genus is believed to have originated in Central Asia and Southwest Asia, and *Pistacia vera* is the only cultivated and economically important species.

Genus *Pistacia* is native to the arid zones of Central Asia. The species was introduced into Mediterranean Europe by the Romans and later extended westward from its center of origin (Al-Saghir, 2009). The Central-Asian origin of *P. vera* is confirmed by A. Sorokin (2018), who analyzed the recent distribution of the native and the domesticated forms of pistachio and concluded that the native forms had persisted in Central Asia, whereas the Middle East pistachio is a descendant of domesticated plants. The northern border of the area of the species runs along the Karatau Mountains in Southern Kazakhstan, Talass, and the Kyrgyz Alatau Mountains in Kyrgyzstan (Khudaikulov, 2016). The southern border of the area of the species is limited to the northern spurs of the Hindukush and the Paropamise (Afghanistan) and the Khorasan foothills (Iran). The western border is delineated by the Western Kopet-Dag and the eastern one reaches as far as the Vanch Ridge in the Pamir Mountains (Khudaikulov, 2016, Zverev et al., 2017a). This geographical area represents a large and diverse region where the wealth of the genetic resources of *P. vera* exists.

The wild pistachio populations in Central Asia are the remnants of previously extensive forests that were cut down many decades ago; those forests are believed to have covered over two million ha during the Stone Age (Khanazarov et al., 2009). The pollen of the genus *Pistacia* is known from the Paleogene of Talass Alatau in the (Karmysheva, 1982). The presence of the Anacardiaceae family is reported in Kazakhstan from the Lower and Middle Eocene (Kornilova, 1966); and the representatives of the genus *Pistacia* appeared first in the Middle Oligocene (*Pistacia oligocenica*, ibid.) in the Turgay Depression. The Central Asian origins of the pistachio is thus supported by the historical and paleontological evidence.

P. *vera* is a drought and saline-tolerant species (Gijón et al., 2011). *P. vera* from Central Asia can be generally characterized as a species tolerant of both heat and cold (Khanazarov et al., 2009)**.** In the recent past (Khanazarov et al., 2009), *P. vera* has been found at an altitude of less than 450 m above sea level. However, due to the over-harvesting of wood near cities, it is no longer found at these lower elevations. In addition to being cut down for various products and timber, pistachio forests have been cleared and ploughed for the planting of other crops. Fires and overgrazing have added to the deforestation and also the limited regeneration of the natural stands, which have in turn led to increased wind and water erosion and a resulting increase in the size of ravines and the disappearance of small streams. Unfortunately, destruction of one type or another continues today in many unprotected regions across Central Asia, as well as in northern Afghanistan. As such, *P. vera* which is endemic to these regions remains at risk of significant genetic erosion.

The goal of the modeling was to analyze a series of abiotic variables and to determine the envelope of each variable that describes the variability of pistachio adaptations. Another possible application of the model which has been developed is for the planning of pistachio farms in South Kazakhstan, as the model reveals a wide area as ecologically suitable for the planting and cultivation of *P. vera*. It was recently proposed (Baytullin et al., 2009) that reserves should be organized in order to protect the areas in Kazakhstan where wild pistachio grows; and our work could provide the tool for selecting the relevant areas, if the decision is made to do so.

Material and methods

Data on pistachio distribution were collected from the published literature (Alexeyev, 1963; Kamelin, 1979; Kordon, 1936; Kravchenko, 1963; Popov, 1979) and from our own field observations in South Kazakhstan. In total, 436 georeferenced points of *P. vera* registration were obtained and used to develop the model (Fig. 1).

Figure 1. Known distribution of *P. vera* in Asia. Yellow dots depict known georeferenced localities used to develop a model.

The modeling procedure used for the current study is based upon a procedure designed and tested with several other species (Malakhov, Chirikova, 2018; Malakhov et al., 2018). We mainly used locations from the supposed area of the species' native distribution. Additional ground points from Turkey, where the pistachio has been introduced and successfully bred, were added to the analysis as the region is geographically close to the supposed center of the species' origin. The analysis of environmental variables associated with this area may provide additional clues to ways of introducing the species to other Asian countries. Pistachio plantations in other countries more distant from the wild populations were not considered in this paper.

The following climatic data sets were applied to develop the current model: WorldClim (monthly temperatures and precipitation, solar radiation, vapor pressure); BioClim, a set of variables derived from WorldClim and meteorological stations (http:/www.worldclim.org); Global Potential Evapotranspiration (http:/www.cgiar-csi.org/data/globalaridity-and-pet-database); the Digital Elevation Model and its derivatives like exposition, slope, curvature, etc., computed with ArcGIS functions. The WorldClim and BioClim datasets and their applications in ecological modeling are well described (Booth et al., 2014; Hijmans et al., 2005). Global-Pet is an index combining transpiration and evaporation (UNEP, 1997).

Data on NDVI and Soil Water Index (SWI) were obtained from Copernicus Global Land Service (https://land.copernicus.vgt.vito.be/PDF/portal/Application.html#Home) and averaged monthly for 20 years and 12 years for NDVI and SWI respectively with QGIS functions.

We applied two basic rules to the selection of key variables: the rule of control points; and the rule of the variable's normal distribution. We applied three randomly selected sets of control points, each equal to 25% of the total of 436 ground points. Each control set was checked for consistency of points to the optimal range of each variable. If the consistency of two or three sets of control points to the optimal range of a given variable was higher than 70%, this variable was considered for further analysis. The next step in the validation of the importance of a variable was to check the value distribution of the variable within the total range of ground points. It can be hypothesized (Beaumont et al., 2005) that variables with normally distributed values may have an important influence on the distribution of the species. Variables that demonstrate skewed distribution may also be relevant. Variables with skewed distributions may be those that do not have a negative value, such as solar radiation; and those that have values between zero and one, such as vegetation indices. Where there is no clear pattern in the distribution histograms for a variable, that variable may be classified as irrelevant. Similarly, where the histogram is normally distributed but is truncated in one or both tails, the variable may also be rejected, as these graphs suggest that the species can tolerate other values of this variable that were not included in the species' climatic envelope. This may occur if the distribution records for a species do not cover its entire geographic range. (Beaumont et al., 2005). Variables passing both checks were used to calculate the model. The list of key variables with the optimal ranges for each variable is represented in Table 1.

The graphic representation of the model was computed with the Weighted Sum function in ArcGIS (Fig. 2).

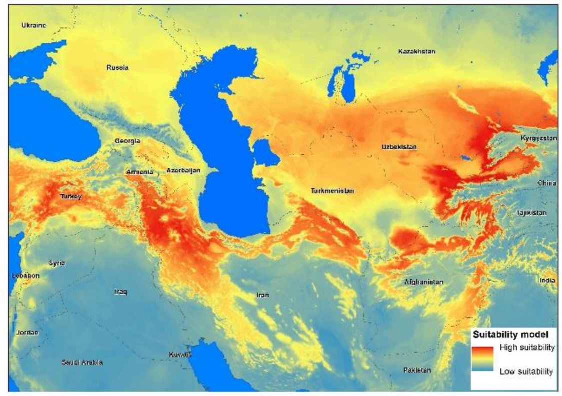

Figure 2. Model of suitability of habitat for *P. vera*.

Results and discussion

The model shows a significantly wider range of suitable conditions for pistachio than the species currently occupies. Possible reasons may be as follows:

1. The lack of modeling data describing biotic variables
2. The shrinking of the species' area due to natural causes and human activity.

Possible reasons for the pistachio area shrink were discussed above, those mainly attributed to human-induced changes due to pistachio forests cutting, overgrazing, etc. The lack of modeling data may include infra- and interspecific relations; the entire spectrum of biotic variables; and other factors that appear to be either difficult or indeed impossible to incorporate into the modeling procedure. The variable is suitable for analysis when it is formalized and geospatially coded, i.e. represented as a georeferenced grid with each cell having a unique value. In fact, any ENM or SDM model works with a very limited set of variables, having a distinct gap in the physiological, biochemical, nutritional (as well as many others) aspects of the existence of a living organism. This gap makes any developed model probabilistic since uncertainty will always remain. Nevertheless, abiotic variables are essential for any living species unable to survive beyond particular limits of the physical parameters. The envelope of the optimal ranges revealed by the model for key abiotic variables represents the very basic environment in which the species can succeed. As revealed by the model, the list of key variables and their optimal ranges for *P. vera* is given in Table 1.

Variable and unit	Optimal range
Aridity Index, dimensionless	0.21-0.54
Clay content, %	19.42-26
Soil density, g/cm^3	1.5-1.65
Annual Mean Temp (bio1), °C	7.7-15.2
Mean diurnal range (bio2), °C	12-14
Max Temperature of Warmest Month (bio5), °C	28.5-36
Min Temperature of Coldest Month (bio6), °C	-12 - -25
Mean Temperature of Wettest Quarter (bio8), °C	4.7-11.5
Mean Temperature of Driest Quarter (bio9), °C	18.2-25.6
Mean Temperature of Warmest Quarter (bio10), °C	19.3-26.6
Mean Temperature of Coldest Quarter (bio11), °C	-5.9 -+3.7
Annual Precipitation (bio12), mm	283-593
Precipitation of Wettest Month (bio13), mm	54-110
Precipitation of Wettest Quarter (bio16), mm	139-290
PET, April, mm/month	85-117
PET, May, mm/month	129-170
PET, June, mm/month	161-206
PET, July, mm/month	179-218
PET, August, mm/month	156-196
Precipitation, January, mm	28-64
Precipitation, February, mm	28-76
Precipitation, March, mm	44-103
Precipitation, April, mm	47-102
Precipitation, May, mm	25-82
Precipitation, December, mm	30-65
Relative air humidity, May, %	54-61
Relative air humidity, June, %	39-48
Relative air humidity, July, %	35-47
Relative air humidity, August, %	36-50
Relative air humidity, September, %	40-53
Solar Radiation, May, MJ m^{-2}	22282-23364
Solar Radiation, July, MJ m^{-2}	24975-27050
Solar Radiation, August, MJ m^{-2}	22653-25149
Maximal temperature, April, °C	14.2-21.7
Maximal temperature, May, °C	20-28
Maximal temperature, June, °C	25.4-33.6
Maximal temperature, July, °C	28.5-36
Maximal temperature, August, °C	27.6-34.8
Maximal temperature, September, °C	22.6-30.3
Mean temperature, April, °C	8.7-15.4
Mean temperature, May, °C	13.5-20.6
Mean temperature, June, °C	18.1-25.4
Mean temperature, July, °C	20.7-28.0
Mean temperature, August, °C	19.4-26.2
Mean temperature, September, °C	14.2-21.4
Mean temperature, October, °C	7.7-15.6
Minimal temperature, April, °C	3.2-9.2
Minimal temperature, May, °C	7.1-13.3
Minimal temperature, June, °C	10.6-17.2
Minimal temperature, July, °C	13-19.8
Minimal temperature, August, °C	11.6-17.9
Minimal temperature, September, °C	6.4-12.7
Minimal temperature, October, °C	1.0-7.6
Vapor pressure, April, kPa	0.63-1.05
Vapor pressure, May, kPa	0.83-1.15
Vapor pressure, June, kPa	0.88-1.22
Vapor pressure, July, kPa	0.9-1.31
Vapor pressure, August, kPa	0.79-1.21
Vapor pressure, September, kPa	0.61-0.99
Vapor pressure, October, kPa	0.53-0.81

Table 1. Key variables and optimal ranges for wild populations of *Pistacia vera.*

Analysis of the list of all the key variables shows the presence of distinct groups for the seasonal, climatic, and soil variables. The distribution of the key variables across the seasons reveals the prevalence of spring and summer (Fig. 3).

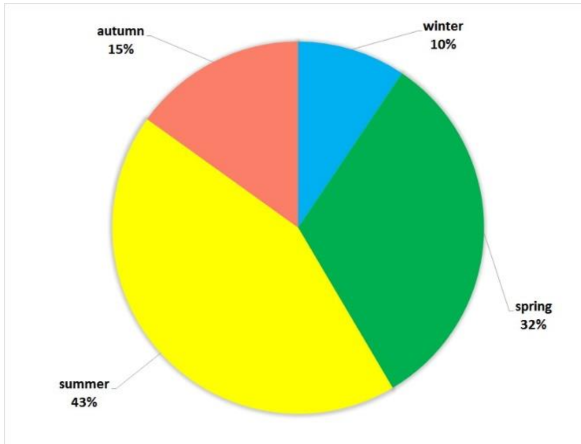

Figure 3. Percentage distribution of the model's key variables by season.

The general distribution of the wild pistachio in Kazakhstan is associated with the intrazonal belt of the mountain forests of the Western Tien-Shen (Gudochkin, Chaban, 1958). The area of the natural distribution of the wild pistachio in Southern Kazakhstan and Uzbekistan may be described as the northernmost and coldest subtropics (Chaban, 1941). Of all the variables, the maximum temperature across July and August shows the limit of the warmest temperature suitable for pistachio growth as well as the amount of solar radiation in the same months. The lack of summer precipitation among the key variables is evidence of a high level of adaptation on the part of the pistachio to extremely arid conditions. The relative air humidity and vapor pressure in the warm months are indicated as key variables. Though there are no direct indications of how those variables influence pistachio development, we presume that the humidity indicators show the suitability of the growing conditions during the hot months, as the benefits for the pistachio of summer cloud cover have been documented (Lovelius, 1979). Solar radiation is known to partially regulate air humidity (Swartman, Ogunlade, 1967) and vice versa, cloud cover being a limiting factor for the amount of solar radiation at the Earth's surface. Daily solar irradiance at the Earth's surface is a fundamental driving variable for the stimulation of the ecosystem in terms of carbon, water, and energy fluxes on local, regional, and global scales (Winslow et al., 2001). Within its natural range, pistachio may appear either as a tree or as a shrub, depending on exposition (Schepotiev et al., 1985). Trees are associated with low altitude (up to 750 m a.s.l) where they grow in seriozems in local depressions, like stream banks, ravines, etc. Trees grow to up to 4 meters in height. Under more arid conditions, related to southern expositions and gravel soils, pistachio grows as a shrub of 2-6 stems reaching as much as 3 meters in height. From such a distribution of pistachio life-forms, it becomes clearer that there is a relationship between the plant's wellbeing and environmental humidity.

The roots of the pistachio trees are more developed, being twice as long as the roots of brush pistachio (up to 3 meters as against 1-1.5 meters) (Schepotiev et al., 1985). In both cases, however, the main portion of the roots is distributed in the superficial soil horizon, as atmospheric moisture represents the main source of water for the species. The deficiency of summer precipitation, on the other hand, supports wind pollination in pistachio populations that appear to be restricted by additional humidity which makes the pollen heavier. The optimal range of the Aridity Index, which lies in the "semi-arid" diapason (UNEP, 1997), confirms the ecological plasticity of the species successfully introduced and cultivated in many areas far beyond the focus of its origin.

Precipitation is of great importance, according to the model, in winter and spring. The most obvious explanation of this temporal distribution of precipitation is that the precipitation of the cold and spring months provides an accumulation of water in the soil, later consumed by plants during the hot season (Rustamov, Kepbanov, 2012; Lovelius, 1979) when the water income from other sources is minimal. It has also been shown (Schepotiev et al., 1985) that the ratio of seeds germinating is 97% against the usual 30% if the seeds have been soaked in water for 24 hours before planting. This means that the spring precipitation in *quantum satis* may positively affect the well-being of pistachio populations, bringing about a drastic increase in the numbers of plants. However, excess water during the growth period may lead to more-or-less serious dysfunction in the pistachio (Kalayda, 1916). The sensitivity of pistachio to the extra humid environment could be a characteristic of the entire genus. It has been demonstrated (Verdú, García-Fayos, 1998) that, in *P. lentiscus*, excessive irrigation brings about a decrease in the final size of the fruit.

The range of temperatures in April as shown by the model resembles the temperature at the start of vegetation. An ambient air temperature of 8-12 C° has been reported as the trigger for launching vegetation (Rustamov, Kepbanov, 2012). Pozitive spring temperatures are of importance during flowering, as the flower buds are quite sensitive to low temperatures and demonstrate a high percentage of dead blooms if the temperature falls beneath 0 C° (Pakkish et al., 2011).

In our model, the range of the minimal temperature in the coldest month is optimal for pistachio, as the plant is known to withstand much lower temperatures, down to minus 40 C° (Zverev et al., 2017a). The species can tolerate long and moderately cold winters (Enfyadzhan, 1954) without significantly suffering. Moreover, the distinct chill period is of importance, since a lack of chill accumulation is usually accompanied by decreased yields (Benmoussaa et al.,2017). A warm winter may shift the timing of the developmental stages; cause irregular or delayed bud break; abscission of the floral buds; altered reproductive morphology; poor fruit set; and changes in vegetative growth.

Pistachios may be found growing on a diversity of soils across Central Asia, although most can be classified as different types of sierozem soils. Pistachios can also be found growing on the brown and light-brown carbonated soils of northern Kyrgyzstan and in the Pamir-Alay region higher than 1,600 m above sea level. These soils generally have a low salt content and low organic matter content (Khanazarov et al., 2009). The model demonstrated (Fig.4) that the predominating soil type for pistachio growth is lithosol, i.e., the kind of primitive gravelly soils that are limited in depth (down to 25 cm) by continuous coherent and hard rock (Kovda, 1973; FAO, 1974).

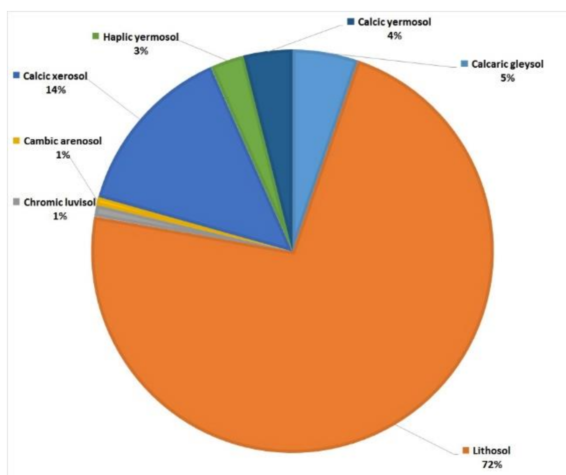

Figure 4. Distribution of known *P. vera* localities by soil types.

Of the remaining types of soil revealed by the model, the dominant cluster unites desert types of soil: yermosol and xerosol. Both types are characterized by calcic or gypsum horizon within 125 cm of the surface (FAO, 1974). The model shows a small contribution of soil types, developed in a semi-humid or humid environment (gleysol, luvisol and arenosol). The impact of the arid soil types is confirmed by the distribution of *P. vera* within the Köppen-Geiger climate zones (Fig. 5) (Kottek et al., 2006). Most of the area associated with pistachio has an arid nature with small summer precipitation.

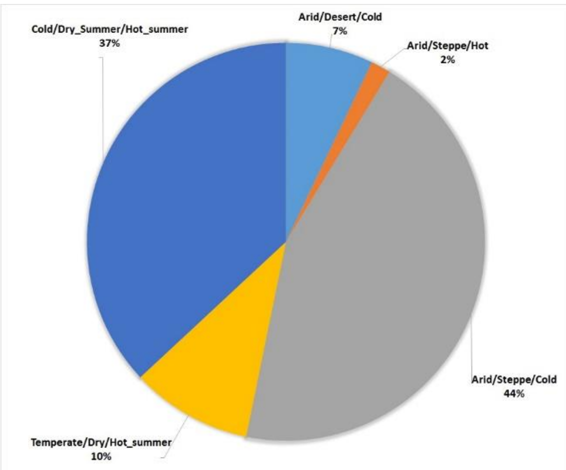

Figure 5. Distribution of known *P. vera* localities within Köppen-Geiger climatic zones.

Both the soil and climatic deflections from arid environments revealed by the model find an explanation in the series of Middle Eastern (Turkey) locations of *P. vera* involved in the modeling procedure.

The model is intended to reveal key environmental variables and optimal ranges for *P. vera;* and it demonstrates a close similarity between the results and the available data on the physiology and ecological preferences of the species. The optimal ranges of those variables are very close if not identical to the ranges obtained during study of the pistachio's life-cycle on the ground. Variables having no direct explanation or link to ground data may appear as the stimulus for developing further the study of the physiological characteristics of the pistachio related to, in particular, the relationship between air humidity and the biophysical and biological peculiarities of *P. vera*.

Apart from the theoretical aspects of ecological niche development, the model can become a geospatial base if a natural reserve is started or continued as a means of introducing pistachio cultivars for commercial purposes in Kazakhstan. The model shows a wider range of suitable areas for wild pistachio (Fig. 6) than may be supposed from the distribution of recently known localities.

The areas as depicted by the model as suitable for pistachio growth extend far to the north and west of the recently known locations of wild pistachio; and this means that the successful cultivation can take place of pistachio cultivars with irrigation and fertilization of the soils in plain areas distant from the natural mountain environments. Successful attempts to organize pistachio plantations are known from Uzbekistan, Tajikistan, and Turkmenistan, where orchards were founded before the Second World War (Schepotiev et al., 1985). In South Kazakhstan, the very first attempts to cultivate pistachio were undertaken in the twenty-first century during 2015-2016 (Fig. 6).

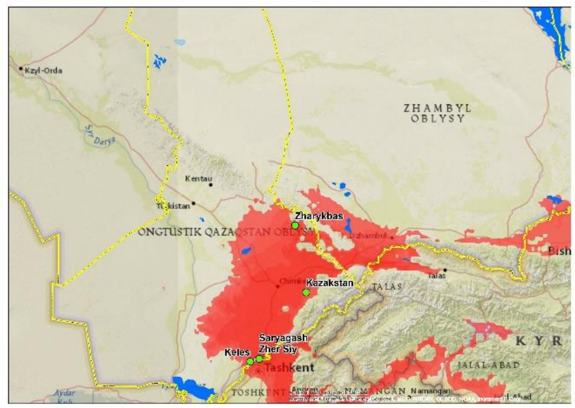

Figure 6. Distribution of suitable conditions in South Kazakhstan is shown in red. Green circles depict newly established pistachio farms.

Pistachio seeds were planted in open ground in Kazakhstan Village (580 m a.s.l.) and in Keles (940 m a.s.l.). In total, 97 trees were planted. More than 80% of the plants survived through to the second year. Stratified seeds were sown in soil containers in Zharykbas Village (630 m a.s.l.) (Fig. 6) where the survival rate was about 66%. An irrigated pistachio farm was set up in Zhemisty Village (shown as "Saryagash Zher Suy" at Fig. 6) where pistachio seedlings, grown from seeds taken in Tajikistan, Turkmenia, and Iran, were planted. Under irrigation, the survival rate of the plants was close to 98%. All the examples of the successful breeding of pistachio in South Kazakhstan fit the area of suitable conditions as shown by the model. Practical recommendations summarizing the various points of pistachio cultivation for Southern Kazakhstan were recently published (Zverev et al., 2017b). Local populations of pistachio, producing nuts of commercial quality, are also known in South Kazakhstan, so there is both a theoretical and practical background for establishing a brand-new branch of agriculture: the commercial cultivation of pistachio nuts in Kazakhstan.

Conclusions

Ecological niche modeling (and its mechanistic approach, species-distribution modeling) is a rapidly developing area of geospatial science. However, the modeling of ecological niches for living species requires a fair expertise in species biology. Having a good knowledge of the species physiology and biology, one can interpret the results provided by the model and identify possible gaps in the information. The results of the modeling may provide further and deeper insight into the species biology and the species relation to the environmental variables, an aspect which might remain hidden when the modeling is being performed mechanistically. The model of the ecological niche for *P. vera* revealed a wider suitable area than the species recently occupies. It may be explained via past fires and the cutting down of pistachio rather than climate change; and thus the results of the modeling provide good-quality information for informing further decision-making regarding expanding pistachio cultivation in Kazakhstan. The results of the current study may be applied directly in choosing a suitable area for planned pistachio orchards; and, along with existing recommendations on the cultivation of the nut-fruit, represent a reliable basis for a commercial pistachio enterprise in Kazakhstan.

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Conflicts of interest

Authors claim no conflict of interests with any person and/or organization.

References

Alexeyev, V.P. (1963). Pistachio - *Pistacia vera*. *Subtropical cultures, 3,* 21-23.

Al-Saghir, M.G. (2009). Evolutionary History of the Genus *Pistacia* (Anacardiaceae). *International Journal of Botany*, *5*(3), 255-257.

Baytullin, I.O., Kurochkina, L.Ya., Ogar, N.P., Rachkovskaya, E.I. (2009). Rare and unique plant communities of Kazakhstan, protection and rational use measures. *Izv. ASRK, ser. Biol*., *4*, 3-10.

Beaumont, L. J., Hughes, L., & Poulsen, M. (2005). Predicting species distributions: use of climatic parameters in BIOCLIM and its impact on predictions of species’ current and future distributions. *Ecological modelling*, *186*(2), 251-270. https://doi.org/10.1016/j.ecolmodel.2005.01.030

Benmoussaa, H., Luedeling, E., Ghrab, M., Ben Yahmed, J., & Ben Mimoun, M. (2017). Performance of pistachio (*Pistacia vera* L.) in warming Mediterranean orchards. *Environmental and Experimental Botany*, *140*, 76-85. http://dx.doi.org/10.1016/j.envexpbot.2017.05.007

Booth, T. H., Nix, H. A., Busby, J. R., & Hutchinson, M. F. (2014). BIOCLIM: the first species distribution modelling package, its early applications and relevance to most current MAXENT studies. *Diversity and Distributions*, *20*(1), 1-9. https://doi.org/10.1111/ddi.12144

Chaban, I.S. (1941). *Kazakhstan subtropics: Bostandyk region of Kazakhs SSR* (vol. 2). In: Vegetation of Kazakshtan. Moscow-Leningrad.

Enfyadzhan, L.A. (1954). The Experience of cultivating true pistachios in Ijevan region. *Izv. As ArmSSR, ser. biol and agricult.*, *7*(2), 17-32.

FAO – UNESCO Soil map of the world. (1974). Paris, Unesco. Vol.1. 59 p.

Gijón, M. del Carmen, Gimenez, C., Perez-López, D., Guerrero, J., Couceiro, J. F., Moriana, A. (2011). Water relations of pistachio (*Pistacia vera* L.) as affected by phenological stages and water regimes. *Scientia Horticulturae, 128*, 415–422. https://doi.org/10.1016/j.scienta.2011.02.004

Gudochkin, M.V., Chaban, P.S. (1958). *Forests of Kazakhstan*. Alma-Ata.

Hijmans, R. J., Cameron, S. E., Parra, J. L., Jones, P. G., and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, *25*, 1965-1978. https://doi.org/10.1002/joc.1276

Kalayda, F.K. (2016). The culture of pistachio (*Pistacia vera*) at the south coast of Crimea. *Imperial Botanical Cabinet and Botanical Garden*, *2*, 22..

Kamelin, R.V. (1990). *Pistachio in Badkhyz*. Leningrad.

Karmysheva, N.H. (1982). *Flora and Vegetation of Western Spurs of Talass Alatau*. Almaty.

Khanazarov, A. A., Chernova, G. M., Rakhmonov, A. M., Nikolyi, L. V., Ablaeva, E., Zaurov, D. E., ... & Funk, C. R. (2009). Genetic resources of Pistacia vera L. in Central Asia. *Genetic resources and crop evolution*, *56*(3), 429-443. https://doi.org/10.1007/s10722-009-9419-1

Khudaykulov, B.S. (2016). *Establishment of anti-erosion pistachio plants on eroded pastures in southwestern Tajikistan*. Dushanbe.

Kordon, R.Ya. (1936). Pistachio. Cultural flora of the USSR. Moscow-Leningrad. *Academy of Sciense of USSR*, *17*, 313-344.

Kornilova, V.S. (1966). The history of flora and vegetation in Kazakhstan. Vegetation of Kazakhstan. *Alma-Ata*, 1, 37-190.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, *15*(3), 259-263. https://doi.org/10.1127/0941-2948/2006/0130

Kovda, V.A. (1973). *The principles of pedology. General theory of soil formation*. Second book. Moscow.

Kravchenko, V.I. (1963). *Pistachio and its breeding*. Moscow.

Lovelius, N.V. (1979). *Variability of tree growth. Dendroindication of natural and anthropogenic processes*. Leningrad.

Malakhov, D. V., & Chirikova, M. A. (2018). Species Distribution Model of *Varanus griseus caspius* (Eichwald, 1831) in Central Asia: An Insight to the Species' Biology. *Russian Journal of Herpetology*, *25*(3), 195.206. https://doi.org/10.30906/1026-2296-2019-25-3-195-206

Malakhov, D. V., Tsychuyeva, N. Y., & Kambulin, V. E. (2018). Ecological modeling of *Locusta migratoria* L. breeding conditions in South-Eastern Kazakhstan. *Russian Journal of Ecosystem Ecology*, *3*(1). https://doi.org/10.21685/2500-0578-2018-1-5

Pakkish, Z., Rahemi, M., Panahi B. (2011). Low Temperature Resistance of Developing Flower Buds of Pistachio (*Pistacia vera* L.) Cultivars. *Journal of Biological & Environmental Sciences*, *5*(15), 153-157.

Popov, K.P. (1979). *Pistachio in Central Asia*. Ashgabat.

Rustamov, I.G., & Kepbanov, P.A. (2012). *Natural populations and pistachio (Pistacia vera) culture in Badkhyz*. Ashgabat.

Schepotiev, F.L., Richter, A.A., Pavlenko, F.A., Molotkov, P.I., Kravchenko, V.I., Iroshnikov, A.I. (1985). *Walnut forest and horticultural crops*. Moscow.

Sorokin A. (2018). Botanical identification of ancient Hebrew phytonym boṭnîm. On domestication history of pistachio (*Pistacia vera* L., Anacardiaceae). *Hortus Botanicus*, *13*, 78-89. http://dx.doi.org/10.15393/j4.art.2018.5422

Swartman, R. K., & Ogunlade, O. (1967). A statistical relationship between solar radiation,' sunshine and relative humidity in the tropics. *Atmosphere*, *5*(2), 25-34.

United Nations Environment Programme. (1997). *World atlas of desertification*. (2Ed). UNEP, London.

Verdú, M., & García-Fayos, P. (1998). Ecological causes, function, and evolution of abortion and parthenocarpy in *Pistacia lentiscus* (Anacardiaceae). *Canadian Journal of Botany*, *76*(1), 134-141. https://doi.org/10.1139/b97-166

Winslow, J. C., Hunt, E. R., & Piper, S. C. (2001). A globally applicable model of daily solar irradiance estimated from air temperature and precipitation data. *Ecological Modelling*, *143*(3), 227-243. https://doi.org/10.1016/s0304-3800(01)00341

Zapryagayeva, V.I. (1964). *Wild fruits of Tajikistan*. Leningrad.

Zverev, N.E., Kalybayev, K.R., & Islamgulova A.F. (2017b). Recommendations on pistachio cultivation in Kazakhstan. *Proc. Inst. Bot.* *23*(2), 62.

Zverev, N.E., Kalybayev, K.R., Kurmantayeva, A.A. (2017a). Evaluation of the fruits of Pistachio, allocated in populations which growing in Kazakhstan. *News NAS RK*, ser. *Biol. and Med.*, *5*(323), 121-126.