CONSEQUENCES OF CLIMATE CHANGE ON THE FLORISTIC COMPOSITION OF KHULAIS REGION, SAUDI ARABIA

ALSHERIF, E. A.[1,2*] – ALMAGHRABI, O. A.[3]

[1]*Biology Department, College of Science and Arts at Khulis, University of Jeddah, Jeddah, Saudi Arabia*

[2]*Department of Botany and Microbiology, Faculty of Science, Beni-Suef University, Beni Suef, Egypt*

[3]*Department of Biology, College of Science, University of Jeddah, Jeddah, Saudi Arabia*

[*]*Corresponding author*
e-mail: eaalsherif@uj.edu.sa; phone: +96-656-097-3189

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Abstract. Climate change has resulted in profound changes in biodiversity throughout the globe. It has also become a serious source of worry for environmentalists and governments alike. The goal of this study is to provide first-hand information about the effects of climate change on floristic composition in the Khulais region, Saudi Arabia, during the last decade. Data obtained from the metrological station showed that the amount of annual precipitation decreased, while the mean annual temperature exhibited an increase. The results showed that Lange, De Martonne and Emberger's drought indices, ranged between ($3x10^{-5}$ to 2.8), ($3x\ 10^{-5}$ to 2.0), and ($2x\ 10^{-4}$ to 14.8), respectively, which decreased in 2020 by between 50% and 230% from 2011. Most plant species in the studied region showed a decrease in their frequency. 50 out of 251 species showed a frequency change of more than ten percent, which was recorded in the first survey. Species that showed the largest declines were mostly a variety of agricultural weeds and valley plants, while species of rocky and mountain habitats were less affected. Only seven species showed a relative increase in their frequency, *Prosopis Juliflora* and *Trianthema portulacastrum* L. recording the highest change in their frequency. This work serves as a warning to those interested in wild plants and to governments to take appropriate measures to protect the arid environment threatened by the impact of climate change.
Keywords: *Prosopis, biodiversity, drought indices, Trianthema, invasive*

Introduction

A major and direct biological consequence of climate change is the has led to of rising ambient temperatures on organisms' thermal performance. Climate change has influenced huge changes in biodiversity across the globe, and it is becoming a serious concern for environmentalists and governments alike. Higher plants are the principal producers in the majority of terrestrial ecosystems, and their distribution and diversity have a significant impact on the distribution and variety of most other creatures (Carvell et al., 2006; Jonason et al., 2010; Berg, 2012). Plant species, on the other hand, are susceptible to a wide variety of environmental changes, frequently to the point where plant communities as a whole or localized species pools are impacted (Arts, 2002; Maad et al., 2009; Cousins et al., 2015; Hedwall and Brunet, 2016; Sun et al., 2022). So, keeping a close eye on changes in the diversity and frequency of vascular plants should be a top goal (Nielsen et al., 2019). Climate change has caused significant alterations in species distributions and abundances during the last 30 years (Parmesan et al., 2003; Root et al., 2003) and has been linked to one species-level extinction (Root et al., 2003). Pounds et al. (1999) stated that flora composition is often used to forecast site circumstances, such as temperature

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and site characteristics (Berges et al., 2006). Due to its continental climate, cold winters, scorching summers, and sporadic rainfall, the Kingdom of Saudi Arabia (KSA) is one of the nations most sensitive to climate change (Al-Wabel et al., 2020).

Despite the fact that the Mediterranean and its surrounding territories have been extensively studied in recent decades (Hoskins and Pedder, 1980; Trigo et al., 2002; Lee et al., 2011). Saudi Arabia's scientific knowledge and literature on climate and climate change is dispersed, fragmentary, and inadequate. Future regional climate change and its impacts on Saudi Arabia have received little attention in study. Alkolibi (2002) looked at how general circulation models predicted climate change, as well as the consequences of increasing temperatures and decreased precipitation on Saudi Arabia's water resources and agriculture. With the exception of a narrow tong running from the north to the center of KSA, Meehl et al. (2007) forecast a 0.1 mm/day increase in mean annual surface evaporation throughout most of KSA by the end of the twenty-first century. Williams et al. (2012) reviewed the effect of climate change on animal in Saudi Arabia, Zekâi (2013) studied the probable links between desertification and climate change in dry areas. Elnesr and Alazba (2010) carried out a study to understand the behavior of its temperature climatology in Saudi Arabia. Climate change and water resources were researched by Tarawneh and Chowdhury (2018), who reported an increase in temperature in all regions and a decrease in rainfall in many regions. According to Al-Wabel et al. (2020), the Kingdom of Saudi Arabia (KSA) is one of the most susceptible nations to climate change owing to its continental climate, harsh winters, scorching summers, and unpredictable rainfall. Many studies (Muller, 1982; Moore, 1986) provided brief and sound climatological information on the Arabian Peninsula, demonstrating that the Arabian Peninsula has a wide climatic spectrum, ranging from the snows of the Asir Province in Saudi Arabia to the overpowering humidity of the Arabian Gulf, from the searing heat of the Rub Al Khali to the monsoon precipitation in the Qara mountains in Dhofar. Plant diversity and distribution data, which must be gathered on a continuous basis due to continuing climate change, are critical for conservation biology and resource management at all scales. The diversity of plant species may be used to determine the sustainability of an ecosystem (Gamoun et al., 2012). The goal of this research is to get firsthand knowledge of the impacts of climate change on floristic composition in the Khulais region, Saudi Arabian.

Materials and methods

Study area

The region under investigation, the Khulais region, is situated between longitudes 15 and 39 degrees east and latitudes 22 and 30 degrees north in the Arabian Shield, which encompasses the western chains of Hijaz and Asir highlands, as well as the western portion of the Nagd plateau (*Figure 1*). Its soils are made up of basaltic volcanic rocks with textures varying from silty clay to coarse sandy, pH levels ranging from 7.2 to 7.6, and salinity levels ranging from 0.4 to 7.4 mM/cm. With an annual average rainfall of 35.1 mm, the climate is hot in the summer and warm in the winter. Rainfall is irregular and unpredictable, in addition to its paucity.

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Figure 1. *Location map showing the study area*

Field survey and the data sets

Two surveys of the flora of Khulais, conducted in 2010–2011 and 2020–2021, were compared in this report. The first survey was carried out during the period of September 2010 to the September 2011, while the second one was carried out between September 2020 to September 2021. The species recorded in the first survey were published by Alsherif et al. (2013). Four study sites were selected to do the second survey, the GPS positions of the sampling sites are as follows: 22° 7'38.41"N 39°17'46.00"E, 22° 7'30.21"N 39°28'49.43"E, 22° 7'47.68"N47.68 '31°39 "E and 21°55'47.29"N 0.02'19°39"E. It was taken into account that the second survey should be in the same areas as the first survey, with the exclusion of areas in which human activity appeared, such as road construction, land use for agriculture and housing construction. Frequency detection was carried out using the quadrat point approach (Daget et al., 1995). The research sites' plant species compositions were obtained by randomly planting one square meter quadrat at ten different locations at each site. Frequency (F), the distribution of a certain species was estimated as % of occurrence:

Frequency (F%) = (Total number of quadrates studied/number of quadrates where the species occurred) X100. With the use of standard flora reference books, plant species within each quadrat were collected and identified (Collenette, 1989, 1999; Chaudhary, 2001; Miller, 2007). Life form categories were constructed according to Raunkiaer's guidelines (Raunkiaer, 1934).

Drought indices determination

The study area's climate data for the previous ten years was obtained from the Jeddah meteorological station. In many locations of Saudi Arabia, aridity knowledge is required to explain landscape features and the efficient use of water resources. Aridity indices provide a straightforward approach to represent the precipitation-to-evaporation ratio.

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The regional variation of three climatic indices, the Lang index, Martonne index, and Emberger aridity index, was explored in this work to establish the climate structure of the Khulais area.

De Martonne index

The Martonne index calculated as described in the following equation:

$$\mathrm{IDM} = \frac{\mathrm{Pav}}{\mathrm{Tav}} + 10 \quad \text{(Eq.1)}$$

where IDM= De Martonne's index, Pav= average rainfall, Tav= average temperature.

Lang index

Lang index was calculated as described in the following equation:

$$\mathrm{L} = \mathrm{R}/\mathrm{T} \quad \text{(Eq.2)}$$

where L= Lang's rainfall factor, R = Average rainfall, T= Average temperature.

Emberger aridity

Emberger aridity was calculated as described in the following equation:

$$\mathrm{IP} = \frac{100\mathrm{x}\,\mathrm{P}}{\mathrm{T} - \mathrm{t}} \quad \text{(Eq.3)}$$

where Ip is the Emberger index, P is the average annual precipitation, T is the average maximum temperature for the hottest month, while t is the average lowest temperature for the coldest month.

Results

General climate and arid indices of the region

Data obtained from the metrology station showed that the amount of annual precipitation that has been recorded in the last decade in general is very small. It is not fixed, it changes from year to year, but it is very clear that it is decreasing. The past ten years have varied in recording the amount of rain and have ranged between 0.001 and 86.4 milliliters throughout the year (*Table 1*). The results also showed that the amount of rain decreased by 85% in the years following the year 2011, except for the year 2018. It's worth noting that the mean annual temperature is constantly increasing from year to year. The average annual temperatures increased by between 0.7 and 1.3 degrees Celsius. A decrease in the relative humidity was observed during the last three years compared to the first three years of this decade by an amount of 7%. The relative humidity showed slightly changing, it ranged between 51% and 57%.

In addition, the three drought indices measured in the current study for the last decade confirmed that the study area is an arid area. The results also showed that Lange, De Martonne and Emberger's indices, ranged between (3x10-5 to 2.8), (3x 10-5 to 2.0) and (2x 10-4 to 14.8), respectively (*Table 2*). All drought indices decreased in 2020 by between 50 and 230% from 2011.

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***Table 1.** The annual total precipitation (ml), mean temperature (°C) and mean relative humidity (%) of the studied area. ± S.D*

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total Precipitation	80.6 ±21.8	12.5 ±2.5	0.001 ±0.0	52.0 ±9.5	33.0 ±6.4	10.5 ±1.7	24.0 ±4.8	86.4 ±20.1	35.3 ±8.5	40 ±5.8	10.1 ±1.8
Mean Temperature	28.4 ±3.4	29.1 ±3.4	29.2 ±2.8	29.5 ±2.9	29.4 ±3.4	29.7 ±3.0	29.3 ±3.3	29.7 ±3.2	29.6 ±3.7	29.3 ±3.7	26.0 ±2.9
Mean relative humidity	57 ±1.2	55 ±2.0	56 ±1.6	53 ±1.4	53 ±1.7	54 ±1.1	55 ±1.1	54 ±1.5	51 ±1.6	52 ±1.3	52 ±1.4

***Table 2.** Aridity indices for the study area during last decade*

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Lange index	2.8	0.4	$3X10^{-5}$	1.72	1.1	0.3	0.8	2.9	1.1	1.3	1.3
De Martonne Aridity Index	2.0	0.3	$3X10^{-5}$	1.3	0.8	0.2	0.6	2.1	0.8	1.0	1.0
Emberger Index	13.5	2.0	$2x10^{-4}$	9.8	5.0	1.7	4.0	14.8	6.5	6.1	6.1

Change in frequency of plant species

The majority of plant species in the studied region showed a decrease in their frequency. 50 out of 251 species showed a frequency change of more than ten percent, which was recorded in the first survey. The species that showed the largest declines over the last decade are mostly a collection of arable weeds and valley plants, while species of rocky and mountain habitats were less affected (*Table 3*).

The greatest changes were noted for the following items when compared to their frequency in the second survey. Digera muricata, Capsella pursa pastoris, Cleome paradoxa, and Indigofera hoschstettei all of which decreased by more than 15%. Only seven species showed relative increases, and the invasive species Prosopis Juliflora and Trianthema portulacastrum L. showed the highest increase, both of which increased by more than 15%. Many common species in open/agricultural lands have also seen severe reductions, but to a lesser extent, such as Convolvulus Fatemensis, Euphorbia granulate, Glinus lotoides, and Lolium perenne (*Table 3*). It is not only the invasive plants that have increased their frequency, but also some native species such as Tamarix aphylla, Portulaca oleracea and Suaeda monica which increased its frequency by 10 to 12%.

Life forms of the changed species

The current results showed that the proportions of the life forms of species that recorded a change in their frequencies slightly differed from the proportions that were recorded in the initial survey of the area (*Table 4*). Therophytes recorded the highest percentage (50.9%) of plants that changed their frequency, followed by chaemophytes, while geophytes recorded the lowest percentage (3.7%). It is also noted that most of the species that showed a change in their frequency were annuals, while perennials recorded the lowest percentage.

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Table 3. *The species that showed a highest change during the study period*

Family	Species	Change %	Habitat	Life form	Chorology
Aizoaceae	*Aizoon canariense* L.	-11	Sandy soil- Wadi	Th	SU
	Sesuvium sesuviodes(Fenzl) Verdc.	13	sabkha- salt affected soil	Ch	TR
	Trianthema portulacastrum L.	15	Cultivated lands- Garden	Th	AM
Amaranthaceae	*Digera muricata* (L.) Mast.	-17	Wadi	Th	TR
Apocynaceae	*Rhazya stricta* Decne.	-12	Wadi	Ch	SA+SU
Asclepiedaceae	*Caralluma acutangula* (Decne.) N.E.Br.	-10	Rocky habitats	Th	SA+SU
	Odontanthera radians (Forssk.) D.V.Field	-14	Wadi	Ch	TR
Asteraceae	*Asphodelus tenuifolius* (Cav.) Baker	-16	Wadi	Th	SA
	Asteriscus hierochunticus (Michon) Wiklund	-11	Wadi	Th	SA+SU
Boraginaceae	*Arnebia decumbens* (Vent.) Coss.&Kralik	-13	Wadi	Ch	SA
	Moltkiopsis ciliate (Forssk.) I.M.Johnst.	-13	Wadi	Th	Cosm
Brassicaceae	*Capsella pursa pastoris (*L.) Medik.	-18	Cultivated lands- Garden	Th	ME+SA
	Schouwia purpurea (F0rssk.) Schweinf.	-16	Wadi	Ch	SU
Capparaceae	*Cadaba farinosa* Frossk.	-11	Wadi	Th	SU
	Diptergium glaucum Decne.	-12	Wadi	Ch	IT
	Mareua oblongifolia (Frossk.) A.Rich.	-12	Wadi	Ch	SU
Chenopodiacea	*Haloxylon scoparium* Pomel	-16	Wadi	Ch	SU
	Suaeda monica Frossk.ex J.F. Gmel.	10	salt affected soil	Ch	SU
Cleomaceae	*Cleome droserfolia* (Forssk.)Delile	-12	Wadi- Cultivated lands	Ch	SU
	Cleome paradoxa R.Br.exDC.	-17	Wadi	Ch	SA
Convolvulaceae	*Convolvulus fatemensis* Kunze	-14	Wadi- Cultivated lands	Ch	Cosm
Euphorbiaceae	*Euphorbia granulata* Frossk.	-11	Wadi- Cultivated lands	Ge	SA
Liliaceae	*Dipcadi erythraeum* Webb & Berth.	-10	Wadi	Th	TR
Lythraceae	*Ammannia baccifera* L.	-16	Wadi	Ph	SA
Mimosaceae	*Prosopis juliflora* (Sw.) DC.	18	Wadi-swampy	Th	ME+IT
Molluginaceae	*Glinus lotoides* L.	-16	Wadi- Cultivated lands	Th	TR
	Mollugo cerviana (L.) Ser.	-14	Wadi	Th	SA
Papilionaceae	*Astragalus vogelii* (Webb) Bornm.	-12	Wadi	Th	SA+SU
	Crotalaria microphylla Vahl	-17	Wadi	Ch	SU
	Indigofera hoschstettei Baker	-19	Wadi	Th	SU
	Trigonella stellata Forssk.	-10	Wadi	Th	SA
	Tephorosia nubica (Boiss.) Baker	-10	Wadi	He	SA+SU
	Trigonella hamosa L.	-12	Wadi	Th	ME+IT

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Family	Species	Change %	Habitat	Life form	Chorology
Poaceae	*Cenchrus ciliaris* L.	-10	Wadi	He	ME+IT
	Lamarckia aurea (L.) Moench	-13	Wadi	He	SA+SU
	Lolium perenne L.	-13	Wadi- Cultivated lands	Th	Cosm
	Panicum turgidum Forssk.	-15	Wadi	He	SA
	Lolium rigidum Gaudin	-13	Cultivated lands	Ch	SA
	Polypogon monospliensis (L.)	-16	Cultivated lands	Ph	SA+SU
Portulacaeae	*Portulaca oleracea* L.	12	Cultivated lands	Ph	SU
Resedaceae	*Ochradenus baccatus* Del.	-10	Wadi	Ch	ME+SA
	Oligomeris linifolia (Fahl ex Hornen) J.F. Macbr.	-16	Wadi	Ch	SA
Rutaceae	*Haplophyllum tuberculatum* (Forssk.) A.Juss.	-11	Wadi	Th	ME+SU
Solanaceae	*Datura innoxia* Mill.	10	Wadi- Cultivated lands	Th	SA+SU
	Lycium shawii Roem. & Schult.	-10	Wadi	Th	SA
	Solanum incanum L.	-14	Wadi- Cultivated lands	Th	ME+IT
Tamaricaceae	*Tamarix aphylla (L.) Karst.*	10	Wadi- Salty habitat	Ph	SU
Tiliaceae	*Corchorus depressus* (L.) Stocks	-12	Cultivated lands	Th	SA+ME
Zygophyllaceae	*Fagonia indica* Burm. f.	-10	Wadi	Th	ME+IT
	Tripulus terrestris L.	-11	Wadi	Th	SU

Table 4. *Life forms and chorotype % of the species that showed the highest change*

Life form		Chorotype	
Hemi-cryptophytes	7.6	Cosmopolitan	5.88
Chamaephytes	30.2	Tropical	9.88
Geophytes	3.7	Mediterranean+ Sudano-Zambezian	15.71
Phanerophytes	7.6	Mediterranean + Sudano-Zambezian	17.64
Therophytes	50.9	Saharo-Arabian	21.56
		Sudano-Zambezian	23.52
		Pluriregional	5.81

Chorological types of the changed species

Table 4 shows the chorological types of species that have a higher (more than 10%) change in their frequency. Sudanian elements had the greatest percentage (23.5%), followed by Saharo-Arabian elements (21.5%), which was the polar opposite of the original survey, which had Saharo-Arabian components scoring higher than Sudanian elements. The largest change occurred in the biregional type which included the Mediterranean type; their change was 17%, while their percentage in the initial survey was 8%.

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Discussion

Since the previous decade, the present research found a rise in mean temperatures and a reduction in total precipitation in the analyzed region. It was fascinating to see whether the flora's makeup mirrored these unusual circumstances. The race between climate change and vegetation has already begun, according to various studies (Hughes, 2000; Walther et al., 2005; Lenoir, 2008). The study of plant diversity in dry regions is crucial for determining their ecological and economic worth, as well as the necessity for conservation and restoration in the face of current climate change. The collected data confirms that the study area is a dry area in general due to the low values of drought indices. It also showed that the area was drier during the second survey compared to the timing of the initial survey. Areas are classified as arid areas if the De Martonne index is less than 10, the Emberger index is less than 30 and the Lange index is less than 40 (De Martonne, 1923; Emberger, 1932).

It was intriguing to see whether these circumstances were mirrored in the flora composition. Adaptations to these environmental changes were certainly reflected in the shift in species frequency, according to the current research. Our findings demonstrate that the overall frequency of the majority of common ground flora species has altered. The key trends show that wadi, garden, and arable weeds are declining, while invasive species are increasing. Climate change has had a substantial impact on changes in the flora during the past century, according to a prior research based on data from Swedish regions (Auffret and Thomas, 2019). Large reductions in arable weeds recorded in the present study could be explained owing to lower water availability and increased evaporation as a consequence of higher average temperatures and lower rainfall. The results of the current study are in agreement with IPCC (2019) who reported that the loss of species variety, decreased plant production, reduction of soil structure and fertility, and an increase in water loss, soil erosion, and sand movements are the major consequences of arid and semiarid ecosystem degradation. Species with a poor tolerance for warmth, limited acclimation capacity, and restricted dispersion ability are at the highest danger of extinction as a result of fast climate change (Williams et al., 2007). The life form therophytes exhibited the most changed life form, because they blossom and produce lush growth after adequate rain (AlSherif et al., 2013, 2022). In the present study, valley habitats showed the highest change in plant species frequency because valleys in arid and semi-arid environments are the most affected sites when it comes to water stress due to drought and high temperatures (Eheart and Tornil, 1999). Smooth rocks in rocky environments help to condense water vapor and thus increase the soil water content (Le Houérou, 1998), which explains the small change in the frequency of species inhabiting the rocky habitats in the current study. In the absence of precipitation, Le Houérou (1998) observed that species living in dry settings use several techniques to gather water from humid air. When mountains or steep slopes obscure the clouds, a fog zone forms. This wetness encourages the growth of plant communities (Moore, 1986; Rundel et al., 1991). The current results indicate the decrease in the amount of rain, which led to the previous result. Although several studies have shown that desert ecosystems are among the least infested in the world, at least in terms of invasive and naturalized species (Lonsdale, 1999; Brooks and Pyke, 2001), the current study contradicts this due to the large spread of *P. juliflora*. Four of the recorded species with an increased frequency were considered invasive species in the area (Jacob et al., 2016). The sudden rise in frequency might be a sign of a changing environment. It was documented that climate change has been linked to extinction in the past via beneficial impacts on species that have unfavorable

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interactions with a target species, such as competitors (Wethey, 2002; Suttle et al., 2007). Warming temperatures, according to Stachowicz et al. (2002), may benefit imported species while aggravating their detrimental impacts on local flora and fauna. *Prosopis juliflora* was reported as one of the currently recorded Saudi invasive species by Jacob et al. (2016). It has a significant impact on ecosystems and agriculture, eradicating or displacing many native species from areas rich in vegetation, especially in valley habitats. *P. juliflora* is characterized by large amount of seeds, fast growth, desirable and diseased pods, seeds that maintain viability for farm animals and wild animal droppings, resistance to surfing (Shiferaw et al., 2004, 2022), extraordinary ability to re-germinate and build canopy quickly, and higher water use efficiency (Shaltout et al., 2013), all of this helps him to conquer new territories. The second most invasive species, *Trianthema portulacastum*, recorded in the current study, was reported as having a high invasion potential (Felker et al., 1983). Fahmy et al. (2019) stated that the characteristics of the seeds and seedlings of *T. portulacastrum* serve as indicators of the species' extensive ecological range. Among these characteristics is the ability to produce a high number of non-dormant seeds that germinate at a wide range of temperatures (20 - 45°C). Lee et al. (2001) documented that the global distribution of *T. portulacastrum*, which is characterized by warm or hot weather and high solar radiation, suggests that the seeds, seedlings, and adult plants are resistant and/or acclimated to stress conditions. The halophytic species *Tamarix aphylla* and *Sesuvium sesuviodes* are among the recorded invasive plants. It may be that changing climatic conditions led to an increase in soil salinity. Gaur and Squires (2018) stated that as a consequence of climate change, dry and semiarid zones where evaporation exceeds rainfall are being considerably worsened, causing soil erosion and salinization, leading to the increase of halophytes. It's important to remember, however, that changes in climate have direct effects on species, but they also have indirect effects on species through climate-induced changes in other environmental conditions like soil water shortage, soil chemistry, drainage, and erosion. The final effect of climate change on the structure and functioning of natural and semi-natural habitats and environments is determined by these abiotic impacts, as well as the direct response of plant species.

Conclusion

In the research area, average temperatures and yearly rainfall have changed, resulting in a decline in the frequency of most plant species and an increase in the frequency of invasive plants, indicating that climate change is having a significant influence on the region's flora. If this change continues, the negative impact on the plants of the region will increase. This phenomenon has a negative impact on not just agriculture, but the availability of water as well. Invasion from non-native plants is seen as a major danger to ecosystem structure and function.

Recommendations

The findings, suggestions, and guidance are supposed to be beneficial to administrators, both local and central in ensuring the environmental situation's long-term viability and maximum benefits. The sharp decline in biodiversity suggests that habitat conservation should be prioritized on a national level. Our results strongly support the need for broad-scale floristic diversity monitoring across both short and long-time scales.

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In addition, decision makers should implement a policy to reduce *P. juliflora*, and protect the native flora from the danger of this plant.

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