sustainability

Article

Predicting the Suitable Current and Future Potential Distribution of the Native Endangered Tree *Tecomella undulata* (Sm.) Seem. in Pakistan

Fahim Arshad *, Muhammad Waheed, Kaneez Fatima, Nidaa Harun, Muhammad Iqbal, Kaniz Fatima and Shaheena Umbreen

Department of Botany, University of Okara, Okara 56300, Pakistan; f19-phd-bot-5013@uo.edu.pk (M.W.); s19-mphil-bot-3002@uo.edu.pk (K.F.); nidaadr@uo.edu.pk (N.H.); iqbal_shakir@uo.edu.pk (M.I.); f19-phd-bot-5005@uo.edu.pk (K.F.); f20-phd-bot-5009@uo.edu.pk (S.U.)
* Correspondence: fahim.arshad@uo.edu.pk

Abstract: The burgeoning human population exhibited a rapid amplification in demand for timber and fuelwood and as a result, the natural population of the native tree *Tecomella undulata* reduced rapidly due to its high economic and medicinal significance. The recognition of appropriate regions for threatened plants in the climate change scenario is a fundamental step for the restoration and conservation of biodiversity. The current study predicts the potentially suitable areas in Pakistan for *T. undulata* restoration. This research identifies the highly appropriate regions for vulnerable *T. undulata* through the maximum entropy model from MaxEnt software. The model's Area Under Curve 0.968 suggested its accuracy. The mean temperature of the wettest quarter, precipitation of the warmest quarter, and mean temperature in the driest quarter significantly shaped the *T. undulata* distribution. Future suitable areas for *T. undulata* were made by using RCP (4.5 and 8.5) for the years 2050 and 2070 through 19 bioclimatic variables and 66 occurrence points. The current highly suitable area for *T. undulata* is approximately 135,749 km^2 (15.4%) while the unsuitable area identified is approximately 404,917 km^2 (45.91%). The highly suitable area for *T. undulata* increases by 3.6–7% under climate change regimes (RCP 4.5 and RCP 8.5). The Central Punjab (District Faisalabad, Nankana sahib, Jhang, Kasur, and Okara), Salt Range, Western Khayber Pakhtunkhwa (KPK), FATA area, Eastern Balochistan, and Thar and Tharparker in Sindh are the current appropriate habitats for *T. undulata*. Under all future climatic circumstances, the extremely appropriate area for *T. undulata* was anticipated to expand, whereas the unsuitable zones would all shrink. The research would be significant for the further development of *T. undulata* management and conservation techniques.

Keywords: climate change; conservation; management techniques; maxent modeling; suitable habitats

check for updates

Citation: Arshad, F.; Waheed, M.; Fatima, K.; Harun, N.; Iqbal, M.; Fatima, K.; Umbreen, S. Predicting the Suitable Current and Future Potential Distribution of the Native Endangered Tree *Tecomella undulata* (Sm.) Seem. in Pakistan. *Sustainability* **2022**, *14*, 7215. https://doi.org/10.3390/su14127215

Academic Editor: Georgios Koubouris

Received: 26 April 2022
Accepted: 6 June 2022
Published: 13 June 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

A species' habitat is made up of the occupied area and ecological factors of the area necessary for an individual, such as the abiotic features and other species [1]. The distribution and ecological patterns of native plants have been significantly impacted by the magnitude and characteristics of their habitats. Disturbance in habitat causes microclimatic change and fragmentation by altering the spatial structure of the remaining habitat [2]. As a result, the destruction of species habitats has long-term negative effects on species diversity. The biodiversity loss, species erosion, and species endangerment are due to habitat destruction of native species [3–5]. Climate change, as well as habitat decline and expansion, are well-documented aspects of our planet's history [6]. Climate change affects the life-history characteristics of a plant, i.e., flowering and fruiting phenology, and habitat needs. It also has an effect on ecosystem functions and structures that can be observed through changes in global temperature over the last several years [7].

Climate change and other extinction facilitators have significantly impacted species distribution patterns for the last few decades and are the primary causes of species loss [8,9]. The restoration and conservation of endangered species are challenging due to insufficient biogeographical data on species [10] Resultantly, new approaches such as the influx of machine learning, ecological theories, and GIS are being extensively used in the disciplines of ecology and conservation [11,12]. Abiotic variables and species presence records in natural habitat relationships are analyzed by using Species Distribution Models (SDMs) [9]. Species Distribution Models have been frequently applied to predict the potentially suitable habitat for species both animals and plants [13] Earlier studies demonstrated that temperature, rainfall, relative humidity, and other environmental variables were used to predict the probable geographical ranges of species [14]. The MaxEnt model is a niche model predicting the possible ecological distributions of species through the maximum entropy principle and machine learning approach. When the species absence data is limited, the MaxEnt predicted the habitat suitability-based presence only records and layer of environmental factors effectively [11].

The small-medium-sized tree, i.e., *Tecomella undulata* (Bignoniaceae) is native to India, Pakistan, and Arabian deserts that has commercial and pharmacological significance [15]. *T. undulata* is a perennial deciduous tree that naturally occurs in arid and semi-arid environments. Colloquially it is also called Rohida (English), Rahora (Punjabi), and Lohiro (Sindhi) [16]. Rohida has a wide range of adaptations to arid environments and thrives in both dry regions and areas where irrigation is not possible. Moreover, it may also be observed at an altitude of 1200 m [17,18]. In arid agroforestry zones, *T. undulata* is a conventional tree due to its capacity to thrive in harsh environments. The tree grows in flat and undulating grounds, as well as modest hill slopes and ravines [15]. The species thrives best in stabilized sand dunes despite having diurnal temporal changes. It can withstand extreme cold (273.15–275.15 °K) in the winter and intense heat (321.15–323.15 °K) during the summer and also flourishes in regions with limited rainfall (around 150–500 mm per year) and harsh temperatures.

T. undulata is the most common source of timber among the desert woody plants in the sub-continent and wood is treasured for engraved agricultural equipment, furniture, turnery, carvings, and toys because of its softness, robust, and polishable nature [19]. The plant stem, leaves, and bark have a wide range of uses in the pharmaceutical industry due to the presence of various bioactive chemicals, as well as playing an essential role in the economy and ecosystem of the region. In both traditional and classical indigenous medical systems, desert teak has a reputation for having excellent therapeutic capabilities [15,20]. The *T. undulata* is a widespread agroforestry species in the Thar Desert that has provided major livelihood assistance to local inhabitants in dry and semi-arid areas [21]. Despite being a diverse and valuable plant for the arid-rural poor, desert teak is in danger of extinction due to over-exploitation and inadequate conservation efforts. Local farmers and herders, on the other hand, often lack scientific guidance when it comes to selecting economic tree places and species, which might explain why economic tree replanting is so unsuccessful. Changes in the underlying surface may be caused by unsustainable farming practices [22,23]. As a consequence, desert teak was selected for the current study subject, which is popular in Pakistan and has a long history of economic utilization. The research objectives of the present study were to identify the region of appropriate habitat and the most critical environmental elements influencing desert teak distribution under present climatic predictions, to explain how the appropriate region will alter as a result of climate change, and to predict ideal locations for its conservation and cultivation. The findings would serve as a theoretical reference framework for desert teak use, management, and conservation.

2. Materials and Methods

2.1. Occurrence Data

The quality and liability of the species location points in niche modeling are directly tied to the credibility of the projected results, and the occurrence data are based on the estimation of likely acceptable distribution under climate change scenarios [24,25]. Information about *T. undulata* distribution places was approached from two different sources, i.e., field surveys and the GBIF website. Field surveys were carried out between 2014–2019 and provided the data for *T. undulata* occurrence in central Punjab, Southern Punjab, Salt Range, and Sindh Province of Pakistan. Occurrence records of *T. undulata* were also assembled from the GBIF website. To eliminate spatial autocorrelation, only one location was chosen nearest to the middle in the 30″ grid plots (about 1 km^2), which was corresponding with climatic layers [26], and finally, sixty-six (66) *T. undulata* geographic sites used in the Maxent model were marked.

2.2. Environmental Data

Precipitation and temperature were chosen as the primary environmental parameters that influenced species distribution, and those two factors had a significant impact on the creation of the species distribution range [27]. Ecologically, these are the main characteristics that explain the adaptations in species, annual rhythms, and seasonality. These variables might be used to explain species distribution on the large scale [28]. The climatic data for the current era (1950–2000) from the Worldclim database have been extensively used for the creation of species distribution models (SDMs). Nineteen (19) climatic variables were selected with a spatial resolution of 30 s and elevation data were collected using the World Climate Database (www.worldclim.org, accessed on 21 December 2020) (Table S1). The WorldClim data sets were obtained in "tiff" format and converted to ASCII files in ArcGIS using "Raster to ASCII" for usage in MaxEnt.

To estimate the possible acceptable ecological distribution and appropriate environment change in future climate variation, expected bioclimatic variables from minimum to maximum representative concentration scenarios (RCP 4.5 and RCP 8.5) for 2050 and 2070 were grouped. Four typical concentration trajectories were produced in the IPCC's fifth report (RCPs). RCP4.5 indicated a moderate level of greenhouse gas emissions, whereas RCP8.5 indicated the highest amo5unt. Because RCP2.6 was a difficult-to-implement stringent mitigation scenario, RCP4.5 was chosen. Future climate change models RCP4.5 and RCP8.5 were used to determine future suitable ranges of *T. undulata* under GCMs. The BCC-CSM1.1 (Beijing Climate Centre–Climate System Modelling 1.1; www.worldclim.com, accessed on 21 December 2020) was recognized as one of the most extensively used general circulation models (GCMs) in Asia [22,29].

The modeling variables were filtered using the processes indicated below to avoid collinearity between environmental variables impacting the model outcomes [23]. For quantifying the percent (%) contribution of distinct variables to the initial prediction findings, the MaxEnt model was first run with *T. undulata* location points and environmental parameters. After that, ArcGIS was used to import all of the distribution points and extract the point values of the 19 bioclimatic variables and elevation. Pearson correlation analysis was performed on the acquired data to eliminate variable spatial autocorrelation using the R program (Figure S1).

The variables having a correlation coefficient of more than |0.8| (very substantial correlation) were filtered, and the percentage (%) contribution of each bioclimatic variable in the baseline model was compared. Following screening processes, six environmental variables were applied to establish the probability of spreading of *T. undulata*, which were bio02 (mean diurnal range), bio04 (temperature seasonality), bio08 (mean temperature of wettest quarter), bio09 (mean temperature of driest quarter), bio16 (precipitation of wettest quarter) and bio18 (precipitation of warmest quarter).

2.3. Modeling Procedure

Using MaxEnt v. 3.3.4, the possible environmental range of *T. undulata* was calculated. The model was run with 10,000 random background points. To train the MaxEnt model, 75 percent of *T. undulata* occurrence data were employed, while the remaining 25% of location points were used to test the model. A total of ten repetitions and the maximum iterations of 5000 were utilized to evaluate the MaxEnt model. To describe the relative significance of each environmental variable, Jackknife was employed and the options of 'create response curves' were selected. The accuracy of the model was tested by the area under the receiver operating characteristic (AUC) [30,31]. Other parameters used default settings according to the MaxEnt model. MaxEnt evaluated the probability of a species being present based on presence data and created random background points using the maximum entropy distribution. MaxEnt provided a range of locality suitability estimates for a species, ranging from 0 to 1 [32]. A map of potentially suitable regions and model prediction for *T. undulata* was created through ArcGIS (version 10.8). Based on expected habitat appropriateness, four classes of suitable habitats for *T. undulata* were categorized as unsuitable (0–0.3), low suitable (0.3–0.5), medium suitable (0.5–0.7), and high suitable (0.7–1) [33].

To assess the model's accuracy, the area under the receiver operating characteristics (ROC) curve was used as an indicator. The value of AUC better than 0.6 denoted 'good' replicated outcomes, whereas AUC values more than 0.9 exhibited 'outstanding' projected results. To determine the appropriateness of *T. undulata* in Pakistan, the model with the best AUC value was selected. After modeling the spatial extent of suitable habitat for *T. undulata* using current climatic data, modeling projections for four future climate scenarios (RCP4.5–2050, RCP4.5–2070, RCP8.5–2050, and RCP8.5–2070) were performed to predict the range of appropriate regions for species in the future.

3. Results

3.1. Model Validation

Validation ensures the accuracy of modeling outputs. The AUC value during the present investigation revealed that the Maxent model run adequately (AUC = 0.968) in the given study (Figure S2). Bio 08 (mean temperature of the wettest quarter), bio 18 (precipitation of warmest quarter), Bio 09 (mean temperature of the driest quarter), which were bio 02 (mean diurnal range), bio 16 (precipitation of wettest quarter), and bio 04 (temperature seasonality) all had an impact on the spread of *T. undulata* under present climatic circumstances. Furthermore, these factors' contributions were greater than the others.

3.2. Significant Environmental Variables

The association between *T. undulata* occurrence frequency and each environmental variable is depicted by the response curves. The species response curve explains the link between bioclimatic parameters, as well as the possibility of a species' existence. The outcomes of Jackknife studies and the relative contributions of environmental variables to the model created through Maxent iterative computing were utilized to uncover the major variable factors controlling the *T. undulata* distribution and their contribution rates (Figure S3).

The mean temperature of the wettest quarter (bio 08) and mean temperature of the driest quarter (Bio 09) contributed 42% and 22.5%, respectively, and were the principal factors for the distribution of the species. Other important environmental variables were precipitation of warmest quarter (bio 18), mean diurnal range (bio 02), precipitation of wettest quarter (bio 16), and temperature seasonality (bio 04) provided the most percentages contributed 11.8%, 11%, 6.75 and 6% percent, respectively (Table 1). The response curves for the major factors revealed the higher impacts on *T. undulata* distribution. The suitability for growth was improved as the mean temperature of the wettest quarter rise, and it was ideally ranged between 30 °C–37 °C, where the driest month's rainfall was sufficient for the species' survival and growth was from 200 to 400 mm during the driest season (Figure S4).

Table 1. Predicted suitable area in km^2 for *T. undulata* habitat suitability under current and future climate.

Suitability	Current	%	RCP 4.5 2050	%	RCP 4.5 2070	%	RCP 8.5 2050	%	RCP 8.5 2070	%
High	135,749.71	15.39	174,464.12	19.79	193,206.13	21.91	164,596.68	18.67	194,750.41	22.09
Medium	212,161.32	24.06	279,259.42	31.67	188,982.02	21.43	254,331.05	28.84	222,877.27	25.28
Low	128,960.75	14.62	125,870.51	14.27	146,356.55	16.60	133,204.16	15.11	132,830.68	15.06
Unsuitable	404,917.59	45.92	302,195.32	34.27	353,244.66	40.06	329,657.47	37.39	331,331.00	37.57

3.3. *Suitable Habitat for Tecomella undulata Current and Future*

Under the current climatic conditions, the dry and semi-arid regions of Pakistan are the most appropriate locations for *T. undulata* restoration. The highly suitable regions were located in Southern Sindh, upper Punjab, Salt Range, Eastern Balochistan, Western zone of Khybar Pakhtunkhwa, part of Thal, Thar, and Cholistan deserts, and a few regions of Western Balochistan (Figures 1 and 2). Currently, highly suitable area for *T. undulata* was approximately 135,749 km^2 (15.4%), medium suitable area 212,161 km^2 (24%), low suitable area 128,969 km^2 (14.6%) and unsuitable area for *T. undulata* suitability was approximately 404,917 km^2 (45.91%) (Table 1).

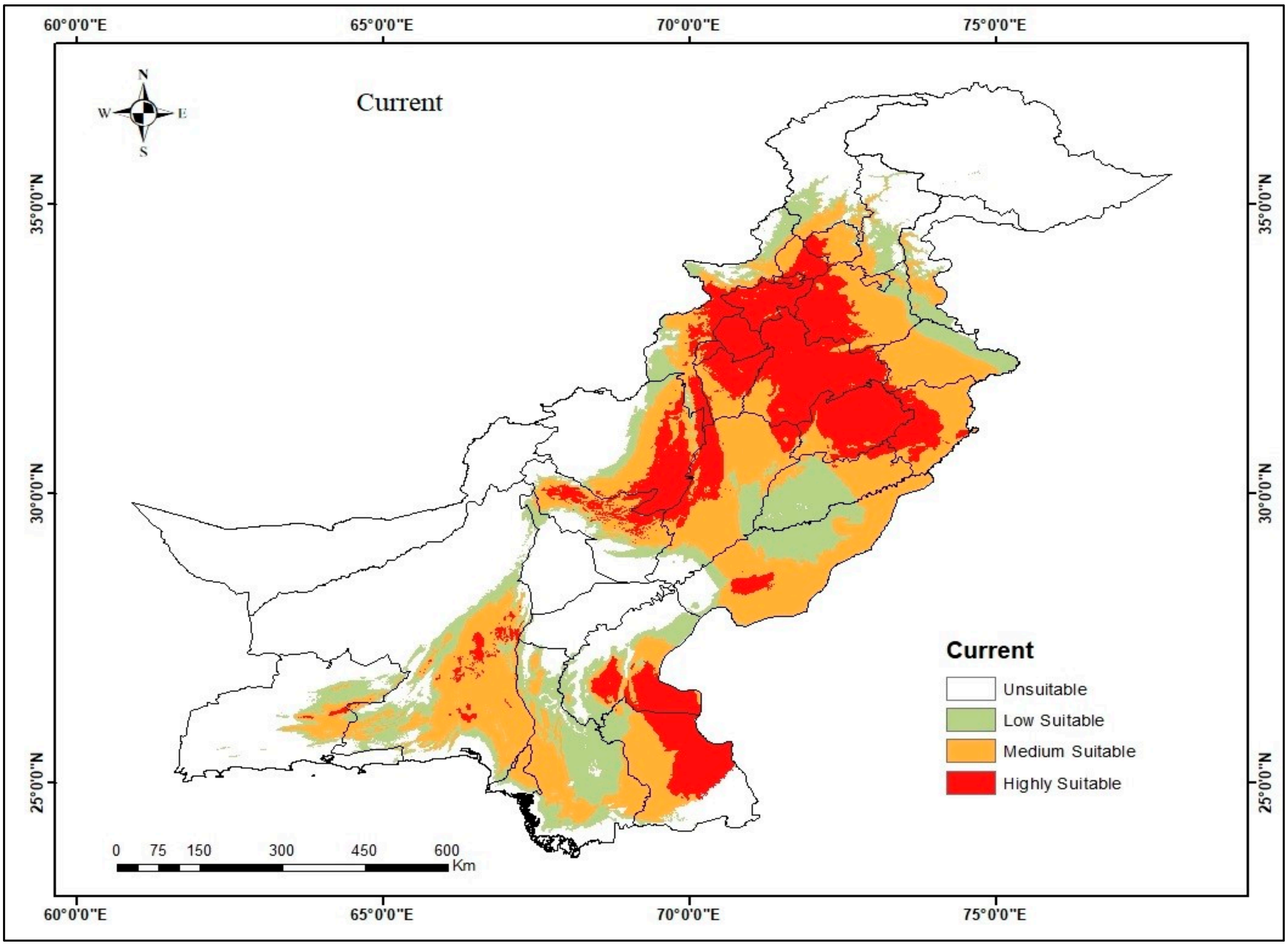

Figure 1. Suitable habitats for *T. undulata* Current.

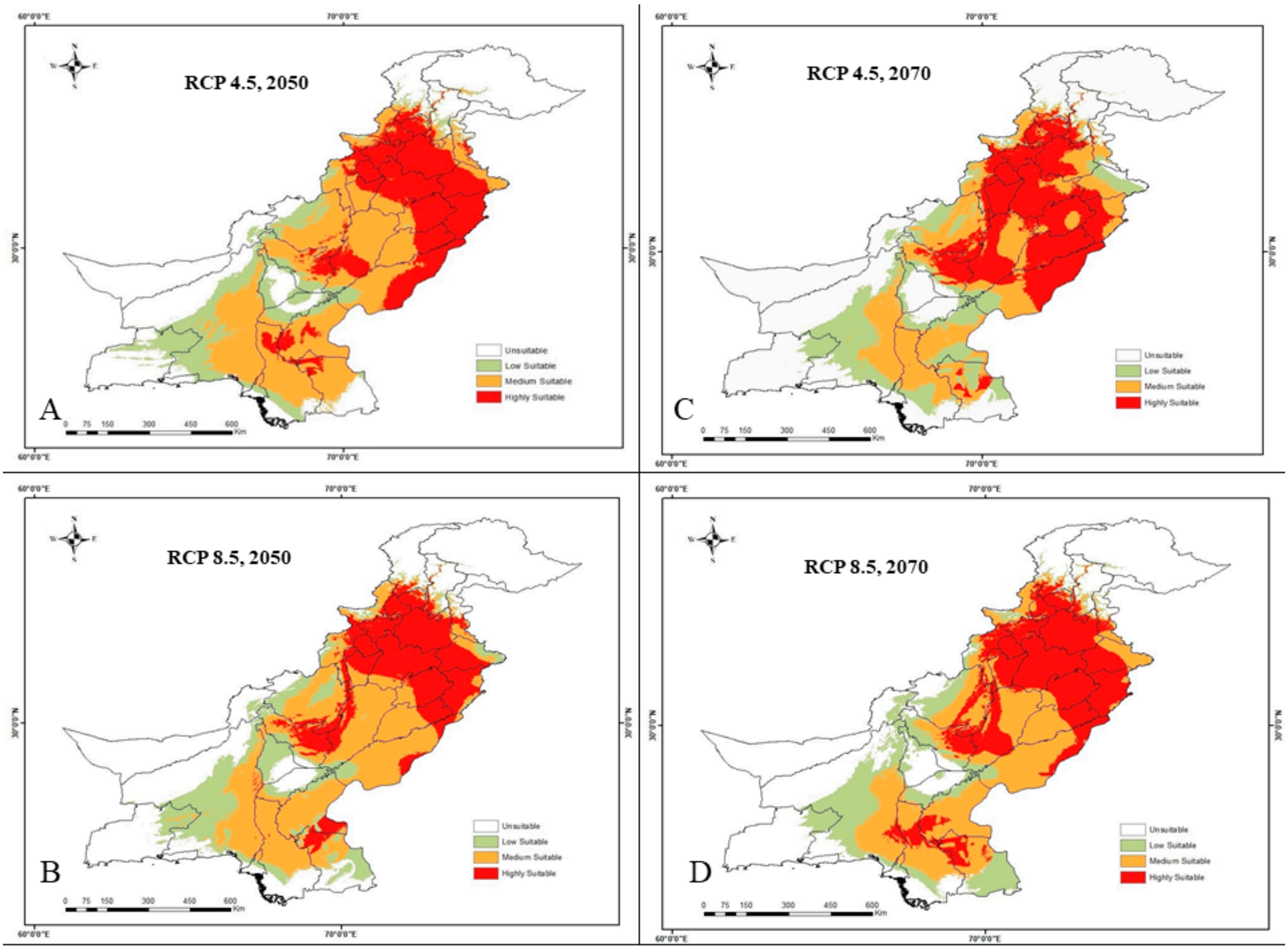

Figure 2. Suitable habitats for *T. undulata* (**A**) 2050s RCP 4.5, (**B**) RCP 8.5 and (**C**) 2070s RCP 4.5, (**D**) RCP 8.5. Highly suitable regions for *T. undulata* distribution would be increased by 4.7% under RCP 4.5 climate change scenario in 2050 and 6.9% for RCP 4.5 in 2070. In comparison with the current climate scenario, the highly suitable regions would be shifted to Eastern Punjab, Federally Administrated Tribal Areas, Northern Khyber Pakhtunkhwa, Federal territory, Southern Punjab, and central parts of Sindh for RCP 4.5 in 2050 and 2070. Under the RCP 8.5 climate scenario, the highly suitable area would be increased by 3.6% in 2050 and 7% in 2070 than the current distribution.

4. Discussion

According to climate models of *T. undulata* distribution, future global warming would have a significant influence on forest ecosystems [34]. Regardless of differences in climate modeling prototypes, the approach might still be used to analyze and anticipate future changes in species spreading [35]. *T. undulata* is a vulnerable plant whose population has been steadily decreasing in its native habitats as a result of a range of human-caused pressures such as grazing, illegal cutting, overexploitation, and habitat fragmentation [15]. *T. undulata*, a commercially valuable species, is also a sign of ecosystem purity and it plays a significant role in the restoration of a damaged environment. Therefore, its conservation is critical for the region. In the milieu of future climate change regimes, *T. undulata* management and policy plans are created in Pakistan using the MaxEnt modeling, which would help in designing the management and conservation strategies and policies for this vital timber plant. *T. undulata* is a vulnerable species in dry zones of Pakistan and India, hence it was selected for the restoration species distribution modeling, to meet the dual goals of prediction of suitable regions for the restoration and impact of climate change on future distribution patterns of habitat. In the traditional agroforestry system of the subcontinent, *T. undulata* is well accepted in the arid environment. This plant grows well in association with the other xerophytic species i.e., *Prosopis cineraria* (L.) Druce, *Zizyphus* spp., *Salvadora* spp. and *Capparis decidua* (Forssk.) Edgew [21]. Rapid construction activities, sand deposition in canal systems, overgrazing, floods, and woodland clearance caused the degradation of land. Planting *T. undulata* alongside canals would help to decrease sand deposition in canals thus stabilizing nature [36].

Presently investigated models attained AUC values of 0.968, which are within the adequate range for excellent models. AUC values were exceeding 0.75, according to [37,38] in analyzing the performance of a niche model, this may be relevant and suitable. MaxEnt found that four variables of temperature (Bio02, Bio04, Bio08, and Bio9), and two for precipitation (Bio16 and Bio18) contributed 98 percent more to the present distribution of *T. undulata* when auto-correlated characteristics were removed. Precipitation and temperature exhibited a major impact in defining the probable distribution habitats of *T. undulata* [18]. Maxent has been widely used for the prediction of possible species ranges in recent years [39,40]. According to the model, species would be found in all places with sufficient climatic circumstances, but not in any regions with unsuitable conditions; it is thought that the bigger a species' entropy under known parameters, the closer it is to reality [32].

Habitat change, climate change, overexploitation, invasive alien species, and pollution are the main threats to the decline of global biodiversity in the twenty-first century, according to experts [41]. Climate change primarily displays itself in rising temperature, alteration in precipitation patterns, and an increase in hazardous climate actions as part of global change; however, unstable climate features will distress species phenology, growth, reproduction, and geographic spreading at the local level [42]. It is vital to identify fluctuations in suitable distribution zones in future climate change situations and to initiate directed management activities as soon as likely to maximize the efficiency of biodiversity conservation [43]. Due to the exponential growth in global greenhouse gas emissions, Pakistan's predisposition for a warmer environment would be deteriorated in the future. Alteration in climate would have a substantial influence on the appropriate spreading areas of *T. undulata*, according to the findings of the present study, and the ideal habitat area would likely to increase with time. Furthermore, it was analyzed that the predictions created using RCP4.5 data differed from those made with other climate scenarios.

Climate transformation, particularly global warming, affects the temperature of various locations and alters the precipitation pattern. The distribution of these plants will be altered based on changes in climatic regimes to the point where they are near to or surpass the adaption threshold of current plant growth [44]. The distribution range of *T. undulata* migrated to higher elevations as the temperature raised, and the outcomes of the research are primarily showing its reliability. Precipitation may restrict and influence species distribution in a variety of ways since water supply has a considerable influence on photosynthesis, plant growth, height, leaf area, and branch number [45]. Increased rainfall during the driest month prolongs the growth period and facilitates plants to shift to more appropriate environments within their range. Moreover, inhospitable hot and cold environments considerably affect plant development. When the lowest temperature of the coldest month falls, plants suffer early freezing damage, and long-term low temperatures induce plant mortality near the distribution limit [46]. While sweltering heat of the warmest month depletes plant water storage, induces protein coagulation, and activates the internal mechanism of hazardous chemicals thus inhibiting plant growth [47]. Extreme climatic conditions were demonstrated to substantially impact plant diversity and distribution. Including them in niche modeling could increase the plant's expected accuracy and range limits under future climate change scenarios [48,49].

Several researches have revealed that global warming will have a detrimental influence on ecosystems and species occurrence [50]. Contrary to popular belief, the simulation findings of the current research revealed that climate change will improve the environment appropriateness and suitable area of *T. undulata*. The native range of *T. undulata*, on the other hand, is in jeopardy, and its population has plummeted. That might be due to the disturbance of the desert ecosystem induced by grazing pressure, human population growth, and overexploitation. For species conservation and restoration, accurate modeling of species distribution regions is critical. However, to attain the objectives, various living and nonliving elements are needed to be addressed. In practice, crucial elements are frequently paid no heed in order to simplify the information required for the model to determine the viability of the study, impacting the operation upshots to some extent, resulting in discrepancies between anticipated and actual results. Species distribution modeling would aid in the conservation management of this rare and vulnerable tree species. Present findings can be used for a variety of purposes, including identifying additional localities where *T. undulata* might already exist but has yet to be discovered; identifying localities where it is likely to be spread; prioritizing areas for introduction and cultivation, and managing rare tree species conservation.

5. Conclusions

A variety of endangered plant species are in dire need of conservation that can be achieved if the impact of climate change is assessed rightly. The Mean Temperature of Wettest Quarter, Precipitation of Warmest Quarter, and Mean Temperature in the Driest Quarter, were recognized as critical variables determining the distribution of *T. undulata*. The current potential suitable habitats for *T. undulata* are Central Punjab (District Faisalabad, Nankana sahib, Jhang, Kasur, and Okara), Salt range (District Chakwal, Mianwali, and Khushab), FATA region, eastern Balochistan, and Thar and Tharparker in Sindh. Overall highly suitable area for *T. undulata* to increase under all future climatic conditions was expected, but the unsuitable zones would all shrink. Overall, appropriate habitat distribution would be shifted to northeastern areas with slightly greater altitudes, and Upper Punjab, Central Khyber Pakhtunkhwa areas would be the ideal-preserved habitat with the most suitable environment for *T. undulata* in the future. The research would have bridged the gaps in the development of *Tecomella undulata* management and conservation techniques. The results of the current study can be utilized to develop future agroforestry groundwork, afforestation, reforestation, and management plans for this commercially important species in the region.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14127215/s1, Figure S1: Illustration of environmental variables after removing highly correlated variables through Pearson correlation ($r < 0.8$); Figure S2: ROC curve for *T. undulata* for habitat suitability of Maxent model; Figure S3: Results of Jackknife test of environmental variables used in Maxent modeling of *Tecomella undulata*; Figure S4: Response curves of *T. undulata* about a Mean Diurnal Range —Bio2, b Temperature Seasonality —Bio4, c Mean temperature of the wettest quarter—Bio8, d Mean temperature of the driest quarter—Bio9, e Precipitation of Wettest Quarter—Bio6 and f Precipitation of Warmest Quarter —Bi018; Table S1: Bioclimatic variables used in Maxent modeling of *T. undulata* and contribution rate and permutation importance of the main environmental variables.

Author Contributions: Conceptualization. M.W. and F.A.; Methodology, F.A., M.W., K.F. (Kaneez Fatima) and N.H.; software, M.W.; validation, M.W., N.H. and M.I.; formal analysis, M.W.; investigation, M.W. and F.A.; resources, F.A. and M.I.; data curation, M.W., N.H. and F.A.; writing—original draft preparation, M.W., K.F. (Kaneez Fatima) and F.A.; writing—review and editing, M.W., F.A., K.F. (Kaniz Fatima), M.I.; visualization, M.W. and M.I., S.U.; supervision, F.A.; project administration, F.A. and M.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yi, Y.-J.; Cheng, X.; Yang, Z.-F.; Zhang, S.-H. Maxent modeling for predicting the potential distribution of endangered medicinal plant (*H. riparia* Lour) in Yunnan, China. *Ecol. Eng.* **2016**, *92*, 260–269. [CrossRef]
2. Purves, D.W.; Dushoff, J. Directed seed dispersal and metapopulation response to habitat loss and disturbance: Application to Eichhornia paniculata. *J. Ecol.* **2005**, *93*, 658–669. [CrossRef]
3. Anadón, J.D.; Sala, O.E.; Maestre, F.T. Climate change will increase savannas at the expense of forests and treeless vegetation in tropical and subtropical A mericas. *J. Ecol.* **2014**, *102*, 1363–1373. [CrossRef]
4. Fischer, J.; Lindenmayer, D.B. Landscape modification and habitat fragmentation: A synthesis. *Glob. Ecol. Biogeogr.* **2007**, *16*, 265–280. [CrossRef]
5. Tilman, D.; Reich, P.B.; Knops, J.; Wedin, D.; Mielke, T.; Lehman, C. Diversity and productivity in a long-term grassland experiment. *Science* **2001**, *294*, 843–845. [CrossRef]
6. Hewitt, G. The genetic legacy of the Quaternary ice ages. *Nature* **2000**, *405*, 907–913. [CrossRef]
7. Grimm, N.B.; Chapin, F.S., III; Bierwagen, B.; Gonzalez, P.; Groffman, P.M.; Luo, Y.; Melton, F.; Nadelhoffer, K.; Pairis, A.; Raymond, P.A. The impacts of climate change on ecosystem structure and function. *Front. Ecol. Environ.* **2013**, *11*, 474–482. [CrossRef]
8. Araújo, M.B.; Alagador, D.; Cabeza, M.; Nogués-Bravo, D.; Thuiller, W. Climate change threatens European conservation areas. *Ecol. Lett.* **2011**, *14*, 484–492. [CrossRef]
9. Franklin, J. Species distribution models in conservation biogeography: Developments and challenges. *Divers. Distrib.* **2013**, *19*, 1217–1223. [CrossRef]
10. Zhang, K.; Zhang, Y.; Jia, D.; Tao, J. Species distribution modeling of Sassafras tzumu and implications for forest management. *Sustainability* **2020**, *12*, 4132. [CrossRef]
11. Brito, J.C.; Acosta, A.L.; Álvares, F.; Cuzin, F. Biogeography and conservation of taxa from remote regions: An application of ecological-niche based models and GIS to North-African Canids. *Biol. Conserv.* **2009**, *142*, 3020–3029. [CrossRef]
12. Warren, D.L.; Glor, R.E.; Turelli, M. Environmental niche equivalency versus conservatism: Quantitative approaches to niche evolution. *Evol. Int. J. Org. Evol.* **2008**, *62*, 2868–2883. [CrossRef] [PubMed]
13. Ab Lah, N.Z.; Yusop, Z.; Hashim, M.; Mohd Salim, J.; Numata, S. Predicting the Habitat Suitability of Melaleuca cajuputi Based on the MaxEnt Species Distribution Model. *Forests* **2021**, *12*, 1449. [CrossRef]
14. Smeraldo, S.; Bosso, L.; Salinas-Ramos, V.B.; Ancillotto, L.; Sánchez-Cordero, V.; Gazaryan, S.; Russo, D. Generalists yet different: Distributional responses to climate change may vary in opportunistic bat species sharing similar ecological traits. *Mammal Rev.* **2021**, *51*, 571–584. [CrossRef]
15. Kalia, R.K.; Rai, M.K.; Sharma, R.; Bhatt, R. Understanding *Tecomella undulata*: An endangered pharmaceutically important timber species of hot arid regions. *Genet. Resour. Crop Evol.* **2014**, *61*, 1397–1421. [CrossRef]
16. Chopra, R.N.; Nayer, S.L.; Chopra, I.C. *Glossary of Indian Medicinal Plants*; Council of Scientific & Industrial Research: New Delhi, India, 1992.
17. Kar, A.; Garg, B.; Singh, M.; Kathju, S. *Trends in Arid Zone Research in India*; Central Arid Zone Research Institute: Jodhpur, India, 2009; Volume 29.
18. Khan, T.; Dular, A.K.; Solomon, D.M. Biodiversity conservation in the Thar Desert; with emphasis on endemic and medicinal plants. *Environmentalist* **2003**, *23*, 137–144. [CrossRef]
19. Singh, A. Endangered economic species of Indian desert. *Genet. Resour. Crop Evol.* **2004**, *51*, 371–380. [CrossRef]
20. Ravishankar, B.; Shukla, V.J. Indian systems of medicine: A brief profile. *Afr. J. Tradit. Complement. Altern. Med.* **2007**, *4*, 319–337. [CrossRef]
21. Singh, G.J. Comparative productivity of *Prosopis cineraria* and *Tecomella undulata* based agroforestry systems in degraded lands of Indian Desert. *J. For. Res.* **2009**, *20*, 144–150. [CrossRef]
22. Xu, W.; Jin, J.; Cheng, J. Predicting the Potential Geographic Distribution and Habitat Suitability of Two Economic Forest Trees on the Loess Plateau, China. *Forests* **2021**, *12*, 747. [CrossRef]
23. Zhang, Y.; Liu, X.; Chen, G.; Hu, G. Simulation of urban expansion based on cellular automata and maximum entropy model. *Sci. China Earth Sci.* **2020**, *63*, 701–712. [CrossRef]
24. Braunisch, V.; Suchant, R. Predicting species distributions based on incomplete survey data: The trade-off between precision and scale. *Ecography* **2010**, *33*, 826–840. [CrossRef]
25. Hefley, T.J.; Baasch, D.M.; Tyre, A.J.; Blankenship, E.E. Correction of location errors for presence-only species distribution models. *Methods Ecol. Evol.* **2014**, *5*, 207–214. [CrossRef]
26. Fortin, M.-J. Effects of sampling unit resolution on the estimation of spatial autocorrelation. *Ecoscience* **1999**, *6*, 636–641. [CrossRef]
27. Zhong, L.; Ma, Y.; Salama, M.; Su, Z. Assessment of vegetation dynamics and their response to variations in precipitation and temperature in the Tibetan Plateau. *Clim. Change* **2010**, *103*, 519–535. [CrossRef]
28. Zhang, L.; Cao, B.; Bai, C.; Li, G.; Mao, M. Predicting suitable cultivation regions of medicinal plants with Maxent modeling and fuzzy logics: A case study of *Scutellaria baicalensis* in China. *Environ. Earth Sci.* **2016**, *75*, 361. [CrossRef]
29. Rana, S.K.; Rana, H.K.; Ghimire, S.K.; Shrestha, K.K.; Ranjitkar, S.J. Predicting the impact of climate change on the distribution of two threatened Himalayan medi cinal plants of Liliaceae in Nepal. *J. Mt. Sci.* **2017**, *14*, 558–570. [CrossRef]

30. Ancillotto, L.; Bosso, L.; Smeraldo, S.; Mori, E.; Mazza, G.; Herkt, M.; Galimberti, A.; Ramazzotti, F.; Russo, D. An African bat in Europe, *Plecotus gaisleri*: Biogeographic and ecological insights from molecular taxonomy and Species Distribution Models. *Ecol. Evol.* **2020**, *10*, 5785–5800. [CrossRef]
31. Soilhi, Z.; Sayari, N.; Benalouache, N.; Mekki, M. Predicting current and future distributions of Mentha pulegium L. in Tunisia under climate change conditions, using the MaxEnt model. *Ecol. Inform.* **2022**, *68*, 101533. [CrossRef]
32. Phillips, S.J.; Anderson, R.P.; Schapire, R.E. Maximum entropy modeling of species geographic distributions. *Ecol. Model.* **2006**, *190*, 231–259. [CrossRef]
33. Wei, B.; Wang, R.; Hou, K.; Wang, X.; Wu, W. Predicting the current and future cultivation regions of Carthamus tinctorius L. using MaxEnt model under climate change in China. *Glob. Ecol. Conserv.* **2018**, *16*, e00477. [CrossRef]
34. Gebrewahid, Y.; Abrehe, S.; Meresa, E.; Eyasu, G.; Abay, K.; Gebreab, G.; Kidanemariam, K.; Adissu, G.; Abreha, G.; Darcha, G. Current and future predicting potential areas of *Oxytenanthera abyssinica* (A. Richard) using MaxEnt model under climate change in Northern Ethiopia. *Ecol. Processes* **2020**, *9*, 1–15. [CrossRef]
35. Iverson, L.R.; McKenzie, D. Tree-species range shifts in a changing climate: Detecting, modeling, assisting. *Landsc. Ecol.* **2013**, *28*, 879–889. [CrossRef]
36. Upadhyaya, A. Shelterbelt plantations effectively check sand deposition in Indira Gandhi Canal. *Indian For.* **1991**, *117*, 511–514.
37. Elith, J. Quantitative methods for modeling species habitat: Comparative performance and an application to Australian plants. In *Quantitative Methods for Conservation Biology*; Springer: Berlin/Heidelberg, Germany, 2000; pp. 39–58. [CrossRef]
38. Swets, J.A. Measuring the accuracy of diagnostic systems. *Science* **1988**, *240*, 1285–1293. [CrossRef]
39. Elith, J.; Graham, C.H. Do they? How do they? WHY do they differ? On finding reasons for differing performances of species distribution models. *Ecography* **2009**, *32*, 66–77. [CrossRef]
40. Sheppard, C. How does selection of climate variables affect predictions of species distributions? A case study of three new weeds in New Zealand. *Weed Res.* **2013**, *53*, 259–268. [CrossRef]
41. Hirsch, T. *Global Biodiversity Outlook 3*; UNEP/Earthprint: Montreal, QC, Canada, 2010.
42. Edwards, P.N. *Complete Bibliography of all Items Cited in A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*; MIT Press: Cambridge, MA, USA, 2010.
43. Williams, J.W.; Jackson, S.T.; Kutzbach, J.E. Projected distributions of novel and disappearing climates by 2100 AD. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 5738–5742. [CrossRef]
44. Parmesan, C.; Yohe, G. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* **2003**, *421*, 37–42. [CrossRef]
45. Zhang, K.; Yao, L.; Meng, J.; Tao, J. Maxent modeling for predicting the potential geographical distribution of two peony species under climate change. *Sci. Total Environ.* **2018**, *634*, 1326–1334. [CrossRef]
46. Harsch, M.A.; HilleRisLambers, J. Climate warming and seasonal precipitation change interact to limit species distribution shifts across Western North America. *PLoS ONE* **2016**, *11*, e0159184. [CrossRef]
47. Lemmens, C.M.; De Boeck, H.J.; Gielen, B.; Bossuyt, H.; Malchair, S.; Carnol, M.; Merckx, R.; Nijs, I.; Ceulemans, R. End-of-season effects of elevated temperature on ecophysiological processes of grassland species at different species richness levels. *Environ. Exp. Bot.* **2006**, *56*, 245–254. [CrossRef]
48. Carrer, M.; Motta, R.; Nola, P. Significant mean and extreme climate sensitivity of Norway spruce and silver fir at mid-elevation mesic sites in the Alps. *PLoS ONE* **2012**, *7*, e50755. [CrossRef]
49. Zimmermann, N.E.; Yoccoz, N.G.; Edwards, T.C.; Meier, E.S.; Thuiller, W.; Guisan, A.; Schmatz, D.R.; Pearman, P.B. Climatic extremes improve predictions of spatial patterns of tree species. *Proc. Natl. Acad. Sci. USA* **2009**, *106* (Suppl. 2), 19723–19728. [CrossRef]
50. Monteith, K.L.; Klaver, R.W.; Hersey, K.R.; Holland, A.A.; Thomas, T.P.; Kauffman, M.J. Effects of climate and plant phenology on recruitment of moose at the southern extent of their range. *Oecologia* **2015**, *178*, 1137–1148. [CrossRef]