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Opuntia Invasion Risk and Management Strategies in China: A Comprehensive Review Under Climate Change Scenarios

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Abstract

Including China, the genus Opuntia—prickly pear cactus—has expanded to be a quite problematic invading species in many other nations. Considering Opuntia's environmental impact, current policies, and recommendations for next control actions, this review assesses the possible distribution and invasion risk of the plant under climate change conditions. We investigate the species' present distribution in China, the biological traits allowing its proliferation, and the environmental elements driving its expansion. Mechanical, chemical, and biological control techniques are among the management strategies under careful evaluation; integrated pest management (IPM) shows great potential. We discuss ecological difficulties, the limited effectiveness of mechanical and chemical methods, and the non-target effects of biological controls. Early identification, public awareness campaigns, and biosecurity policies combined with proactive preventative programs will help to reduce future invasions. The paper underlines the importance of ongoing research to better understand the dynamics of Opuntia invasions and the development of more rational, region-specific control techniques. Improving early-warning systems, increasing stakeholder involvement, and developing adaptive management techniques to handle the expanding threat Opuntia presents in China's ecosystems and agricultural sectors should take the front stage in future initiatives.

Keywords: Opuntia, Invasion Risk, Climate Change, Distribution Patterns, Management Strategies

1. Introduction

Native to the Americas, the genus Opuntia—often known as prickly pear cactus—is a quite broad collection of succulent plants. These plants have attracted a lot of interest because of their possible commercial use as food, feed, and source of several other items [1,2]. Opuntia species introduced beyond their natural habitat have, however, also raised questions over their possible invasiveness and effects on nearby ecosystems [3]. Comprising more than 200 species, the genus Opuntia belongs to the Cactaceae family; Opuntia ficus-indica Mill is the most often grown and commercially important species in this group [2]. These plants differ mostly in their flat, paddle-like cladodes (stem segments) and spines, which vary in density and size [4]. Opuntia species' great adaptability to many environmental conditions—including drought, high temperatures, and poor soil—allows them to be resilient and successful both in native and introduced ranges. Climate change is expected to affect the distribution patterns and invasion potential of certain species even more [3,5]. Their unique cladodes, act as the main photosynthetic organs and allow water storage in their fleshy tissues, therefore enabling their survival in arid and semi-arid conditions. These characteristics enable Opuntia species to especially fit for challenging environmental circumstances [6]. Beyond their fortitude, Opuntia is quite important in ecology, farming, and culture. Their edible fruits, pads (cladodes), and seeds—which provide food, fodder, and other uses—are grown Ecologically, they are vital in dry and semi-arid environments since they give different species food and habitat. Culturally speaking, the prickly pear cactus is important—especially in Latin America, where it is closely entwined with regional customs and ceremonies [7-9]. Often referred to as prickly pear cactus, the genus Opuntia has a broad distribution spanning both its natural habitat in the Americas and regions of introduction. This addresses a review of its past and present distribution patterns as well as projections for future changes under conditions of climate change [10,5]. Originally American, Opuntia species are most varied in Mexico and the southern United States. Originally introduced to other

regions over time including Africa, Europe, Asia, and Australia mostly for agricultural and decorative purposes, these species have [3,11]. Opuntia species currently found on every continent except Antarctica have developed populations in numerous countries. Their distribution is affected by elements like climate conditions, soil properties, and human activity including both deliberate introductions and inadvertent dissemination. Efforts at mapping have given important new perspectives on their present distribution [12,13]. Looking ahead, climate change is expected to greatly influence the future distribution of Opuntia. Modeling approaches predict changes in suitable habitats for different species under different climate scenarios, so guiding the identification of areas that might become more or less suitable for Opuntia growth and invasion in the next decades [14,15].The whole assessment of invasion threats for the genus Opuntia demands a thorough research of the variables affecting their invasive capacity, including biological characteristics, ecological interactions, and the effect of human activities [16,17]. Rapid vegetative development, effective seed distribution systems, tolerance to different environmental stresses, and the capacity to outcompete native plant species help Opuntia species exhibit several biological traits that increase their invasiveness, so enabling them to colonize and dominate disturbed habitats [18]. Ecologically, by changing habitat structure and species composition and hence upsetting native plant-animal interactions like pollination and seed distribution networks, Opuntia incursions can greatly affect local ecosystems. Furthermore, their introduction can help other invading species to establish using habitat changes [19]. Major causes of Opuntia's proliferation have been human-mediated actions including deliberate introductions for agricultural, horticultural, and ornamental uses as well as inadvertent dissemination through contaminated goods and transportation. In some places, the absence of efficient management and control strategies aggravates invasion threats [3]. Several biological traits of Opuntia species improve their invasive potential: fast vegetative growth and propagation via cladode fragmentation effective seed distribution systems sometimes made possible by animals, and a great tolerance for many environmental circumstances including drought and poor soils [19,4]. These species inhabit damaged areas and outcompete native plants. Ecologically, Opuntia invasions can greatly change habitat structure and species composition in natural and semi-natural ecosystems, disturb native plant-animal interactions including pollination and seed dispersal networks, and help other invasive species to establish themselves by habitat modifications [20,21]. Human activities also significantly contribute to their spread: deliberate introductions for agricultural, horticultural, and ornamental uses; inadvertent dissemination via contaminated agricultural products, machinery, and vehicles; insufficient management and control measures in some areas [3,18]. The purpose of this review is to explore the potential distribution patterns and invasion risk of the genus Opuntia under climate change scenarios in China and globally. The review aims to investigate the historical and present distribution patterns of Opuntia species in both native and introduced areas; assess the invasion risk based on biological traits, ecological interactions, and human activities; evaluate the impacts of climate change on the future distribution and invasion potential of Opuntia species; and discuss strategies for managing and minimizing the invasion risks, including prevention, control, and eradication activities.

1.1 Biological Characteristics and Invasion Mechanisms of Opuntia

Studies of Opuntia species—including Opuntia stricta, Opuntia ficus-indica, Opuntia monacantha, and Opuntia humifusa—showcase the complex interactions among these invasive species and their surroundings. Among the several ways these organisms are known to upset natural ecosystems, allelopathy and mutualism disturbance are two. Managing these species calls for a multimodal strategy including ecological, chemical, and technological considerations. Because of their great impact as invading species, many studies on invasion and control have concentrated on Opuntia species including Opuntia stricta, Opuntia ficus-indica, Opuntia monacantha, and Opuntia humifusa. Originally introduced, these cacti have spread around the globe mostly avoiding domestication and becoming invasive in areas including the Mediterranean, Africa, and Australia. Variations in local abiotic conditions, invader quantity, and native community traits and composition mean that the impacts of a biological invasion on native communities are expected to be unequal over invaded areas. One approach to improve prediction capacity about the effects of an invading species given changing conditions is by exploiting the recognized mechanisms behind their success. Commonly seen in invading species are allelopathic traits, which can be either directly or indirectly harmful to plants via altering root symbionts such as mycorrhizal fungi. The indirect approach is expected to affect plants depending on mycorrhizas by upsetting mutualism; non-mycorrhizal plant species will not be affected (Roche et al., 2023).Native Lactuca indica combined with four invasive species found that the native plant's response relies on the identification and variation of the invading species. The study indicated that the total biomass of the native plant reduces at high density and increases at low invading plant richness. Increasing invasive plant richness increases the leaf nitrogen content of the native plant, implying more effect from invading plant identity (Kama et al., 2023).

Climate change, global trade, and human mobility are all helping exotic invasive vegetation to spread. Their secondary metabolite emissions—that of root exudates and volatile organic compounds—VOCs—change ecosystems. These molecules have been well investigated and are known to increase invasiveness. Still, their ecological effects are little known. A systematic analysis of studies spanning 2012–2022 reveals that invasive plants display increased chemical variation and distinct chemical behavior in native than invaded environments. VOC emissions are influenced by herbivory, soil microbes, temperature changes, and carbon dioxide levels. Environmental changes could make invading plants less variable in VOC emissions (Clavijo McCormick et al., 2023). The biodiversity and ecological services are seriously threatened by invading alien species. Managing them depends on knowing their dispersion and proliferative processes. Data collecting is much improved by unmanned aerial vehicle (UAV) monitoring. Six RGB indices were evaluated using UAV images

for their ability to detect invading plant species. Results for the common milkweed cover area showed that TGI and SSI indices were the most accurate; for the blanket flower cover area, the index was the most suitable. These methods allow those in conservation fast, cheap, and efficient data processing (Bakacsy et al., 2023). Although the invading features of Opuntia species occupy the stage, their possible advantages as a food source and in arid terrain agriculture should not be overlooked. Still, their invading characteristics usually outweigh these benefits and need careful control to protect nearby ecosystems. As provided in the table below, we summarized the current research findings on some Opuntia Species and their regions or countries of study.

Continent	Country	Species	Findings of the studies	References
America	Crimea	*Opuntia engelmannii,* *O. fragilis,* *O. humifusa,* *O. macrorhiza,* *O. phaeacantha,* *O. polyacantha,* *O. tortispina,* *O. tunoidea*	Distribution and Naturalization	(Bagrikova & Perminova, 2022)
	Mexico	*15% of Opuntia species* *O. ficus-indica* *O. albicarpa* *O. megacantha* *O. xoconostle,* *O. robusta* *O. streptacantha* *O. vulgaris,* *O. microdasys,* *O. dillenii O.dejecta* *O. hyptiacantha,*	Genetic Diversity and Taxonomy, Implications for Biodiversity and Agriculture Knowledge of Flower-Visiting Insects, Cultural and Economic Importance, Biological and Environmental Factors, Beneficial effects of *Opuntia spp* Geographic Distribution and Habitat Suitability Phytochemical and Health Benefits Global Studies on *Opuntia ficus-indica*	(Caruso et al., 2010) (Moctezuma et al., 2015) (Escandón et al., 2022) (Nondumiso Dlamini, n.d.) (Orozco, 2024) (Eseverri et al., 2023) (Jiménez et al., 2023) (Santillán et al., 2022, p. 1) (Shoukat et al., 2023)
	Santiago, Chile	multiple *Opuntia species*	Agricultural Applications	(Jacobo & González, 2001)
	Brazil	*Opuntia species* *O.bonaerensis*	Initial performance evaluation of *Opuntia spp*. Conservation and Biogeographic History	(Santos et al., 2023) (Köhler et al., 2020)
	Uruguay	*Opuntia bonaerensis*	Conservation and Biogeographic History	(Köhler et al., 2020)
	United States Midwestern United States	*prickly pear cactus* *O. fragilis* *O. humifusa* *O. macrorhiza*	Detection and Spatial Patterns Environmental Constraints and Genetic Studies	(Jaime et al., 2023) (Majure & Ribbens, 2012)
	Argentina	*Opuntia anacantha* *O. bispinosa* *O. brunnescens* *O. discolor* *O. distans* *O. hildemannii* *O. kiskaparrot* *O. pampeana* *O. sulphurea* *O. vulpina*	Taxonomic Studies	(Oakley et al., 2024)

	Canada	*Opuntia dillenii*	Studies in Tropical and Subtropical Regions	(Lu et al., 2023)
	South-East Pacific Islands	naturalized alien species richness and native species richness	Ecological Impact and Naturalization	(Polgrossi et al., 2023)
	----------	*Opuntia stricta,* *O. ficus-indica,* *O. monacantha*	Challenges in Management	(Humphries et al., 2022)
Europe O.tortispina,	Spain	*Opuntia ficus indica*	Global Studies on *Opuntia ficus-indica*	(Shoukat et al., 2023)
	Italy	*Opuntia ficus indica*	Global Studies on *Opuntia ficus-indica*	(Shoukat et al., 2023)
Africa	Morocco	*prickly pear* *Opuntia dillenii (Ker Gawl.) Haw.* *O. ficus-indica (L.) Mill*	Propagation and Conservation Phytochemical and Health Benefits	(Marhri et al., 2023) (Bouhrim et al., 2021)
	Ethiopia	*Opuntia ficus-indica* *O. stricta* *O. robusta*	nutritional and chemical composition of *Opuntia species,* Climate Change and Distribution Modeling, Socio-Economic Impacts	(Teklu et al., 2023) (Hussein & Estifanos, 2023) (Shackleton et al., 2017)
	South Africa	Alien plants <u>*Opuntia fcus-indica (L.) Mill*</u>	Decline in Invasion Risk in Southern Africa, Genetic Diversity and Adaptation, Economic Contribution Demographic Insights Lack of Awareness Socio-Economic Factors Gender Dynamics Uses of Prickly Pear Policy Implications Global Studies on *Opuntia ficus-indica*	(Omer et al., 2024) (Modise et al., 2024) (Moshobane et al., 2022) (Shoukat et al., 2023)
	Tanzania	*Opuntia stricta*	Socio-Economic Impacts	(Shackleton et al., 2017)
	Kenya	*Opuntia stricta*	Socio-Economic Impacts	(Shackleton et al., 2017)
	Tunisia	*Opuntia dillenii*	Studies in Tropical and Subtropical Regions	(Lu et al., 2023)
	Algeria	*Opuntia dillenii*	Studies in Tropical and Subtropical Regions	(Lu et al., 2023)
	Nigeria	*Opuntia dillenii*	Studies in Tropical and Subtropical Regions	(Lu et al., 2023)
	----------	*Opuntia stricta,* *O. ficus-indica,* *O. monacantha*	Challenges in Management	(Humphries et al., 2022)
	----------	*O. streptacantha,* *O. hyptiacantha,* *O. albicarpa,* *O. megacantha* *O. ficus-indica*	Phytochemical and Health Benefits	(Santillán et al., 2022, p. 1)
Asia	Pakistan	*Opuntia dillenii, O.ficus-indica,* *O.monacantha*	Distribution and Naturalization Studies in Tropical and Subtropical Regions	(Bartolomeo, et al., 2021) (Lu et al., 2023)
	Bangladesh	*Opuntia dillenii*	Studies in Tropical and Subtropical Regions	(Lu et al., 2023)
	South Korea	*Opuntia ficus-indica* *Alien plant species*	Biological Properties and Applications Climate Change and Distribution Modeling	(Nam et al., 2023) (Adhikari et al., 2022)

Implications for Biodiversity and Agriculture	China	Invasive species *Opuntia dillenii*	Distribution Modeling Studies in Tropical and Subtropical Regions Biological Properties and Applications	(Wang et al., 2023) (Lu et al., 2023) (Lu et al., 2023)
	----------	*O. streptacantha,* *O. hyptiacantha,* *O. albicarpa,* *O. megacantha* *O. ficus-indica*	Phytochemical and Health Benefits	(Santillán et al., 2022, p. 1)
	----------	*Opuntia stricta,* *O. ficus-indica,* *O. monacantha*	Challenges in Management	(Humphries et al., 2022)
	----------	*prickly pear cladodes*	Nutritional and Health Benefits	(Kashif et al., 2022)
	----------	*Opuntia ficus indica*	Product Development and Storage	(Sakhraoui et al., 2023)
	----------	*Opuntia ficus-indica*	Phenotypic Plasticity and Invasion Success	(Tesfay et al., 2023)
	----------	*Opuntia maxima* *O. dillenii,*	Material Science	(Castellano et al., 2021)

Table 1: Summary of current research findings on some Opuntia Species and their Regions or Countries of Studies

1.2 Global and Local Distribution of Opuntia and Its Expansion Potential in China

a. Historical Distribution

Native to the Americas, the genus Opuntia, sometimes known as prickly pear cactus, ranges from Canada to Chile [3,16]. Opuntia's native range consists of desert, semi-desert, and dry, subtropical areas in which the plants have evolved to flourish in arid and semi-arid surroundings. Often utilized as a fruit crop, cow feed, or adornment, Opuntia species have been extensively introduced and cultivated all over the globe including Africa, Europe, Asia, and Australia [9]. Some populations over time have grown naturalized and invasive in these new areas, endangering native ecosystems [16]. Opuntia's successful introduction in many parts of the world can be ascribed to several elements, including its capacity to propagate vegetatively, the dispersal of its fruits and seeds by animals, and its adaptation to many environmental conditions, including drought tolerance and the capacity to grow in nutrient-poor soils [3,4]. Often used as a fruit crop, cattle fodder, or adornment, Opuntia species have been extensively introduced and cultivated over time in many regions of the world, including Africa, Europe, Asia, and Australia. Introduced Opuntia populations growing naturalized and invasive in these new regions sometimes endanger native ecosystems. This can be ascribed to the genus's propensity to spread vegetatively, the way its fruits and seeds are distributed by animals, and its adaptation to many environmental circumstances, including drought tolerance and the aptitude to grow in nutrient-poor soils [22].

b. Current Distribution

Though the genus is most common in the Americas, where it is native, Opuntia species are now found in many other areas worldwide. Opuntia has been brought and naturalized outside of its native area in numerous regions including Africa, Europe, Asia, and Australia [3,18,9]. Mostly imported into and grown in China, opuntia species have been used as a food crop and as a fodder crop. Some introduced populations—especially in the southern and central parts of the nation—have become invasive, though. Other areas, including sections of Europe and Africa, have also observed the naturalizing and invading spread of Opuntia species, which can have a major effect on nearby ecosystems and biodiversity [16,23,24]. Tracking the spread and distribution of Opuntia species in China and other areas is dependent on constant monitoring and surveillance as their potential for invasion and effect on native ecosystems can be substantial.

1.3 Mapping of existing populations in China and globally

Though the genus is most common in the Americas, where it is native, Opuntia species are now found in many other areas worldwide. Opuntia has been transported and naturalized outside of its native range in several countries including Australia, Europe, Asia, and Africa [16,9]. The native distribution and invasion of Opuntia Species worldwide are shown here.

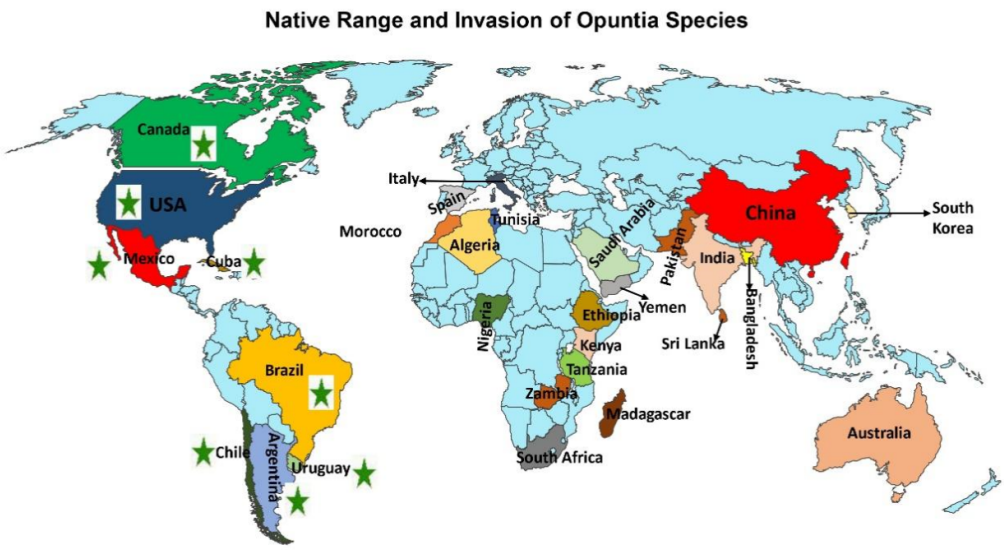

Figure 1: The Map Depicting the Native Range (Marked with Green Stars) and The Global Invasion of Opuntia Species.

Figure 2: The Map of Opuntia Invasion in Chinese Provinces

1.4 Factors Influencing the Current Distribution

Many elements influence the present range of Opuntia species, including historical introductions and cultivation for uses including decorative, agricultural, and cattle feed. Their flexibility to many environmental conditions—including drought tolerance and the capacity to flourish in nutrient-poor soils—has helped them to establish an even more broad spectrum. Often helped by animals, Opuntia species also show efficient vegetative propagation and seed distribution systems, which help them to disperse and build populations in new areas [25,26]. In places where Opuntia has been brought in, continuous monitoring and management projects are essential to assist reduce any possible impact on nearby ecosystems.

1.5 Projected Distribution under Climate Change Scenarios

The prospective distribution of Opuntia species in both their natural ranges and regions where they have been introduced is most likely going to be seriously altered by climate change. Changes in precipitation patterns and rising temperatures are probably going to affect the suitability of habitats for Opuntia, thereby perhaps causing range expansions in some areas and contraction in others. Areas that Opuntia finds inappropriate now could turn out to be a better fit, so creating new introductions and invasion opportunities. On the other hand, locations that are now fit could become less so, maybe resulting in the extinction or reduction of current populations [27,28,29]. Projecting the possible distribution of Opuntia species under various climate change scenarios using several modeling techniques including species distribution modeling and climate-based risk assessment These models assess areas that might become suitable or unsuitable for Opuntia in the future by using elements of temperature, precipitation, and other climatic variables together with knowledge on the species ecological needs and current distribution [12,30,15]. Projections on climate change suggest that Opuntia species distribution will vary in the next decades. Currently, inappropriate regions could become more appropriate, therefore helping Opuntia to be introduced and

established in other places. On the other hand, certain regions that are now fit could become less so, resulting in the extinction or reduction of present populations. Opuntia's past of invasiveness in many parts of the world demands cautious consideration on introduction or cultivation [12,16,9].

2. Ecological and Socioeconomic Impacts of Opuntia Invasions

2.1 Current Climate Change Trends

Mostly brought on by human activities altering the global atmosphere and ecology, the temperature of the Earth is changing significantly. Global average temperatures have increased by around 1.1°C since the late 19th century; this trend is expected to continue [16]. Precipitation patterns have also changed; some areas experience more severe rain while others suffer protracted drenches. Wide effects of these fluctuations in temperature and precipitation are found in ecosystems, biodiversity, and human populations all around [16,31]. Rising atmospheric carbon dioxide concentrations, global temperature fluctuations, and precipitation pattern changes define key climate change factors affecting Opuntia's distribution and invasion potential. Since the Industrial Revolution, atmospheric carbon dioxide levels have risen by more than forty percent, directly influencing plant development including the photosynthetic efficiency and water-use capacity of Opuntia species [27]. Although precise reactions to elevated CO2 remain poorly known and need more study, elevated CO2 levels may improve the growth and productivity of Opuntia, hence enhancing its competitive ability and invisibility [32,33]. Opuntia distribution is likely to be much influenced by rising world temperatures. Warmer temperatures might let Opuntia spread into previously confined areas of higher latitudes and elevations from colder times. In some areas, nevertheless, higher frequency and intensity of heat waves and droughts could have harmful effects on specific Opuntia populations. Given much of this warming occurring in recent years, the Earth's average surface temperature has already increased by roughly 1.1°C; forecasts indicate additional warming contingent on future greenhouse gas emissions [16,27,34].

The spread and invasion potential of Opuntia are also greatly shaped by variations in precipitation patterns. Changes in precipitation patterns, such as extended droughts or heavy rainfall events, could influence habitat appropriateness for Opuntia, so allowing spread into previously unsuitable regions and so lowering suitability in others. Changing water supply in certain regions and decreased availability in others could greatly affect Opuntia spread and establishment [32]. Future climate change scenarios—including those offered by the Representative Concentration Pathways of the Intergovernmental Panel on Climate Change—offer interesting forecasts for evaluating prospective changes in Opuntia distribution and invasion threats in different places. These realizations will guide policies for controlling how climate change affects Opuntia population [35,27,32,33].

3. Future Projections

Projections for future climate conditions are offered by models and scenarios including the Representative Concentration Pathways created by the Intergovernmental Panel on Climate Change. These simulations suggest that the degree and speed of climate change would most likely rise in the following decades with significant effects on the distribution and invasion potential of many plant species, including Opuntia. Evidence indicates that the distribution and abundance of invading species, including the genus Opuntia, are mostly influenced by climate change [32]. Variations in key climatic variables, such as temperature and precipitation, could influence the potential of a species to survive and grow in new environments, therefore influencing invasion risk. Regional models relevant for China and other countries: Various climate change models—including the Representative Concentration Pathways—offer projections for future temperature and precipitation patterns over different regions. These simulations suggest that the degree and speed of climate change would most likely rise in the following decades with significant effects on the distribution and invasion potential of many plant species, including Opuntia. For example, climate models indicate that the geographical distribution of Opuntia may widen in northern latitudes, where warmer winters and greater temperatures could help the species grow and spread. However, in other regions, the increased frequency and intensity of droughts and heat waves associated with climate change may negatively impact Opuntia populations. [16,27].

4. Expected Impacts on Ecosystems and Biodiversity

Shifts in species distributions, changes in community composition, and potential threats to vulnerable habitats and species are anticipated as a result of climate change [36,37,31]. Invasions of invasive Opuntia species can have major effects on native ecosystems including changes in habitat structure and resources, modification of fire patterns, and competition with native plants. As Opuntia can outcompete and replace native plant communities, the possibility for more distribution and abundance under climate change scenarios could endanger the biodiversity of areas where it is introduced [3].

5. Invasion Risk Assessment

5.1 Definition and Importance of Invasion Risk Assessment

Invasion risk assessment is very crucial in determining whether a non-native species could become invasive in a new location. It means carefully evaluating factors in a habitat where a species is not native that can influence its chances of effectively establishing, spreading, and producing negative effects. By assessing the invasion risk of Opuntia species, decision-makers and land managers can make informed decisions about the introduction, cultivation, and management of these plants, to minimize the potential for negative ecological and economic impacts [3,38,21].

5.2 Factors Contributing to Invasion Risk

The invasion risk of Opuntia species is generated in several major ways. Climate adaptability is quite significant since Opuntia can react to a wide range of environmental conditions, including various temperature and precipitation patterns. Moreover, their efficient reproductive and dispersal systems—including vegetative propagation and animal-mediated seed distribution—help their spread and establishment in new areas [3,38]. Opuntia's competitive strength—which consists of tolerance to drought,

nutrient-poor soils, and capacity to outcompete native plants—increases its invading potential even more [3]. Their invasive success in imported environments also results from the lack of herbivores, pathogens, or natural enemies including predators. Furthermore affecting the probability of their establishment is propagule pressure, determined by the frequency and extent of introduction events as well as the amount of people introduced [19]. The biological characteristics of Opuntia species underline their adaptability and resilience. Through vegetative propagation, these plants can reproduce both sexually and asexually despite demanding climatic conditions including dryness, poor soils, and high temperatures [3]. Animals often help to distribute the seeds, therefore facilitating their colonization of new environments. Through outcompeting and replacing native vegetation, Opuntia can alter the composition and structure of an ecosystem. Sensible risk assessment approaches for Opuntia species depend on an awareness of these features and invasion paths.

5.3 Ecological Interactions

Opuntia species invasions can have a major impact on ecosystems and human activities. Often altering the mix and placement of native plant populations, Opuntia invasions outcompete and replace native species. Moreover, these invasions affect nutrient cycling and soil properties, therefore changing the dynamics of the ecosystem. Opuntia affects relationships with natural species including herbivores and pollinators as well. A knowledge of these ecological interactions helps one to appreciate the consequences of Opuntia invasions and develop reasonable control strategies. Opuntia invasions have major ecological effects since the species can outcompete native plants and change ecosystem structure and function, therefore compromising biodiversity and ecosystem services [19]. Opuntia has a competitive edge over native species since it thrives in disturbed, nutrient-starved environments [19]. Its efficient dispersal mechanisms—which include vegetative reproduction and animal-mediated seed distribution—help it even more to reach new places [16,21]. Besides, Opuntia infestations cost money. Among these include reduced property prices, less agricultural output, and higher administrative and control costs. A vital instrument for assessing the possibility of non-native Opuntia species invading new areas and directing preventative actions to lower their financial and environmental impact is invasion risk assessment.

5.4 Human Activities and Spread

Opuntia species have been introduced and distributed differently depending on different human activities in recently conquered regions. One significant cause is commercial farming, in which Opuntia has been extensively brought as a crop for fruit, feed, and other agricultural applications, establishing it in many different countries all over [3,7,39]. Often planted for their esthetic appeal as ornamental plants, opuntia species can also cause wild escape and naturalization. Beyond intentional planting, Opuntia has been exploited for agricultural uses including food crops and animal feed, therefore promoting its spread [3]. The unintentional spread of Opuntia has been facilitated in great part by human-mediated pathways. Opuntia fruits and seeds have been unintentionally moved thanks to the transportation of cattle, machinery, and goods; vehicles and machinery have been especially successful in spreading these species into new habitats [40,18]. Further helping to spread the species are traffic and transportation activities including commodities and animal movement. Whether deliberate or inadvertent, human-driven paths have been vital in Opuntia's global distribution. A thorough evaluation of these elements is necessary to solve this problem together with consideration of their ecological and socioeconomic consequences. Such assessments can guide efficient management and decision-making, therefore helping to prevent future introductions, control of current populations, and reduction of negative effects on native ecosystems and human activities.

5.5 Assessment Methodologies

Combining several methodological approaches can let one evaluate the invasion risk and possible distribution patterns of Opuntia species under climate change scenarios. These demand quantitative as well as qualitative methods. While qualitative risk evaluations rely on expert-based assessments of Opuntia's features and invasion history, quantitative approaches use species distribution modeling and climate niche modeling to estimate possible invasion paths [19,16]. Case studies from regions where Opuntia is either present or can spread—such as China—offer the perceptive study of the species' behavior, consequences, and future growth potential. In such case studies, important issues include historical patterns of Opuntia introduction and spread, interactions with human land use and economic activities, environmental factors influencing its distribution and invisibility, ecological and economic impacts on native ecosystems and human activities, and the effectiveness of present management strategies [3,19,16,38]. Combining these case studies will help one to be fully aware of Opuntia's invasion risks and dispersion patterns under climate change. Holistically considering Opuntia's possible invasion hazards calls for a different strategy. This entails evaluating the species' present distribution, habitat preferences, and ecological and socioeconomic consequences in addition to combining qualitative and quantitative assessment techniques with regional case studies. Developing sensible plans to reduce the dangers connected with Opuntia invasions in the framework of a changing environment depends on such a combined approach [3,16,38,33].

5.6 Risk Assessment Results

The significant invading potential of Opuntia species presents ecological, financial, and management problems requiring thorough risk assessments and proactive mitigating solutions. Based on significant findings from risk studies, Opuntia species have a high chance of ongoing spread and invasion, particularly under conditions of climate change. These species have a competitive edge over native species since they show a broad climate tolerance and can survive in varied habitats including disturbed and nutrient-starved areas. This adaptability underscores the potential for Opuntia to expand its distribution and invade new regions as climate patterns shift [3,35,16]. The species' prolific vegetative reproduction and efficient seed dispersal mechanisms, combined with its adaptability to various climatic conditions,

enable rapid establishment and spread. Opuntia invasions can have major financial effects including lower property prices, higher management expenses, and lower agricultural output [3,38]. Furthermore, the proliferation of Opuntia can upset natural ecosystems, therefore changing the composition and structure of the plants and animals. Effective management practices are necessary to reduce these risks. Early diagnosis, quick reaction, and mechanical, chemical, and biological control techniques taken together have effectively handled Opuntia infestations. Active, all-encompassing policies comprising containment and targeted control efforts would help to prevent and decrease the negative consequences of Opuntia invasions in China and other countries. Emphasizing the need for better control and risk management techniques, the widespread human-mediated introduction and cultivation of Opuntia for both commercial and ornamental uses has greatly helped to explain its global proliferation. By comprehensively assessing the potential distribution patterns, invasion risks, and impacts of Opuntia under climate change scenarios, policymakers, and land managers can create better educated plans for minimizing the effects of its intrusions. Understanding the species' invasive potential and developing sensible management strategies depends on a multifarious approach combining qualitative and quantitative techniques and regional case study analysis [41].

5.7 Identified high-risk areas

Several sites in China and other countries are highly vulnerable to possible Opuntia invasions under climate change scenarios utilizing the analysis of climatic appropriateness, habitat preferences, and historical invasion patterns. These include sites where the species has already shown invading tendencies or areas with like climatic circumstances to its native range [3,16,38]. Moreover, areas with a great degree of human-mediated disturbance—such as agricultural fields, cities, and traffic hubs—can help Opuntia flourish [16]. Opuntia species closely match their ecological needs by thriving in areas with a high proportion of suitable habitats, including nutrient-poor, semi-arid, and disturbed settings [38]. Prioritizing preventive and management activities as well as putting early detection and quick response systems into use to help avert possible incursions depends on an identification of these high-risk regions. well-documented invasiveness of Opuntia ficus-indica in many regions, notably the Mediterranean and drylands, where it has had considerable consequences on native ecosystems and human activities both environmentally and economically. Several factors influence Opuntia's invading potential and distribution patterns under scenarios of climate change. Important players include its adaptability to a broad spectrum of climatic conditions, including drought tolerance and the capacity to flourish in disturbed, nutrient-starved ecosystems [3]. Its fast establishment and long-distance dissemination are made possible by its abundant vegetative reproduction through fragmentation and effective seed distribution systems sometimes supported by animals. Moreover, encouraging its dissemination has been human-mediated introductions for decorative, agricultural, and other purposes. Furthermore, revealed by historical patterns of invasion are Opuntia's typical establishment in regions with climatic conditions similar to those of its natural range. A fair evaluation of Opuntia's invasion threat and likely dispersion patterns in China and other parts of the globe depends on an integrated, multidimensional approach. Together with quantitative models of climate adaptability and habitat preferences, this involves qualitative evaluations of historical invasion patterns, ecological requirements, and human-mediated introductions [12,19]. These evaluations can point up locations particularly vulnerable to invasion and direct focused preventive and management policies. A thorough risk assessment, incorporating case studies from different regions and examining the species' adaptability and reproductive traits, is critical to evaluating its invasive potential under climate change scenarios. The species' wide climatic tolerance and ability to outcompete native species underscore its capacity to establish and spread rapidly in new regions [16,9]. Combining qualitative and quantitative methods will enable legislative bodies and land managers to develop informed, practical strategies to address issues of Opuntia invasion and protect fragile ecosystems.

5.8 Potential economic and ecological impacts

The invasion of Opuntia species can have considerable consequences on native ecosystems and human activities, therefore disturbing both ecological and socioeconomic aspects. Since it alters the structure and purpose of ecosystems and reduces biodiversity, the displacement and competition with native plant species mostly present a problem [3,19,16,38]. Opuntia's spread over farms and pastures also reduces agricultural output and cow grazing capability, therefore costing farmers and herders financial losses. Furthermore, the development of thick, impenetrable forests inhibits human and animal mobility, reduces resource access, and disturbs infrastructure [20]. Opuntia's flammability and ability to change fuel loads raise even another major issue about fire risk. Invaded areas risk more severe fire regimes and fire breakouts, therefore compromising natural habitats as well as human communities. Apart from that, Opuntia's sharp spines and glochids cause human health and safety hazards that result in injuries and infections; on the other hand, the invading species could also have negative effects on tourist and leisure activities in impacted regions. The ecological effects reach disturbances in nutrient cycling systems and ecosystem services in invaded regions [20]. This covers effects on cattle output, lower agricultural yields, and damage to natural habitats. Moreover, the expenses related to mechanical, chemical, and biological control strategies for Opuntia infestations impose a financial load. Direct expenses include less agricultural output, environmental damage, and negative impacts on infrastructure and human welfare. The degree of these effects will be determined by the particular area, surroundings, and socioeconomic background; so, proactive management techniques become even more important to stop and lower Opuntia invasions. Early identification of high-risk sites—especially given climate change—will define both early detection and fast response methods as well as preventive aims. To guide resource allocation, justify risk management techniques, and address Opuntia invasion concerns, first one must project their ecological and economic implications [3,20,16].

6. Case Studies and Management Strategies for Opuntia Invasions: Global and

6.1 Global Case Studies: Lessons for China

Although Opuntia has been extensively brought and grown all around, the genus has also become invasive in many areas of the globe with major effects on ecology and economy. Despite the main emphasis of this study being on the probable distribution patterns and invasion danger of Opuntia in China, it is equally crucial to take into account cases from other regions of the world where the genus has spread actively. For example, numerous Opuntia species transplanted to Australia have grown to be important agricultural and environmental pests, therefore seriously harming the ecology and economy. Similarly, in parts of Africa, Opuntia has been reported to outcompete native vegetation, reduce biodiversity, and negatively impact livestock productivity. Different management techniques have evolved and been applied following the invasion of Opuntia in several areas. Opuntia numbers have been somewhat managed using biological control strategies like the cochineal insect and the prickly pear moth—natural enemies. Moreover, good control of Opuntia invasions combines mechanical, chemical, and biological approaches. These global case studies offer perceptive analysis and lessons that can guide the development of particular management strategies for future Opuntia invasions in China. By learning from these incidents, stakeholders can use successful and better-educated plans to minimize Opuntia's impact on human activity and ecosystems [3,19,16,9].

6.2 Invasion in Mediterranean and Developing Countries

The Mediterranean region is identified as a worldwide invasion hotspot, hence the invasion of alien species in emerging nations and the Mediterranean itself generate major ecological and financial problems. Mostly driven by human-mediated paths including trade and aquaculture, which have caused major financial losses and damage to biodiversity, invasive species have exploded in this region. Over the past three decades, the Mediterranean basin has lost invasion costs of approximately $27.3 billion largely from damage rather than administrative costs [42]. These challenges highlight the basic need for coordinated worldwide management projects to fitly control the consequences of invading species. Particularly with species like Opuntia stricta and Opuntia maxima establishing themselves in different regions and aggravating land-cover changes affecting native ecosystems, the invasion of Opuntia species in the Mediterranean and developing countries presents major ecological and agricultural problems. These cacti disturb native flora and species, therefore lowering the biodiversity [43]. Their effective invasion is facilitated by mutualistic interactions with surrounding seed dispersers, such as birds and mammals, therefore enhancing their distribution [44]. Agricultural effects are especially noteworthy as the Opuntia cochineal scale (Dactylopius opuntiae) has evolved from a biological control agent to a pest endangering key Mediterranean prickly pear crops for food security [45]. Opuntia species have exploded in locations where agricultural land has been abandoned, filling once-used crop fields [43]. Their clever reproductive tactics and building of long-term seed banks [46]. complicate the elimination of these invading species and demand careful management with a twofold approach of prevention and long-term eradication plans to lower their impact. Apart from that, the invasive character of Opuntia stricta has grown to be a major issue in many nations, especially in the Mediterranean basin where it has just been identified as a pest. Originally somewhat extensively dispersed, covering Africa and Asia where it has not yet been recorded as a pest, this species has evaded domestication. Apart from Spain, several North African nations have reported Opuntia stricta, highlighting its ability to disturb natural ecosystems [47]. Although effective biological control initiatives have stemmed their spread in some regions, the likelihood of future introduction remains a major worry, especially concerning the nursery business.

6.3 Invasion in Australia and Africa

Originally intended for decoration, the invasion of Opuntia species like Opuntia aurantiaca and Opuntia stricta has drastically changed ecosystems in Australia and Africa, where these plants have thrived and generated financial and environmental issues. Changes in soil nutrient dynamics define their invasiveness; O. aurantiaca has been demonstrated to raise soil nitrogen and phosphorus contents by factors of up to 7 and 44, respectively [48]. Furthermore, the number and biomass production of native grass species decreases in invaded regions, therefore compromising rangeland productivity [48]. With notable infestations recorded in many areas, O. stricta has established sizable populations across Australia, South Africa, and Namibia. In Australia, Opuntia stricta and Opuntia aurantiaca are the most notable invasive species, having escaped cultivation and established widespread populations in southeastern Queensland and northeastern New South Wales [48,47]. In Africa, the ornamental trade poses a threat to new introductions, as O. pubescens in South Africa [49] shows. Biological control agents including cactus moths and cochineal have been used in management plans to assist in lowering O. aurantiaca numbers [48]. Though invading, Opuntia spp. can also be a good fodder source for cattle—particularly in semi-arid conditions (Sipango et al., 2022) [50].

7. Insight in China

7.1 Opuntia Invasion in China

China has traditionally used Opuntia farming—especially O. ficus-indica—for varied horticultural and agricultural purposes. Though Opuntia has been introduced in and naturalized in many areas of China, little research has been done on potential distribution patterns or invasion danger under climate change scenarios. Certain preliminary research suggests that China's different climatic conditions—from temperate to subtropical and desert areas—could provide suitable habitats for the spread of Opuntia species [16]. By helping Opuntia to grow and spread, the increasing frequency and intensity of extreme weather events—including droughts and heat waves—linked with climate change may worsen the invasion risk. These components underscore the need for a comprehensive assessment of Opuntia's likely spread and invasion risk in China as well as the development of reasonable management measures to reduce the financial and environmental effects of potential invasions.

8. Regional Impacts

The degree of naturalization and invasion by Opuntia species in China varies greatly according to the different climatic conditions and habitats found there. Opuntia has been recorded to spread widely in arid and semi-arid regions of northwest China, including the Xinjiang Uygur Autonomous Region, sometimes outcompeting native vegetation [3,19]. In Inner Mongolia and other northern regions, similarly, degraded grasslands and rangelands have seen the development of dense, impenetrable Opuntia thickets, so upsetting cattle grazing and restricting access to vital supplies. Furthermore, greatly affected are coastal areas and islands such as Hainan and Taiwan Province. Here Opuntia has invaded and changed coastal ecosystems, therefore changing their dynamics. Southern China's subtropical areas, including Guangdong and Guangxi provinces, raise further questions since Opuntia thrives in these conditions and could endanger nearby ecosystems [16,9]. These geographical case studies show how readily Opuntia could overrun various Chinese environments. They underline the need for a comprehensive national assessment to guide managerial policies. Reducing environmental and economic consequences and maximizing Opuntia's utilization hinges on balancing its potential benefits with the invasion risk.

9. Management Strategies Employed in China

Opuntia has been observed to cause extensive thickets and disturbance of native ecosystems in Guangdong and Guangxi provinces in Southern China. These regional case studies underline the many climate change and ecosystems in China that are sensitive to Opuntia invasions, therefore highlighting the need for a comprehensive, national assessment to guide management operations [19,16]. Opuntia invasions in China have been addressed with many strategies with varied degrees of success. Mechanical methods including hand removal and cutting have helped with small-scale infestations. These methods, meantime, are labor-intensive and usually unable to limit regeneration from left-over plant fragments. Although chemical control with herbicides has also been investigated, its efficacy is limited and the use of chemicals has hazards of unanticipated environmental effects. Opuntia might find ideal climatic conditions for establishment and spread in temperate parts of northern China, especially given climate change. Potential Opuntia invasions in these areas have financial and environmental consequences that demand quick attention and the creation of reasonable development strategies. Combining targeted grazing, biological control, and varietal selection might provide more practical long-term solutions for Opuntia control [3,19,16,9]. These regional case studies show the many climate conditions and ecosystems in China susceptible to Opuntia invasions. They stress the need for a comprehensive national assessment to guide and direct national projects in line.

10.Successful Management Scenarios and Lessons Learned

Apart from good management techniques, overseas experience can also provide analytical knowledge to address probable Opuntia invasions in China. One of the main teachings is the need for early identification and aggressive prevention. Early identification and management of many invading species, including Opuntia, significantly helps to control them before they have had the opportunity to spread far and cause substantial ecological and financial damage. Still, extremely essential lessons are the engagement of stakeholders and cross-sectoral cooperation. Successful management of Opuntia invasions usually depends on the cooperation of various parties, including residents, government departments, and the sectors of industry and forestry. Including these lessons in the development of management strategies for prospective Opuntia invasions in China would ensure more strong and successful outcomes. Although Opuntia invasions have presented major difficulties in many areas, China may learn from the successful management initiatives that have been shown here. For example, the cochineal insect's introduction as a biological control agent has been blamed for greatly lowering the abundance of invading Opuntia species in numerous Australian regions [3]. Likewise, in other parts of Africa, the combination of mechanical, chemical, and biological management techniques coupled with the support of alternative, non-invasive cultivars has succeeded in minimizing the consequences of Opuntia invasions [16]. These cases demonstrate how effectively a multi-pronged approach tailored to the local conditions and issues may control Opuntia invasions. Although Opuntia has a history of invading various regions of the globe, care is advised when bringing the plant to new sites. For example, the invasion of Opuntia species has been observed to alter habitat structure and species composition in the Mediterranean region; albeit dense and extensive stands are restricted to a few species [19]. Likewise, in some underdeveloped nations where Opuntia was brought for agricultural use, the plant has grown invasive and causes environmental issues, therefore complicating attempts to stop its growth. One of the most often used and commercially valuable cactus species, Opuntia ficus-indica, has caused major environmental problems when it has grown invasive. In Portugal, O. ficus-indica is even categorized as a controlled invasive alien species, suggesting knowledge of its potential harm to ecology [3]. These case studies emphasize the need for a sophisticated approach to Opuntia care that balances the possible benefits with the invasive risks. At last, under scenarios of climate change, potential distribution patterns and invasion risk of Genus Opuntia in China and other countries necessitate rapid attention and the development of reasonable management strategies [3,51,41,52]. Learning from other countries and effective management techniques will enable China to develop a comprehensive, multi-pronged plan to control Opuntia infestations and limit their financial and environmental repercussions.

11. Management Approaches for Controlling Opuntia Invasions

11.1 Current Management Practices

Opuntia invasions in China have been under control with different degrees of effectiveness using multiple strategies. Mechanical management approaches including hand removal and cutting have been used to handle small-scale infestations; but, these operations are labor-intensive and usually ineffective in stopping regrowth from surviving plant fragments [3]. While chemical control with herbicides has also been studied, its effectiveness is limited and the use of chemicals can lead to environmental consequences.

Although overgrazing can lead to other environmental issues and grazing animals, including goats, have demonstrated some success in reducing Opuntia numbers, this is not suitable for every ecosystem. Using natural enemies like the cochineal insect and the prickly pear moth, biological control—in some places—has demonstrated promising results. But China has utilized biological control relatively sparingly given concerns about probable non-target effects and challenges with commercial Opuntia production [3]. Emphasizing the need for a comprehensive national assessment to guide future management initiatives, the current Chinese management plans have had little success controlling Opuntia invasions [51,53]. Sometimes integrated systems incorporating mechanical, chemical, and biological control strategies have proven higher successful. Still, the success of various strategies differs, which highlights the need for more coordinated and major projects to manage the growing prospect of Opuntia invasions in China.

11.2 Prevention Strategies for Future Invasions

Managing Opuntia invaders' establishment and spread depends on prevention plans. Addressing infestations before they become uncontrollable depends mostly on early identification and quick reaction. Establishing early warning systems and strong monitoring and surveillance systems helps to enable prompt Opuntia detection. Strengthened border biosecurity regulations including inspections and quarantine processes will help Opuntia and other invading species to be stopped from reaching China. Public education and community involvement are just as important since they help to identify and record Opuntia sightings, therefore helping early detection and preventive projects. Reducing the risk of dispersion would depend on the encouragement of the acceptance of non-invasive Opuntia cultivars and the rejection of identified invading species. Moreover, educational initiatives let surrounding residents participate actively in these projects. Combining these projects is crucial to appropriately manage Opuntia invasions and protect China's agricultural systems against their harmful effects. Crucially also are proactive preventive policies [3,54,16].

11.3 Integrated Pest Management and Its Role in Mitigating Opuntia Invasions

Managing places where Opuntia invasions have already become entrenched depends on control and eradication initiatives. Good management could call for a mix of control strategies. Small-scale infestations can benefit from mechanical control techniques including physical removal, cutting, and burning; yet, sometimes repeated attempts are needed to stop regrowth from plant fragments. Chemical control—utilizing licensed herbicides—can also be advantageous; although, long-term environmental effects have to be closely investigated. Biological control—using natural enemies like the cochineal bug and the prickly pear moth—has shown promise in some locations, but its usage has been limited due to concerns with industrial farming and non-target consequences. In several disciplines, integrated management solutions integrating mechanical, chemical, and biological control techniques have proven better performance. Regular monitoring and assessment of the effectiveness of these control projects will help management strategies to be refined and changed over time. Cooperation with international experts and knowledge of successful management techniques overseas helps China to further improve control and eradication strategies. Combining information from the global management of Opuntia invasions allows China to develop more effective and sustainable solutions for this issue [3,55,56,41].

11.4 Recommendations for Future Management

Future management is suggested based on the examination of potential distribution patterns and invasion risk assessment of the genus Opuntia in China and other countries. To properly control Opuntia invasions, integrated pest management techniques should incorporate early identification, preventive, and control tactics. These approaches should include mechanical, chemical, and biological control techniques, catered to the particular environmental and financial situation of every area of China. Moreover very crucial in an integrated pest control plan is promoting the richness and diversity of beneficial organisms like natural enemies, pollinators, and decomposers [57]. From a policy aspect, it is necessary to draft and apply comprehensive legislation and regulations to prevent Opuntia and other invading species from being brought forth and multiplied. Good application and adoption of management methods relies on incorporating relevant stakeholders including land managers, farmers, conservation organizations, and citizens. Giving landowners and land managers incentives and enabling the application of best practices for opuntia invasion control would help to further enhance these programs [58,59].

12. Conclusion

Under climate change, the potential distribution and invasion risk of Genus Opuntia in China and other regions of the world raises serious issues that demand thorough and coordinated management activities. Although some control strategies have been tested, their effectiveness has been inconsistent; hence, additional research and funds are needed to develop and implement integrated pest management plans. China can better safeguard its ecosystems and agricultural systems from the possible effects of Opuntia invasions by using a multifarious strategy combining preventive, early identification, and control actions.

13. Summary of Key Findings

Globally and in China, climate change is predicted to modify the geographic ranges and effects of invading species including Opuntia. Mechanical, chemical, and biological control techniques among other management approaches have been used to control Opuntia invasions to varied degrees of success. Opuntia invasions in other areas have shown more potential for integrated pest management techniques, which mix several control tactics. Early identification and quick response will help to stop the beginning and spread of these invasions. Strengthening biosecurity policies, increasing public awareness, and motivating participation of stakeholders constitute fundamental components of effective preventive and management strategies. Early discovery and proactive avoidance are vital for the management of Opuntia invasions in China. Continuous research and financing in integrated

pest control strategies are needed to manage the potential risks Opuntia offers under climate change scenarios.

14. Implications for Biodiversity and Ecosystem Health

Especially in highly endemic and ecologically sensitive places, the invasion of Opuntia species substantially compromises biodiversity and ecosystem integrity. Opuntia invasions can outcompete native plant species, alter the structure and function of ecosystems, and disrupt nitrogen cycling pollinator activities as well as other positive organism activity. Maintaining the particular biodiversity and ecological integrity of China's natural environments requires combating Opuntia invasion.

15. Future Research Directions

Several future projects are suggested to help to better grasp and control potential distribution patterns and invasion danger of the genus Opuntia in China under climate change scenarios. Targeted research on the biological and ecological features of Opuntia species, their most likely distribution patterns, and the relationship between climate change and invasion dynamics would be much welcomed. Finding over long timeframes how Opuntia invasions affect ecological processes, biodiversity, and ecosystem services is especially important in sensitive or protected places. Starting projects for long-term and thorough observation can help one to track the spectrum, frequency, and consequences of Opuntia invasions over several regions of China. These projects should mix best practices from other sectors with creative research findings with continuous management modification and control approach success evaluation [60-99].

Conflicts of Interest

The authors have no conflicts of interest to declare relevant to this article's content.

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