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TECHNOGENESIS AS A DRIVER IN THE DEVELOPMENT OF RECREATIONAL AREAS FOR SUSTAINABLE DEVELOPMENT AND BIODIVERSITY CONSERVATION

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Abstract: In the face of intensifying anthropogenic pressures, rapid urban expansion, and widespread environmental degradation, the preservation of biodiversity and the implementation of sustainable land-use strategies have emerged as pressing global imperatives. This review critically examines the complex ecological challenges that arise in industrialized regions, offering insights into contemporary mechanisms of ecosystem restoration, the strategic value of recreational spaces, and the multifaceted role of protected areas (PAs) in promoting biodiversity conservation and enhancing societal well-being. Particular emphasis is placed on the ecological significance of steppe ecosystems, which constitute one of the most fragile and underrepresented biomes in global conservation discourse. Despite their ecological richness and potential for supporting rare and endemic species, steppes continue to face habitat fragmentation, overexploitation, and limited legal protection. Through a comprehensive synthesis of interdisciplinary literature, this review demonstrates that the integration of recreational and green zones into industrial and urban environments yields substantial ecological and social benefits. These include the recovery of native flora and fauna, the mitigation of urban heat island effects, improved air and water quality, and the promotion of physical and psychological health among local populations. Moreover, such interventions serve as platforms for fostering environmental awareness, stimulating sustainable economic activity through ecotourism, and strengthening community engagement in conservation efforts. The analysis further highlights the indispensable role of Pas – particularly in steppe and post-industrial landscapes – in preserving ecosystem services such as carbon sequestration, soil fertility, and hydrological regulation. Cross-national case studies from Kazakhstan, Germany, China, and South Korea underscore the success of integrative management approaches that synergize scientific research, participatory governance, and environmental legislation. Given the accelerating pace of ecological disruption, the expansion, functional enhancement, and adaptive management of PAs in steppe and industrial zones must become a central focus of both national and international environmental strategies. These efforts are essential not only for halting biodiversity loss, but also for fostering climate resilience and ensuring long-term human-nature coexistence.

Keywords: technogenesis, sustainable development, biodiversity, recreational zones, protected areas, steppe zone, ecosystem restoration, environmental security

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INTRODUCTION

Technogenesis – defined as anthropogenic impact on the natural environment – has emerged as a major driver of biosphere transformation in the 21st century. Its manifestations vary depending on the level of industrialization, spatial planning frameworks, and the rigor of environmental policy (Antrop, 2005; Safarov & Berdenov, 2021).

Among the global challenges associated with technogenesis are pollution, soil degradation, resource depletion, biodiversity loss, and climate change. This review considers the specific features of technogenic issues in post-Soviet countries, industrialized Western nations, as well as in selected regions of Latin America and Asia (Kamann & Nijkamp, 1991; Osipov & Rumyantseva, 2019). In the Commonwealth of Independent States (CIS), technogenesis bears the distinct imprint of a "hard" industrial legacy. A key concern is the high concentration of industrial facilities operating without adequate filtration and treatment systems. In countries such as Russia, Kazakhstan, and Ukraine, many cities with monofunctional industrial economies– e.g., Norilsk, Temirtau, and Donetsk – continue to suffer from extreme levels of atmospheric and soil contamination. Additional issues in these regions include radioactive contamination (e.g., Chernobyl, the Semipalatinsk nuclear test site), chemical pollution resulting from outdated manufacturing processes and

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unmanaged waste, and severe degradation of water bodies. One notable example is the Aral Sea, which has experienced depletion and pollution due to aggressive irrigation schemes and unchecked industrial discharge.

Urban densification without enough integration of natural compensatory mechanisms has further disrupted ecological networks and landscape connectivity. The overarching problem remains the lack of coherent environmental policy and the slow adoption of sustainable development technologies. In the United States and Canada, technogenic impacts are subject to stricter regulatory oversight compared to many other regions. Nonetheless, the legacy of large-scale 20th-century industrialization continues to manifest in various environmental forms. Although environmental impact assessment (EIA) mechanisms are firmly institutionalized, a persistent tension remains between economic interests and ecological safety (Hall et al., 1998; Monz, 2010; Noje et al., 2025). In South American countries such as Brazil, Peru, Chile, and Argentina, technogenic issues are often entangled with agricultural expansion and extractive industries geared toward export. Major challenges include illegal mining – particularly mercury extraction in the Amazon Basin – deforestation for agribusiness (e.g., soybean monocultures or cattle grazing), hydrotechnical projects that disrupt hydrological regimes (e.g., dam construction along the Amazon), and a lack of regulatory transparency, which hampers effective environmental governance. In East and South Asia (notably China, India, and Japan), technogenesis is characterized by both extreme pressures and uneven environmental regulation, shaped by high population densities and rapid economic development (Zheng et al., 2019). China remains the world's largest emitter of CO_2. Despite major efforts toward a green transition, industrial concentration – particularly in provinces such as Guangdong and Shandong – continues to cause severe localized air and water pollution. India experiences the compounding effects of rapid urbanization, underdeveloped wastewater treatment infrastructure, and unsustainable agricultural practices, contributing to soil erosion, contamination of the Ganges River, and worsening sanitary conditions (Avishek, 2025).

Japan, by contrast, offers a case of partial recovery from historical technogenic disasters of the 1950s-60s (e.g., Minamata, Yokkaichi), having since implemented stringent environmental standards. However, technogenic risks persist in the form of technological hazards, as exemplified by the Fukushima nuclear accident (Leung, 2012).

The issue of technogenesis is not merely a byproduct of industrial progress; it also serves as a diagnostic marker of a nation’s ecological maturity. While developed countries are increasingly moving toward managed technogenesis through comprehensive environmental reforms, in the CIS and other developing regions the problem remains defined by acute tensions between industrialization and sustainability. Addressing these challenges requires a systemic approach involving infrastructure transformation, legal enforcement, public engagement, and international cooperation. Nevertheless, industrial development is widely regarded as a central driver of modernization, economic growth, and improved living standards. However, the environmental consequences of industrial zones are profound, manifesting in ecosystem degradation, contamination of natural components, biodiversity loss, and a decline in the quality of life for local populations. These impacts extend across a wide array of processes – from disruptions in biogeochemical cycles to dysfunctions in social and economic systems. One of the most pressing issues associated with technogenesis is air pollution caused by industrial emissions and vehicular traffic. In cities with a strong industrial base – such as Temirtau (Kazakhstan), Donetsk (Ukraine), and Wuhan (China) – exceedances of permissible air pollutant concentrations are regularly recorded, particularly during the winter months (Ivanov, 2024; Seidualin, 2025). Studies by the World Health Organization (WHO) confirm a direct correlation between air pollution and increased mortality from respiratory and cardiovascular diseases (Dustin et al., 2018).

Of concern are industrial facilities that generate substantial volumes of solid and liquid waste, including slag, ash, acid effluents, and sewage sludge. In the absence of modern treatment and recycling technologies, such waste is stored in tailings ponds and sludge repositories, where it is prone to erosion and infiltration into groundwater. In Kazakhstan, thousands of hectares are occupied by sludge storage facilities (Beketova, 2019; Dzhanaleyeva et al., 2017; Berdenov et al., 2016), especially in the areas surrounding Lake Balkhash, as well as the cities of Khromtau, Rudny, and Zhezkazgan. In Eastern Europe, legacy storage sites for toxic chemicals and industrial waste from the Soviet era continue to pose ongoing threats to ecosystems. Comparable concerns exist in the United States, where abandoned metallurgical sites – brownfields – represent a persistent source of environmental risk. As a result, the ecological costs of industrialization are often overlooked in the short term, yet they exert significant long-term pressure on regional economies. These costs include declining agricultural productivity due to soil contamination, the loss of recreational and tourism potential, and the reduction of fish stocks in water bodies affected by eutrophication and toxic discharges.

Regions with high levels of environmental pollution are also becoming increasingly unattractive to foreign investors, particularly considering the global shift toward ESG compliance (Environmental, Social, and Governance criteria). Such areas face major obstacles in attracting sustainable business development, including in sectors such as ecotourism, agriculture, and renewable energy. The environmental challenges faced by industrialized territories represent a systemic threat encompassing all dimensions of human well-being – from biological and ecosystem-level processes to economic stability and social resilience. Industrial development pursued without adequate environmental oversight leads to environmental degradation, biodiversity loss, increased disease burden, and a decline in the investment attractiveness of affected regions. Contemporary solutions demand the integration of sustainable development principles into industrial policy, land use planning, and environmental governance.

METHODOLOGY

This review was conducted using a systematic qualitative methodology, with the aim of synthesizing interdisciplinary scientific knowledge on the interrelation between technogenesis, sustainable development, and the role of recreational areas in biodiversity conservation. The methodology followed general principles of transparency and reproducibility, informed by the PRISMA guidelines (2009/2020), adapted for conceptual environmental and geographical reviews. The literature selection and analysis process was carried out in four stages: Identification, Screening, Eligibility, and Inclusion (Figure1).

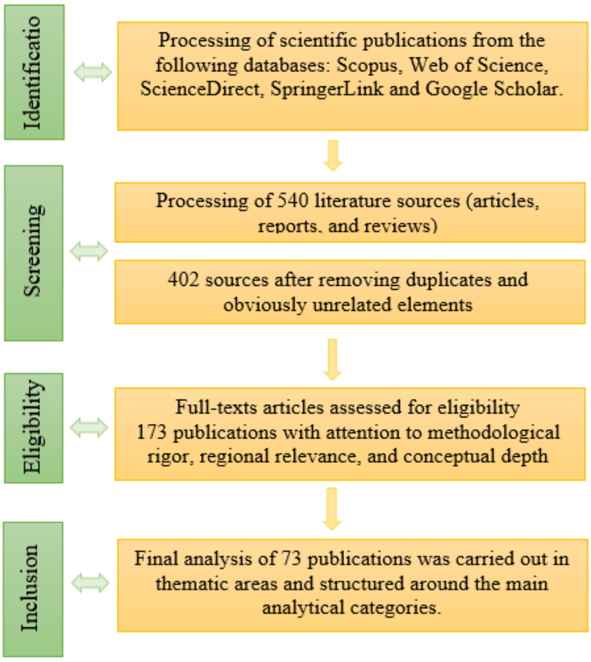

Figure 1. PRISMA 4-phase flow diagram of the literature selection process (Source: own construction)

Identification: A targeted search strategy was developed to identify peer-reviewed journal articles, conceptual papers, and systematic reviews published between 2000 and 2025. The review focused on works exploring technogenic transformations in industrial landscapes, ecosystem restoration, recreational land use, and the role of protected areas in environmental recovery. The databases consulted included Scopus, Web of Science, ScienceDirect, SpringerLink, and Google Scholar. Search terms combined keywords such as technogenesis, sustainable development, recreation, industrial zones, steppe ecosystems, biodiversity, and green infrastructure. The initial search yielded 540 articles, reports, and reviews, of which 402 were retained after removing duplicates and clearly unrelated items.

Screening: Records were screened based on titles and abstracts to assess relevance. The inclusion criteria were: (a) English-language publications; (b) published in peer-reviewed journals or academic volumes; (c) dealing substantively with the interaction of anthropogenic impact and natural ecosystems; (d) addressing recreational or protected areas in post-industrial or technogenic contexts; and (e) contributing to conceptual, theoretical, or applied ecological and spatial frameworks. Exclusion criteria involved publications focusing narrowly on technical engineering solutions, single-site case reports without broader theoretical framing, and non-peer-reviewed gray literature. This phase resulted in 173 records being selected for full-text evaluation.

Eligibility: The full texts of 173 publications were analyzed with attention to methodological rigor, regional relevance, and conceptual depth. Each article was assessed on the basis of whether it addressed: (1) the ecological consequences of technogenesis; (2) approaches to restoration or land transformation; and (3) the integration of recreational or conservation frameworks. Special attention was given to articles presenting comparative case studies from various countries, particularly Kazakhstan, Germany, China, South Korea, the USA, and others. A final selection of 73 works was made, comprising systematic reviews, theoretical papers, and case studies with implications for policy and planning.

Inclusion and Analysis: The final corpus of 73 articles was analyzed thematically, structured around the main analytical categories defined in the Literature Review section: technogenesis and environmental degradation; nature-based solutions and restoration strategies; role of recreational zones in post-industrial recovery; and steppe ecosystem conservation. Data were extracted on the geographic focus, methodological approach (where applicable), and conceptual contributions. The selection spans a range of disciplinary fields – geography, urban planning, ecology, environmental science, and regional development – ensuring a multidisciplinary synthesis.

A majority of the included works were published in high-impact journals such as GeoJournal of Tourism and Geosites, Sustainability, Ecologies, and Environment and Planning, indicating the academic quality and relevance of the sources. Several studies were government-funded or affiliated with environmental institutions, reflecting both academic and applied significance. Where applicable, visual data such as satellite imagery, geospatial modeling, and ecological indicators were noted, although the focus of this review remains primarily conceptual and policy-oriented.

The entire selection process was documented and conducted by a team of seven researchers with expertise in landscape planning, biodiversity conservation, urban geography, and environmental policy.

Inter-reviewer consistency was ensured by double-checking the inclusion criteria and synthesizing themes collaboratively. The result is a robust, comprehensive, and globally contextualized analysis of how technogenesis, recreational infrastructure, and biodiversity intersect in the context of sustainable territorial development.

LITERATURE REVIEW

Amid ongoing environmental degradation driven by technogenesis and industrial activity, ecosystem restoration has emerged as a critical strategy for achieving the Sustainable Development Goals (SDGs), particularly at the regional level. Restoration efforts not only improve ecological indicators but also generate employment opportunities, enhance quality of life, reduce social inequality, and mitigate the impacts of climate change.

Restored ecosystems contribute to improved water and air quality, climate regulation, and the reduction of risks associated with floods, droughts, and erosion. Biodiversity conservation plays a central role in enhancing ecosystem resilience to both natural and anthropogenic stressors.

Nature-based solutions offer cost-effective alternatives to traditional infrastructure: for instance, restored wetlands often outperform engineered treatment plants in water filtration efficiency.

Sectors such as ecotourism, sustainable agriculture, and renewable energy are increasingly becoming viable economic drivers based on the recovery and sustainable management of natural systems.

Today, China is implementing the world's largest ecosystem restoration initiative – the "Great Green Wall" project in the northern and northwestern regions of the country. Since 1978, forests have been planted across millions of hectares to combat desertification, particularly in the provinces of Gansu, Inner Mongolia, and Shaanxi. The outcomes of this policy include a reduction in the frequency of dust storms in Beijing and northern provinces, increased soil moisture, stabilization of agricultural production, and job creation in rural areas. China is also actively restoring wetlands and river systems, such as the Yangtze River, while promoting the concept of an "ecological civilization."

Costa Rica underwent a major transformation in the late 20th century, shifting from a deforestation-driven economy to an environmental development model. In the 1970s and 1980s, the country faced one of the highest deforestation rates in the world. However, beginning in the 1990s, it adopted a radically different policy centered on payments for ecosystem services (PES), ecotourism, and reforestation.

Today, approximately 60% of Costa Rica's territory is forested, while GDP continues to grow steadily – partly driven by sustainable tourism and the export of environmentally certified products.

Germany has long invested in the reclamation of industrial landscapes and the development of "green belts." Particularly in former coal-mining and metallurgical areas such as the Ruhr region, large-scale land restoration is underway. Abandoned mines and quarries have been transformed into parks, lakes, and recreational zones. "Green corridors" are being created to link urban centers. Techniques such as bioremediation and phytoremediation are widely used. A notable example is the Emscher Landschaftspark – a network of former industrial lands repurposed in the 21st century as a combined recreational and conservation area.

South Korea has prioritized urban greening and ecological planning. As part of the U-City program and "smart" sustainable development projects, the city of Seoul restored the Cheonggyecheon stream – previously covered by an elevated highway turning it into an ecological corridor in the heart of the metropolis. Former industrial zones are being converted into green belts, helping to mitigate the urban heat island effect and improve overall city ecology. This example illustrates how ecosystem restoration can be successfully integrated into urban planning strategies.

As a young state, Kazakhstan began its transition toward environmental reclamation and the establishment of protected areas (PAs) in the early 21st century (Saparov et al., 2024; Berdenov, 2024; Dmitriyev, 2023; Zakiryanov et al., 2022). Ecosystem restoration is being advanced through the national "Zhasyl Kazakhstan" initiative, along with afforestation programs such as the creation of forest belts around Astana. Notable progress has also been made in the rehabilitation of the Aral Sea region – particularly through saxaul planting on the desiccated seabed. Additionally, the expansion of protected areas contributes to the conservation of steppe biodiversity.

Globally, the ecosystem-based approach has gained traction Summers et al., 2012; Taff et al., 2019; Wolf et al., 2017, viewing nature as an interconnected system and restoration as a multidimensional process that integrates social and ecological contexts. A key trend is the shift toward inclusive planning, in which local communities are actively involved in monitoring, decision-making, and benefit-sharing from restored ecosystems. Scientific and technological tools are widely applied, including geospatial monitoring of degraded lands using drones and artificial intelligence (AI) (De Castro et al., 2021), remote sensing data for evaluating restoration success (Mangewa et al., 2022; Ntouros et al., 2025; Pettorelli, 2011; Qi et al., 2024; Cardoso, 2011), and biotechnological methods such as phytoremediation and microbiological treatment (Reed et al., 2011; Obaideen, 2022; Ilies et al., 2024).

Thus, ecosystem restoration is not merely about recovering natural landscapes – it is a strategic investment in the long-term resilience of regions. It is directly linked to climate stability, food security, biodiversity preservation, public health, and sustainable economic development. Case studies from countries that have successfully implemented restoration initiatives demonstrate that even severely degraded areas can recover their ecological functions and catalyze a transition toward more equitable and sustainable development models (Carpenter et al., 2009; Potschin et al., 2013; Willis, 2015; Roh et al., 2025; Nawrath, 2022). A genuine transition to sustainability is impossible without recognizing the intrinsic value of nature. The regeneration of ecosystems represents a cornerstone of a new regional development paradigm in the 21st century (Loreau et al., 2003; De Groot et al., 2010; Taff, 2019).

RESULTS

Thus, the development of recreational zones in industrial regions holds both global significance and profound social relevance. Industrial areas are traditionally associated with high levels of environmental pollution, urban congestion, monofunctional land use, and a declining quality of life for the population (Dzhanaleyeva et al., 2017; Berdenov et al., 2015). Under such conditions, the creation of recreational spaces – parks, green belts, riverwalks, forest parks, and ecotourism zones – becomes a crucial component of sustainable territorial development. These initiatives are not only a means of ecological compensation but also serve as strategic instruments for public health improvement, cultural integration, and regional attractiveness (Herman et al., 2019; Beketova et al., 2019; Grama et al., 2022). Recreational zones in industrial regions serve not only as public leisure spaces but also function as geochemical buffers (Berdenov, 2021). Their benefits include:

- Reduction of air pollution: trees absorb carbon dioxide, particulate matter, and toxic gases;
- Mitigation of the urban heat island effect: green spaces lower air temperatures in overheated industrial and urbanized areas;
- Water bioremediation: restored landscapes have the capacity to filter surface runoff and groundwater.

A large-scale example of regional recreational transformation is found in Germany's Ruhr Basin, one of the most industrialized regions in Europe. The Emscher Landschaftspark was established through the reclamation of former coal mines and metallurgical sites. This initiative included the development of extensive cycling networks, public parks, and water bodies, as well as the repurposing of old industrial structures into museums and cultural centers. This strategy improved environmental conditions, reduced unemployment, and transformed the Ruhr into a model of "green industrial transformation" (Dustin et al., 2018; Romagosa et al., 2015; Safarov et al., 2024).

Another notable case is the High Line Park in New York City, USA. Built on a disused elevated freight railway in Manhattan, the High Line has become a narrow yet elongated green recreational corridor featuring landscaping, benches, and public art installations (Monz et al., 2010; Ruzicka & Miklos, 1990).

A major project has also been implemented in Poland – the Nowa Huta initiative in Kraków. Once an industrial district associated with metallurgical pollution (Von Lindern, 2015). Nowa Huta has, in the 21st century, undergone a transformation into a recreational urban space. A network of public gardens, playgrounds, and bicycle routes has been established, contributing to social integration and the revitalization of a post-industrial neighborhood.

Research indicates that access to parks and green spaces significantly reduces the risk of cardiovascular and respiratory diseases, increases physical activity across all age groups, and improves psychological well-being – especially among children and the elderly (Berdenov, 2024). Many contemporary recreational projects incorporate environmental education elements such as informational signage (Herman, 2019), ecological trails, outdoor workshops, festivals, and community fairs. Parks become inclusive social spaces, fostering communication, dialogue, and equitable access. In contexts of social polarization (often characteristic of industrial cities) recreational zones function as "social glue", bridging divides and supporting cohesion (Zhansagimova et al., 2022; Wolf et al., 2019; Wang & Yu, 2018; Von Lindern, 2015). Many transformed industrial zones evolve into spaces of collective memory, housing museums of industrial heritage in Germany or post-industrial cultural clusters in the UK (Stojanović et al., 2024).

Thus, the development of recreational zones in industrial regions is not a luxury, but a necessity – essential for improving environmental quality, mitigating the damages of technogenesis, and promoting sustainable development. Such spaces become vital components of the green transition, enabling the integration of ecological, social, and economic functions within a single landscape (Ahmed et al., 2020). Successful international experiences confirm that even under deep industrial transformation, it is possible to create spaces where nature regenerates, community well-being is restored, and regional identity is strengthened (Inamura et al., 2022; Majeed et al., 2021; Neagu, 2021). For Kazakhstan and other post-Soviet countries, this direction holds strategic significance, particularly in areas burdened by high levels of technogenic stress and a lack of green infrastructure. In the context of accelerating urbanization, environmental pollution, and deteriorating public health, nature-based recreation and the development of green infrastructure have become critical factors for societal well-being Dustin, 2018; Nawrath et al., 2022; Romagosa et al., 2015; Venter, 2014. Recreational zones are not merely leisure spaces – they are multifunctional environments where ecological, medical, social, and cultural functions converge to provide physical restoration, mental balance, and social inclusion (Hermes et al., 2018; Kuklina, 2018; Marion et al., 2016; Monz et al., 2013). Developing such spaces near industrial or urban areas is particularly important, as they compensate for the negative effects of technogenic pressure, offering communities access to restorative natural environments. In the 21st century, nature-based recreation is increasingly viewed not as a privilege but as a fundamental social right (Sumanapala & Wolf, 2019).

Creating recreational zones is one of the most effective tools for both improving quality of life and protecting biodiversity. Well-designed and properly managed recreational landscapes function as buffer zones, ecological corridors, species habitats and migratory pathways, centers for environmental education, and platforms for sustainable practices Bourma et al., 2023; Inogwabini, 2014; Kitikidou et al., 2024; Opdam et al., 2003.

Moreover, recreation can be a functional component of ecological reclamation. Industrial waste heaps, abandoned quarries, and former military sites are increasingly being converted into green spaces and nature reserves. Restoration techniques such as phytoremediation and natural succession are employed to reestablish vegetation cover and soil function Hartig et al., 1997; Gholamhosseinian et al., 2021. Over time, colonizing species establish themselves on these restored lands, gradually forming new ecosystems. In Germany, for example, former mining fields are being transformed into urban forests (Grünzug), which support emergent flora and fauna. The Biotopvernetzung program integrates natural corridors across agricultural and urban landscapes. Similarly, the Netherlands has developed a national ecological network strategy, in which city parks and green zones serve as connective elements between protected natural areas (McDonald, 2013). In conclusion, the development of recreational zones represents a critical instrument for biodiversity conservation in the face of mounting technogenic and urban pressures. These zones can serve as refuges for species, hubs for environmental education, and key nodes in regional green infrastructure networks. When planned and managed effectively, they form the nucleus of sustainable regional development, aligning ecological integrity with social and economic resilience. Biodiversity conservation through recreation must be recognized as a strategic imperative of the 21st century. Extensive agricultural development in the 20th century led to the conversion of over 70% of Eurasian steppe lands into arable fields. This process resulted in the loss of pastureland mosaics and the disruption of fire and hydrological regimes. Today, the steppe biome is one of the least protected ecosystems globally: according to WWF estimates, only around 5% of Eurasian steppe territories are under formal protection, in contrast to forests and mountain systems, which benefit from significantly broader conservation coverage (Ambarlı et al., 2016; Duman et al., 2024).

The steppe zone represents a unique ecological and cultural landscape, playing a critical role in maintaining biological diversity, climatic stability, and the economic vitality of many Eurasian nations. However, these areas remain among the most vulnerable and undervalued, particularly in the context of nature conservation and environmental governance (Maksanova, 2023; Schulte, 2014). Establishing and expanding protected areas in steppe regions is a strategic priority of the 21st century. Achieving this goal requires an integrated approach that combines scientific justification, international cooperation, community engagement, and sustainable funding mechanisms. Only through such a comprehensive framework can steppe ecosystems be safeguarded for both current and future generations.

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