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Review

Ecological Degradation and Restoration Process in the Source Region of Yangtze River: A Review Using the DPSIR Framework

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Received: 2 April 2025; Accepted: 15 May 2025; Available online: 19 May 2025

ABSTRACT: By the end of the 20th century, the Source Region of the Yangtze River (SRYR) suffered severe ecological degradation driven by the combined effects of climate change and human disturbances. To counteract ecological degradation, the Chinese government implemented multiple ecological protection and restoration measures. Based on a literature review, this study analyzed the entire process of ecological degradation and restoration in the SRYR using the DPSIR (Drivers-Pressures-States-Impacts-Responses) framework. It revealed that climate warming and grazing expansion were the main drivers. Under the dual pressures of natural and anthropogenic disturbances, grasslands experienced severe degradation, accompanied by significant losses of soil nutrients. The decline in grassland quality weakened ecosystem service functions and reduced the livelihood levels of herders. After implementing the ecological protection and restoration projects in China, the ecosystem had been effectively restored. Herders' income levels had been improved. However, a mismatch persisted between ecological compensation standards and livestock reduction costs for herders. Future efforts should focus on the innovation of the institution and ecological restoration techniques. This study offers critical insights into ecological protection and restoration strategies, providing practical references for decision-makers to accelerate the realization of China's ecological civilization objectives.

Keywords: DPSIR; The Source Region of the Yangtze River; Grassland degradation; Ecological protection; Ecological restoration; Ecological compensation

1. Introduction

Land degradation poses a significant threat to global ecosystems, with estimated economic losses reaching $23 trillion by 2050, and Asia and Africa will be affected most severely [1]. To address this challenge, the United Nations Convention to Combat Desertification (UNCCD) proposed the Land Degradation Neutrality (LDN) target in 2015, aiming to balance ecological conservation and economic development by 2030 [2]. Aligned with sustainable development goals, the Chinese government established ecological civilization construction in 2012, prioritizing the creation of a harmonious human-nature coexistence framework [3]. In 2022, the 20th National Congress of the Communist Party of China further emphasized ecological civilization advancement, advocating the accelerated implementation of major ecosystem protection and restoration projects in national key ecological functional zones and protected areas.

The Source Region of Yangtze River (SRYR) serves as China's critical ecological barrier and a priority for ecological governance [4]. Since the late 20th century, climate change and anthropogenic activities have driven persistent ecosystem degradation in this region, manifesting as alpine meadow retrogressive succession, soil organic carbon loss, and heightened livelihood vulnerability among herders, collectively threatening regional ecological security [5]. Ecological protection and restoration constitute essential pathways for ecological civilization implementation, focusing on restoring ecosystem structure, functionality, and socio-ecological resilience through scientific interventions [6]. Chinese government initiated comprehensive restoration efforts through the 2005 "Ecological Protection and Construction Master Plan for Three-River Source National Nature Reserve", investing 7.5 billion RMB (approximately

https://doi.org/10.70322/ecolciviliz.2025.10008

$1.1 billion) in measures including grazing prohibition, black soil land remediation, ecological compensation, and integrated rodent control [7]. In 2021, the "National Major Ecosystem Protection and Restoration Projects Master Plan (2021–2035)" was implemented, which highlighted the necessity of ecological protection and restoration programs. After that, the ecosystem status and human well-being have both changed [8].

The DPSIR (Drivers-Pressures-State-Impacts-Responses) model was first introduced by the Organization of Economic Cooperation and Development [9] and the European Environment Agency [10] in the 1990s for socio-ecological systems management. By deconstructing complex environmental issues into five interconnected components, this model offers systematic insights into the causal relationships between human activities and ecosystem dynamics. Initial applications focused on water resource management and land degradation. For instance, Karageorgis et al. (2004) implemented the model to assess hydrological systems [11], and A. Vacca (2004) concurrently applied it to evaluate soil degradation in the Po River-Adriatic Sea coastal system [12]. Over the past decade, its scope has expanded significantly, with emerging applications in biodiversity conservation and climate resilience planning. In China, research has prioritized ecologically vulnerable areas, notably the Tibetan Plateau and Yellow River Basin.

Current DPSIR-based studies on ecosystem restoration predominantly employ empirical approaches, emphasizing ecological status evaluations and driving factor identification while neglecting systemic analyses of restoration processes. A case in point is Sobhani et al. (2023), who evaluated ecotourism safety drivers in an Iranian protected area without addressing process-level interactions [13]. Similarly, Yang (2023) mapped spatiotemporal ecological security patterns in the Three Gorges Reservoir using DPSIR-Data Envelopment Analysis integration, but neglected the links between model dimensions [14]. This limitation persists in restoration assessments, as demonstrated by Dong et al. (2022), whose grassland security classification in Xilin Gol League failed to elucidate inter-indicator causality within the DPSIR framework [15].

Thus, the goal of this review is to analyze the entire chain of ecological degradation and restoration using the DPSIR framework. To achieve these goals, we first selected the indicators for each DPSIR component. Then, we analyzed the specific indicators of drivers and derived how drivers contributed to pressures. Following the pressures, we assessed the states of ecosystem degradation at the end of the 20th century. Furthermore, we linked degradation states to ecological and socio-economic impacts. Afterwards, we reviewed China's ecological restoration policies and projects and evaluated their implementation effectiveness in this region. Finally, we identified the challenges and gaps in policy execution and derived the implications. This study can contribute to supporting adaptive ecological restoration governance and promote sustainable ecosystem management in vulnerable plateau regions.

2. Study Area

The Source Region of Yangtze River (SRYR) is situated between the Kunlun and Tanggula Mountains in the hinterland of the Tibetan Plateau (Figure 1). As the core component of the Three-River Source National Nature Reserve, it spans a vast area of 137,800 km^2 with an average elevation of 4295 m [16]. The region spans Yushu County, Zaduo County, Zhiduo County, Chengduo County, and Qumalai County within the Yushu Tibetan Autonomous Prefecture, as well as Tanggula Township in Golmud City, Haixi Mongol and Tibetan Autonomous Prefecture. Dominated by alpine meadow ecosystems, the region supports critical ecological functions, including water conservation, biodiversity preservation, and regional climate regulation. Its primary rivers include the Tuotuo, Dangqu, and Chumar Rivers. The permafrost zone in this region ranks among the most climate-sensitive areas globally. Permafrost underlies 77% of the area (107,619 km^2), with thickness ranging from 10 to 120 m, while seasonally frozen ground occupies 23% (30,754 km^2), primarily in valleys [17].

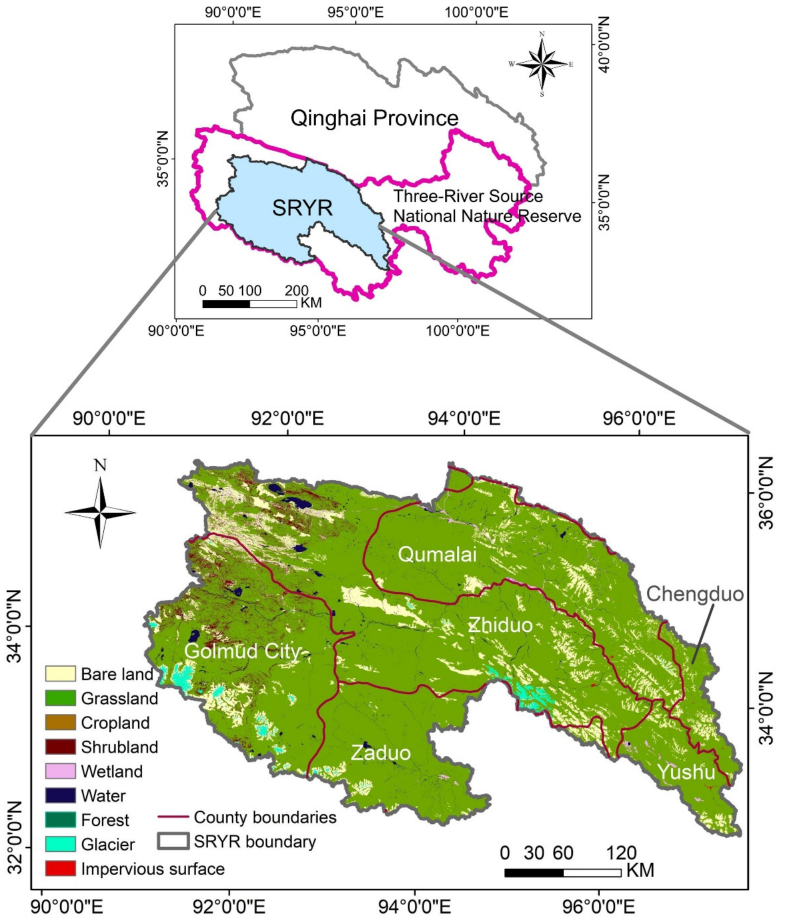

Figure 1. The location of the Source Region of Yangtze River. This map is based on the standard map from the Ministry of Natural Resources of China (Approval Number: GS (2020) 4619), downloaded from the National Standard Map Service website (http://bzdt.ch.mnr.gov.cn/index.html) on 28 February 2025 and rendered using ArcMap 10.8. The base map has not been modified.

3. Data and Methodology

3.1. Data Collection

Data sources included peer-reviewed articles, books, theses, grey literatures, and statistical data. Peer-reviewed articles were published in international journals and acquired from the Web of Science and CNKI database. We set 'ecological degradation', 'ecological restoration', 'DPSIR', 'Qinghai', and 'the Source Region of Yangtze River' as keywords. We first gained an overall understanding of the ecological degradation and restoration status in the SRYR region and identified specific indicators for each layer of the DPSIR framework. Then, to obtain specific indicator values and verify the validity of the logical relationships between them, we analyzed the relationships between pairs of indicators at different levels. For example, if we want to obtain the effect of climate warming on the change of permafrost, we set the keywords as 'climate', 'permafrost', and 'the source region of the Yangtze River'. In total, we searched 80 related literatures, and through evaluation and screening, we selected 63 literatures for this study. The grey literatures, including governmental and scientific reports, were derived from the province or national governments and international communities (e.g., European Environment Agency). Due to the intensified ecological degradation of the SRYR at the end of the 20th century, to analyze the evolution of ecological degradation, we screened the references published in the 19th century and in the 21st century that documented this degradation process. After 1998, China's ecological restoration entered a new phase with the implementation of the National Ecological and Environmental Protection Construction Plan. Therefore, the response data (ecological policies, projects, measures, *etc.*) were collected from 1998 to 2024. Statistical data were sourced from the Qinghai Statistical Yearbook.

3.2. Methodology

The Driver-Pressure-State-Impact-Response (DPSIR) framework is an adaptive management tool used for analyzing environmental problems by establishing cause-effect relations between anthropogenic activities and their environmental and socio-economic consequences [18,19]. Firstly, to analyze the whole chain of ecological degradation and restoration process, we used the DPSIR framework based on a literature review. We screened the D, P, S, I, and R layer indicators based on the characteristics of the SRYR region through the literatures. We then selected the indicators that were frequently mentioned in the literature as valid indicators. We used the literature review to explore quantitative relationships between the indicators in different layers. If quantitative data is not available, a qualitative description was applied.

3.2.1. DPSIR Indicator Selection

We developed three levels of indicators, namely indicator dimension, indirect indicators, and direct indicators, respectively. Indicator dimensions correspond to each of the five DPSIR components—Drivers, Pressures, States, Impacts, Responses, respectively. Indirect indicators represent the primary thematic aspects within each dimension, e.g., climate warming and livestock expansion under Drivers. And direct indicators serve as quantitative or qualitative metrics to describe these indirect indicators. The details for each of the DPSIR components are as follows.

- Drivers (D) refer to the potential factors driving system changes, covering both natural and socio-economic aspects, and serving as the root cause of environmental changes. In SRYR, we found that climate warming and livestock expansion frequently appear in grassland ecology research literature. We used temperature (°C) and the total livestock (sheep units) to quantify the indirect indicators.
- Pressure (P) represents the degree to which an ecosystem is subjected to disturbances. In this study, permafrost degradation and overgrazing were identified as two core indicators. To quantify these pressures, we employed the permafrost active layer thickening rate (cm/a), permafrost degradation area (hm^2), number of overloaded livestock (sheep units), and overloading ratio (%) as measurement metrics.
- Ecosystem status (S) denotes the health and ecological environmental quality of an ecosystem. We categorized grassland degradation into vegetation degradation and soil degradation. Specifically, the grassland degradation area (hm^2) and rodent burrow density (per hectare) were employed to quantify vegetation degradation. Meanwhile, the desertification area (km^2) and carbon-nutrient loss rate in soil (%) were utilized to measure soil degradation.
- Impacts (I) refers to the consequences of changes in the ecosystem state on both the ecological environment and socio-economics. In this study, ecological impacts were quantified using Net Primary Productivity (NPP), fractional vegetation cover, and soil and water conservation capacity. Socio-economic impacts, conversely, were primarily assessed through qualitative analysis of pastoralist income, establishing a bridge between ecological changes and human livelihood outcomes.
- Ecosystem response (R) involves measures addressing ecosystem changes, reflecting human management of ecological issues. For grassland governance, ecological protection/restoration, and livelihood improvement are key response strategies. We used the ecological restoration area (kha) and the compensation amount to quantify these responses.

3.2.2. Establishment of the Linkages among Ecological Degradation and Restoration Indicators Based on DPSIR

In the DPSIR framework, social and economic development puts pressure on the ecosystem, and ecological conditions change as a result. This leads to impacts on human society and ecosystems, eventually leading to social responses, which will bring feedback to D, P, S, and I [20] (Figure 2). In this study, we examined linkages between D–P, P–S, S–I, I–R, and R–D/P/S/I through combining quantitative data and qualitative analysis. We assessed logical relationships by evaluating how one or more indicators in a preceding layer influenced indicators in the subsequent layer. To be specific, drivers (D) exert pressures on both social and ecological systems by encompassing a combination of natural and anthropogenic indicators. Natural drivers such as climate change (notably global warming) have been identified as key factors contributing to permafrost degradation. Meanwhile, anthropogenic pressures are primarily manifested through livestock expansion, representing this region's dominant human-induced driver. Pressures (P) change the ecosystem status. Overgrazing has been identified as a primary anthropogenic pressure of grassland degradation in the SRYR [21,22]. Permafrost degradation alters surface hydrological processes, exacerbating soil erosion and grassland desertification. States (S) may bring ecological and social impacts [23]. These impacts drive human responses. Mitigation measures—such as restoration projects and management strategies [24]—create feedback loops. We used qualitative analysis to assess influences on drivers and quantitative data to pressures, states, and impacts, respectively.

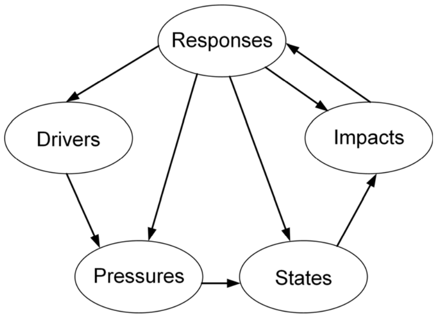

Figure 2. Basic structure of the DPSIR framework.

4. Results

4.1. Drivers (D) and Pressures (P)

Our review found that grassland degradation in the SRYR stemmed from synergistic effects of climate change and human disturbances [25] (Figure 3). On climate change, the SRYR had witnessed accelerated warming since 1960s, with a mean temperature increase of 0.321 °C per decade [24,26], exceeding the average for the whole Tibetan Plateau and showing heightened climate sensitivity [27]. The warming contributed to permafrost degradation, with a reduction in permafrost coverage, from 13.94×10^4 km^2 in 1962 to 12.57×10^4 km^2 in 2012, with an annual loss rate of 0.0401×10^4 km^2. Furthermore, the active layer had thickened from 186.0 cm in 1962 to 219.84 cm in 2012 at 0.802 cm/yr [28].

As for the social-economic development, this review indicated that the continued increase in the grazing number has resulted in overloaded overgrazing. To be specific, the total livestock in the SRYR, measured in sheep units, increased significantly from 30.9131 million in 1966 to 44.4012 million in 1993. Meanwhile, the number of overloaded livestock had increased from 1.9095 million sheep units in 1966 to 15.3976 million in 1993, with the rate from 6.6% to 53.1% [29]. Over-grazing mainly impacted grassland degradation through two primary mechanisms. Firstly, it directly reduced vegetation cover and disrupted the structure of plant communities. Secondly, livestock trampling increased soil compaction, thereby weakening the ecosystem's self-restoration ability.

4.2. States (S) and Impacts (I)

4.2.1. Grassland Ecosystem Status

Our findings demonstrated that the grassland ecosystem in the SRYR had undergone significant degradation driven by coupled natural and socio-economic pressures. We analyzed the degradation in terms of both vegetation and soil degradation (Figure 3). Degraded grasslands covered 716,423 ha (17.8% of total) in Zhiduo County and 2,864,930 ha (79.5%) in Qumalai County [30]. Severe grassland degradation generated "black soil patches" [31], where rodent burrow densities reached between 2183 and 4423 per hectare, far exceeding the sustainable threshold of 636 burrows per hectare [32]. Meanwhile, soil status is one of the indicators used to assess the state of grasslands. We found that soil degradation was characterized by a 2.59 km^2 expansion of desertification between the 1970s and 1990s [33], accompanied by deteriorating soil habitats with reduced fertility and nutrient content under repeated disturbances [34]. Alpine meadow and grassland ecosystems showed significant declines in soil organic carbon (SOC), nitrogen (N), and phosphorus (P) ratios [35–38]. Specifically, degraded pastures exhibited a 42% reduction in SOC, 33% decrease in total N, and 17% decline in total P compared to non-degraded areas, with these changes concentrated in the topsoil layer (0–10 cm) [39,40].

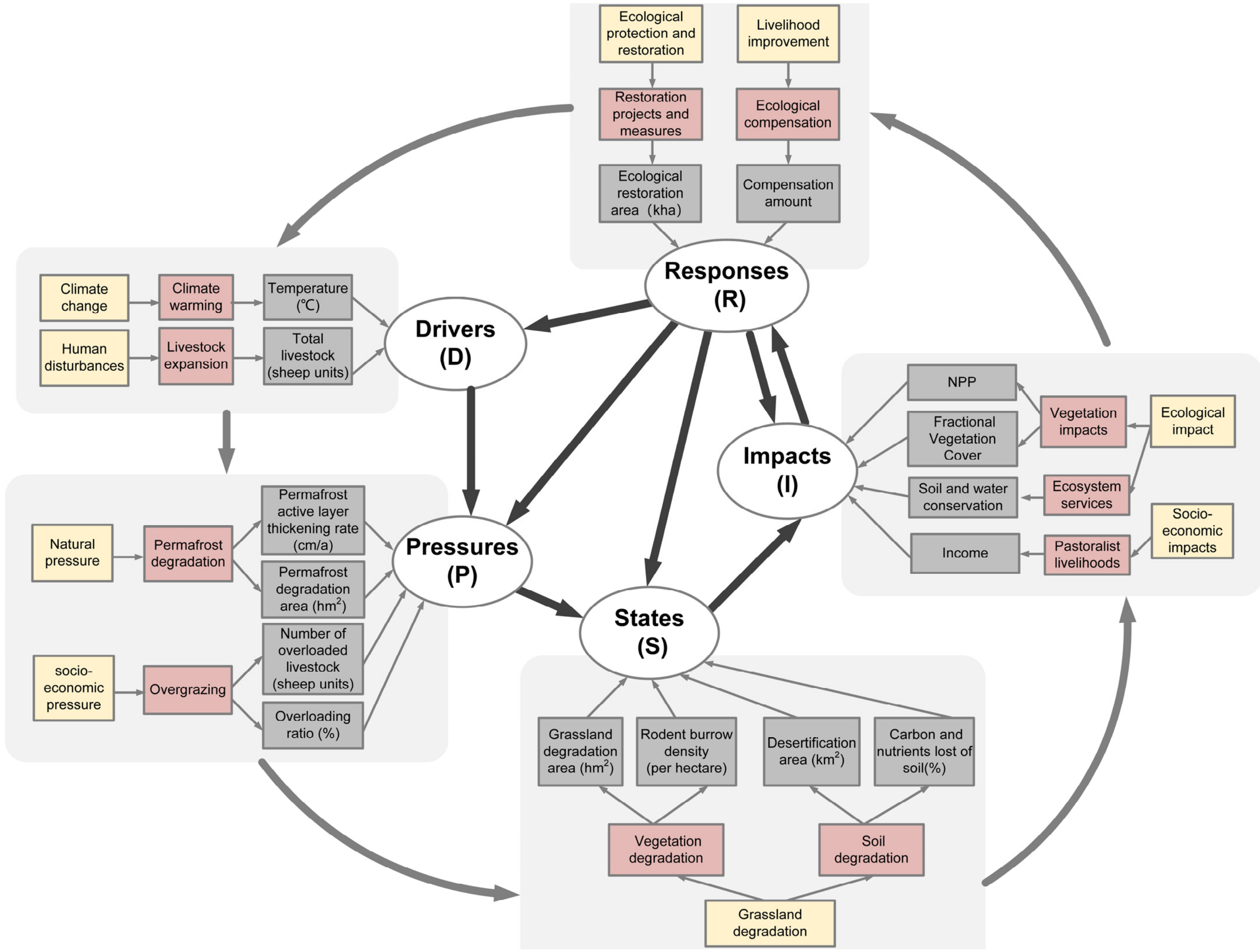

Figure 3. DPSIR analytical framework for grassland ecosystem protection and restoration in the SRYR. Light yellow boxes represent the dimensions of the indicator, light red boxes are indirect indicators, and obscure boxes are direct indicators.

4.2.2. Ecological and Socio-Economic Impacts

Our study also found that grassland degradation has significant impacts on both ecological and socio-economic systems [41]. We identified a clear inverse relationship between grassland degradation severity and soil-water conservation functions, with increasing degradation leading to proportional declines in hydrological regulation capacity [42,43]. By the late 20th century, 25% of the SRYR had experienced vegetation cover deterioration, coinciding with a 46.66% decline in net primary productivity (NPP) [33]. These changes reflect a systemic weakening of ecosystem resilience under cumulative pressures.

In terms of socio-economic impacts, pastoral livelihoods are considered to be the main indicator of the impact. At the global level, we found that degraded grasslands resulted in losses of US$6.8 billion in pastoral production between 2001 and 2011, particularly severely impacting human well-being [44]. In SRYR, our analysis revealed that grassland livestock farming is the most important source of livelihood for herders. However, grassland degradation directly leads to a decline in pasture productivity and quality, which reduces the carrying capacity of the grassland [45]. To sustain the traditional scale of animal husbandry, herders tend to purchase feed, which has resulted in increased grazing costs and reduced income, thereby exacerbating the vulnerability of herders' livelihoods [46].

4.3. Responses (R) Analysis

4.3.1. Response Actions

To analyze the response actions, we selected two key management strategies to address grassland degradation in the SRYR: ecological restoration interventions and livelihood compensation mechanisms. Ecological restoration was quantified through the ecological restoration area, such as the damage prevention area by rats, the damage prevention area by pets, the new fenced area, and the new sown area (Figure 4). We also used the compensation amount to quantify the livelihood improvement of herding households.

We found that, to alleviate grassland degradation and livelihood vulnerability in the SRYR, the Chinese Government has taken lots of management measures [47,48]. In 2003, the Grazing Prohibition and Grassland Restoration Program was initiated in Qinghai Province [49], followed by the Three-River Source National Nature Reserve Conservation Project in 2005 with a total investment of 7.5 billion CNY [50]. The degraded grasslands were restored according to the degree of degradation. The above initiatives deployed integrated restoration techniques, including grazing bans, rotational grazing, grazing rest, grass-animal balance, fencing and breeding, and biological measures [51–53]. New fencing reached 1300 kha in 2013 (Figure 4). And the rats and pests monitoring system has been developed [54,55], with peak control areas covering 4050 kha in 2006 (Figure 4).

On social-economic improvement, our study found that concurrent livelihood support measures, such as providing subsidies and creating job opportunities for local herders, focused on enhancing economic resilience. Annual grazing prohibition subsidies increased from 6.0 to 7.5 CNY/mu between 2011 and 2016 [56], complemented by grassland-livestock balance rewards rising from 1.5 to 2.5 CNY/mu [57]. From 2012 to 2022, 145,100 ecological stewardship positions were created in Three-River Source National Nature Reserve, boosting household income by 21,600 CNY annually.

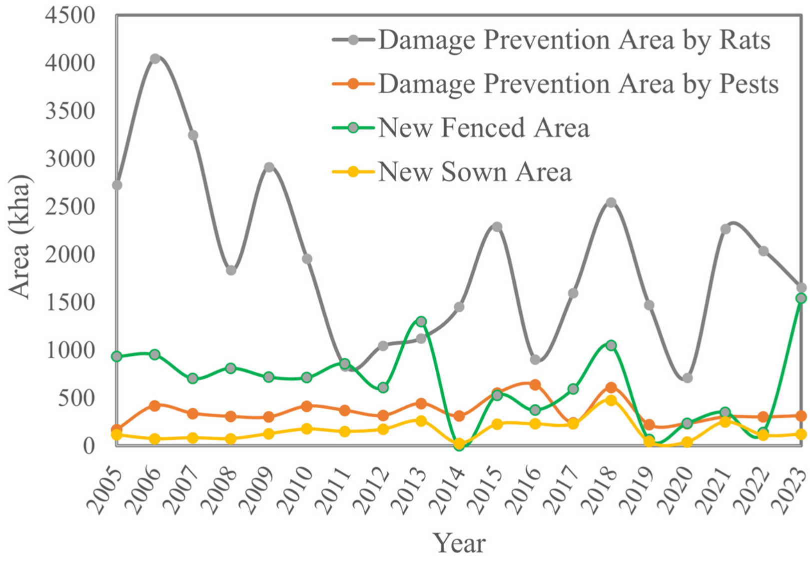

Figure 4. Grassland restoration area in Qinghai Province from 2005 to 2023. (Data from Statistical Bureau of Qinghai Province).

4.3.2. Influences of Response to Drivers, Pressures, States and Impacts

In this review, we demonstrated different influences of response to drivers, pressures, states and impacts, respectively. We evaluated the effectiveness of policy responses across the DPSIR framework in addressing grassland degradation in the SRYR, revealing a complex interplay of successes and limitations. First, in response to drivers, human-driven degradation was partially mitigated through grazing bans and subsidies, reducing livestock numbers. However, natural drivers like climate warming remained unaddressed, exacerbating permafrost loss and desertification expansion. Secondly, it was found that human-driven pressures were significantly reduced by grazing prohibition policies, with livestock overloading rates decreasing from 25% to 13% between 2011 and 2015 [58]. Despite this, desertification pressures intensified due to unresolved climatic stressors, with 5.16% in 1999 to 14.57% in 2018 [59]. Thirdly, on responses to states, from 2000 to 2015, the NDVI showed an annual growth rate of 0.013% per year [60], but the ecological states have not returned to the relatively good ecological state observed in the 1970s [61]. Rodent population control remains a persistent challenge in the region (Figure 5). In 2021, the rodent population once again exceeded 9000, further highlighting the urgency and thus demanding innovative and adaptive management strategies. Finally, as for responses to impacts, we analyzed the ecological and social-economic changes. Ecological degradation in the SRYR has been partially mitigated through the implementation of the ecological restoration projects. Specifically, vegetation coverage improvements exceeded 72.10% of the total vegetated area, while net primary productivity (NPP) increases were recorded across 73.82% of the region [33,62]. However, between 2000 and 2015, ecosystem service functions were found to have significant declines, marked by the respective decreases of 18.06% in water conservation per unit area and 22.9% in soil retention capacities [60]. Regarding the socio-economic impacts, our research discovered a mixed picture. On the positive side, the livelihoods of pastoralists have shown an upward trend. Since 2016, relocated herders have been getting subsidies of 9000 CNY per household per year [63], which has helped boost their incomes. However, on the downside, the compensation mechanism has flaws. A significant portion, 47.9% of the funds, was wrongly allocated to non-compliant households [57]. This misallocation led compliant herders to suffer income losses, forcing them to engage in illegal grazing, and consequently causing ecological damage. Therefore, improving the compensation system to balance ecological protection and herders' livelihoods is crucial.

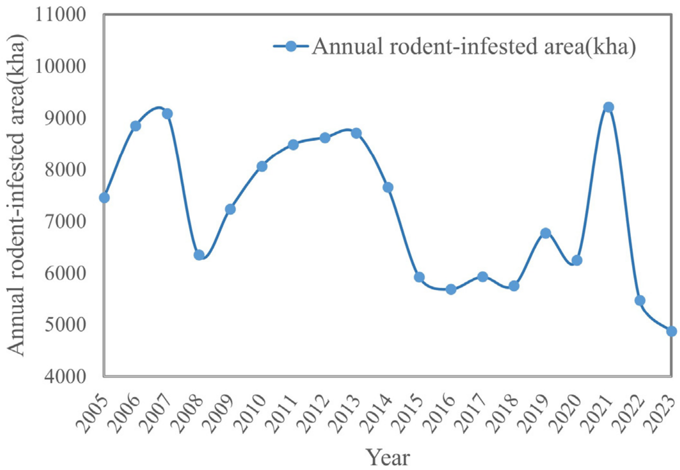

Figure 5. Annual rodent-infested area in Qinghai province. (Data from Statistical Bureau of Qinghai Province).

5. Discussion

This study employed the DPSIR framework to analyze the ecological degradation and restoration processes in the SRYR, providing insights into balancing ecological conservation and human development. After the grazing prohibition and grassland restoration projects were implemented, institutional innovations such as grazing prohibition subsidies and ecological stewardship employment were put in place. These innovations achieved dual objectives of enhancing grassland coverage and improving pastoral livelihoods. This demonstrates that ecological protection does not mean halting development. Instead, a balance between ecological conservation and human well-being can be achieved with institutional innovation. Ecological civilization emphasizes the harmonious coexistence of humans and nature, stressing the importance of equilibrium rather than prioritizing one over the other. Therefore, a central challenge for future research lies in figuring out how to boost human well-being while lessening the environmental burden.

However, current policies still show significant imbalances. Herders suffer economic losses because of reduced grazing, but the grassland ecological compensation they get doesn't match up. The gap reveals a misalignment between the costs of conservation and the benefits to livelihoods. This situation may weaken policy effectiveness and sustainability. So, future measures should either dynamically adjust compensation standards or bring in market-based ecological credit trading mechanisms.

Furthermore, technological innovation is needed to address compound pressures like rodent infestations, permafrost degradation, and land desertification. Future governance strategies should integrate advanced technologies, including AI-driven rodent spread prediction models and precision soil hydrothermal regulation in permafrost zones, to enhance governance efficacy.

Thus, future research should prioritize two directions. One is to quantify the coupling between ecological thresholds, such as carrying capacity limits, and human well-being, like livelihood benefits per unit restoration investment. The other is to innovate green industries tailored to alpine ecosystems to foster sustainable livelihoods without compromising ecological security. The SRYR's practices offer a reference for achieving Sustainable Development Goals (SDGs) in global ecologically fragile regions, which proves that ecological civilization is a dynamic, balanced coexistence between humanity and nature.

While this study leverages existing quantitative evidence to establish indicator linkages, future research could quantify site-specific causal-effect pathways. These approaches would enhance the DPSIR framework's predictive power, particularly for interactions in fragile alpine ecosystems.

6. Conclusions

Based on the DPSIR framework, this study analyzed the whole causal chain of degradation and restoration in the SRYR. We developed the DPSIR indicator system that is applicable to the SRYR. It revealed that climate warming and human activities, particularly overgrazing, acted as primary drivers, creating pressures through permafrost degradation and livestock overloading. These pressures altered ecological states, causing grassland degradation, soil carbon loss, and the formation of "black soil patches". Consequentially, ecosystem services decline—water conservation and soil retention capacities are significantly reduced—while herder livelihoods suffer from income losses. Policy responses, including grazing prohibitions and compensation subsidies, have improved vegetation in some areas but still failed to address root causes. Ecological degradation persists due to thawing permafrost and rodent infestations. A persistent mismatch remains between the economic losses incurred by pastoral households due to livestock reduction and the grassland ecological compensation funds they receive. To advance ecological civilization goals, this study proposed that the institution's innovation and ecological restoration techniques are needed to balance nature and humans. Future work should quantify ecological thresholds and innovate green industries to achieve ecological civilization goals.

Acknowledgments

We are grateful to Yamasaki Kikuko from Ibaraki University for her invaluable insights and critical feedback during all stages of this study.

Author Contributions

Conceptualization, X.L. and L.Z.; Methodology, X.L. and L.Z.; Formal Analysis, X.L.; Data Curation, X.L.; Writing—Original Draft Preparation, X.L.; Writing—Review & Editing, X.L. and L.Z.; Visualization, X.L.; Supervision, L.Z.; Funding Acquisition, L.Z.

Ethics Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data available on request/reasonable request.

Funding

This research was funded by the Major Projects of the National Social Science Fund of China (20&ZD096).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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