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Global Population Dynamics and Conservation Outcomes of the Genus Panthera

Qimo She[1, *]

[1] Department of Wildlife Resources, Northeast Forestry University, Harbin, Heilongjiang, China
*Corresponding author: 2022220907@nefu.edu.cn

Abstract:

As apex predators within global ecosystems, Panthera species play a crucial role in maintaining ecological balance and biodiversity. However, influenced by multiple factors such as human activities, habitat loss, poaching, and illegal trade, their populations have continued to decline worldwide. This paper comprehensively analyzes the population dynamics and conservation effectiveness of Panthera species and their subspecies across different intercontinental regions, drawing on multi-source databases including the IUCN Red List of Threatened Species, the Living Planet Index (LPI), GBIF, and CITES. The results reveal that most populations are in decline; although certain regions show signs of recovery due to conservation measures, the overall situation remains critical. The study further highlights that the establishment of protected areas, cross-border cooperation, and anti-poaching policies have improved the survival status of some species to a certain extent, yet substantial regional disparities persist. By comparing global conservation outcomes and population trends, this research provides a scientific foundation for developing more targeted conservation strategies, offering important insights for future global biodiversity conservation.

Keywords: Panthera; Population Dynamics; Conservation Strategies.

1. Introduction

The genus Panthera comprises five species and twelve subspecies [1], distributed across all continents. As large felines, panthers occupy apex predator positions in diverse ecosystems, forming a vital component of ecological networks. However, these species now face significant survival threats, with five species, seven subspecies, and two subpopulations listed on the IUCN Red List (data source: IUCN). Human activities have profoundly impacted leopard survival. Examples include the Amur tiger, jaguar, snow leopard, and African lion, whose habitats have been fragmented and encroached upon by

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human activities; the jaguar, snow leopard, and African lion, whose populations have declined due to intensified human-wildlife conflicts; and the snow leopard and African lion, affected by illegal poaching and wildlife trade [2-5]. Panthera populations indeed serve as indicators of ecosystem health. Assessing the population dynamics and conservation outcomes of these keystone apex predators provides crucial evidence for evaluating the effectiveness of global conservation strategies, with results directly impacting the maintenance of ecosystem integrity and the future of biodiversity worldwide.

A study of China's Lishan Nature Reserve revealed that while reserve establishment effectively preserves North China leopard habitats, it has failed to halt habitat fragmentation within protected areas [6]. A research team from the University of Jayawardenepura Kandy in Sri Lanka conducted a 16-month field survey in Kumana National Park (KNP), southeastern Sri Lanka. This study provided the first analysis of the spatial distribution and survival strategies of Sri Lankan leopard populations, filling a gap in research on their numbers and distribution [7]. Nevertheless, comprehensive studies on global leopard population dynamics and conservation effectiveness remain scarce. Systematically evaluating leopard population trends and conservation measure efficacy not only validates existing policies but also informs future regional and global conservation strategies.

This study aims to examine the relationship between population dynamics and conservation measures by reviewing global leopardid population trends, analysing current population sizes, and evaluating conservation outcomes. This foundational research will inform the development of future leopardid conservation strategies. As apex predators, leopards play an important role in maintaining the stability of the food chain and regulating population structure in the ecosystem. Their distribution and population changes not only directly affect the number and distribution pattern of small and medium-sized herbivores, but also indirectly determine the succession of vegetation communities and the performance of ecosystem service functions [8]. However, with the intensification of global climate change and human land use intensity, the living environment of leopards is facing unprecedented challenges. Habitat loss and fragmentation caused by deforestation, agricultural expansion, and infrastructure construction have significantly reduced the habitat connectivity of leopards, which in turn affects their gene exchange and long-term viability. In addition, cross-border illegal wildlife trade remains rampant, exacerbating the downward trend in populations.

In recent years, the construction of protected area networks, the restoration of ecological corridors, and the promotion of international cooperation have alleviated the pressure of leopard habitat degradation and overhunting to a certain extent. For example, some countries in East Africa and South Asia have achieved partial improvements in the coexistence of leopards and humans by establishing cross-border nature reserves and strengthening participatory community conservation. However, there are still significant regional differences in the overall effectiveness of these measures, and in some areas, the protection effect is far from as expected due to insufficient law enforcement and lack of funding. Therefore, a systematic global assessment of the dynamics of leopard populations and the effectiveness of conservation measures will not only help to reveal the driving mechanisms behind species distribution and population changes, but also provide a scientific basis for formulating more targeted conservation policies in the future. Especially in the context of the continuous decline of global biodiversity, the conservation of leopards is not only about the survival of a single species, but also about the stability of the entire ecosystem and the future of sustainable human development.

2. Methods

2.1 Data Sources

Research on conservation outcomes and population dynamics of the Panthera genus relies on authoritative databases and long-term monitoring programmes. The IUCN Red List, as the world's most authoritative inventory of endangered species, systematically documents taxonomic information, changes in conservation status, population trends, and primary threats for Panthera species, serving as the core data platform for tracking their conservation status. The Living Planet Index (LPI), which has continuously collected and published wildlife monitoring data since 1970, includes monitoring sequences for Panthera species across multiple sites. These sequences reveal long-term trends at both global and regional scales and provide crucial evidence for analysing the relationship between conservation measures and population recovery. The Global Biodiversity Information Facility (GBIF) aggregates global species distribution point data. By leveraging its extensive spatio-temporal records, researchers can identify shifts in leopard habitat patterns across different regions. The CITES international trade database preserves records of both legal and illegal trade of leopard species, offering supporting evidence to understand the potential impacts of poaching and wildlife trade on population numbers.

In addition to these core databases, annual reports and monitoring results published by WWF, UNEP-WCMC, and regional conservation agencies provide detailed ac-

counts of protected area establishment, habitat restoration, and policy implementation, thereby offering contextual information for evaluating the effectiveness of conservation measures. Socio-economic and environmental datasets from the World Bank, as well as land-use datasets such as LUH2, reveal the persistent pressures on feline habitats from human activities including population growth and land-use change. The integration of these diverse data sources enables a systematic review of historical population trends and conservation strategies in a global context, while providing multi-dimensional insights to guide future conservation actions.

2.2 Data Processing Methods

When collating and analysing multi-source data on Panthera species, researchers typically employ a multi-step processing workflow. Species information from the IUCN Red List is first organised by species and subspecies, with conservation status and population trends converted into time series to facilitate cross-period comparisons. To visualise trend shifts, assessments are compared against historical data, and population dynamics are categorised as "improved," "deteriorated," or "unchanged." Species lacking continuous records or with unclear trends are classified as "unknown." This framework facilitates the synthesis of global conservation trajectories across species.

Integration of monitoring data from the LPI allows for more detailed analyses of Panthera population changes. Long-term monitoring sequences are often converted into annual index values or rates of change. Using frequency statistics and percentage change calculations, researchers can compare population trends across species, regions, and conservation statuses. For instance, calculating the proportion of samples that show increasing, decreasing, or stable population numbers over a given period provides insights into global dynamics of Panthera species.

For cross-regional comparisons, data are often stratified by continent or ecoregion to examine how geographical distribution influences population trends. This approach helps identify regions where conservation measures have been effective and those where significant challenges remain. A common strategy also involves comparing population trends before and after changes in conservation status. By contrasting dynamics prior to and following conservation status adjustments, researchers can evaluate the practical effectiveness of conservation interventions.

From a statistical perspective, basic frequency counts and percentage analyses remain the most frequently applied tools. To enhance clarity, results are typically visualised through line graphs, bar charts, or spatial distribution maps. In some studies, chi-square tests, trend analyses, or regression models are further employed to validate correlations between variables, such as the link between conservation status adjustments and population trends. This combined approach makes analyses of Panthera population dynamics not only visually intuitive but also statistically robust, thereby providing stronger evidence for understanding global conservation outcomes for the genus.

3. Results

3.1 Trend Characteristics of Endangered Leopard Species

The overall trend of leopard populations shows a clear deterioration. Within the genus Panthera, there are 5 species, 8 subspecies, and 2 subpopulations. Except for the Panthera leo Asiatic subpopulation, the populations of the remaining 5 species, 8 subspecies, and 1 subpopulation have all exhibited downward trends. For Panthera tigris, which has been listed as Endangered (EN) in 11 IUCN assessments from 1986 to mid-2022, both IUCN evaluations and Living Planet Database (LPD) data consistently indicate a deteriorating population trend. According to IUCN analyses of threat status, population changes in this species have generally worsened. Although Panthera tigris was rated EN in seven assessments between 1986 and 2008, and later downgraded to Vulnerable (VU) in the 2017 assessment, the number of mature individuals continues to decline, confirming ongoing population deterioration.

Between 1982 and 2017, Panthera uncia maintained a Vulnerable (VU) status in only four evaluations from 1982 to 1990. After being assessed as Near Threatened (NT) for the first time in 1996, it retained this NT status in three subsequent assessments. Despite the rating improvement, overall population numbers have declined, and the species shows a worsening endangerment trend. Panthera pardus and its eight subspecies have also experienced significant declines between 1986 and 2025. Although the global status of P. pardus was downgraded from VU to NT in 2008 and has remained at NT, population trends continue to deteriorate. Among the eight subspecies (ssp. nimr, ssp. melas, ssp. delacouri, ssp. kotiya, ssp. fusca, ssp. tulliana, ssp. pardus), only ssp. pardus has a single VU rating in 2025. The remaining seven subspecies each have five or more assessments, all of which consistently reflect rapid population declines and severe deterioration.

For Panthera leo and its two subpopulations, overall population fluctuations are less pronounced, yet the decline in the number of mature individuals directly drives the deterioration of the species trend. The two subpopulations—

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P. leo West Africa and P. leo Asiatic—show contrasting dynamics. The West African subpopulation is declining due to fragmentation and reductions in mature individuals, while the Asiatic subpopulation shows an increase. However, its growth is constrained by environmental carrying capacity and counteracted by intensified poaching, leading to an overall fragile stability.

3.2 Trend Characteristics of Endangered Leopard Species in Different Intercontinental Regions

The overall number of leopards continues to decline, although population trends vary considerably across different regions. In Africa, populations are generally stable or show slight fluctuations, though some populations display a downward trajectory. Records from the Living Planet Database (LPD) indicate signs of recovery in certain areas. However, the LPD data for Africa are sparse, with many missing years, making it difficult to construct continuous time series analyses. In Asia, leopard populations exhibit an overall upward trend, supported by relatively continuous datasets. Most records are concentrated in the Gir Forest of India, where conservation measures have been notably effective. For Panthera onca in Latin America, population numbers fluctuate widely, and overall trends remain mixed. Some populations show evidence of recovery, with densities and numbers increasing between 2004 and 2006, possibly due to strengthened protection measures. However, the data are limited and volatile. While certain areas report increases in density and population, others document declines, and inconsistencies in LPD data units further complicate long-term trend analysis.

In some regions of Africa, leopard populations have increased, likely due to effective conservation actions or habitat restoration. Nonetheless, LPD data remain sparse and lack uniform metrics, making accurate assessments difficult. In Asia, Panthera pardus populations display heterogeneous patterns, with increases in some regions and declines in others. Compared with Africa, the LPD data for Asia are more continuous and varied in measurement units. Regional variations in population trends are influenced by conservation intensity, habitat fragmentation, and poaching pressures.

For Panthera tigris, population dynamics within Asia are inconsistent. Certain subspecies and regions show recovery, while others continue to decline, reflecting stark differences in conservation effectiveness and threat exposure. Populations in areas with high habitat fragmentation and intense poaching generally exhibit declines. By contrast, tiger populations in Europe and Central Asia appear stable or even increasing, particularly where protection is stronger, conservation measures are more effective, and management practices are more robust. Despite these findings, LPD data for tigers remain constrained by inconsistent metrics, sparse temporal coverage, and uneven regional representation.

4. Conclusion

The number of endangered leopards in the world is continuing to decline, and as large predators, the decline in numbers caused by various aspects is inevitable, and the general impact of adult decline on leopards is also difficult to solve. Although there are differences in the number of leopards between different continents, the overall deterioration trend is still not optimistic. Although there is a significant positive association between the implementation of conservation policies and population recovery, there are still a few successful conservation cases. Most of the existing protection assessment systems still rely on static classification and hierarchical classification and lack model support based on dynamic data and effective early warning mechanisms, which limits the timeliness and accuracy of protection actions.

To ensure reliable conservation data for leopards, long-term population monitoring programs for endangered species should be promoted to ensure that data are detailed and timely. Establish a standardized data platform, unify data measurement standards, improve global comparability, and provide quantitative support for international protection agreements.

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