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Population Viability Analysis (PVA) for Long-Term Conservation of Snow Leopards

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Abstract

Objective: The snow leopard (*Panthera uncia*) is one of the most endangered big cats. It was commonly found in the high mountains of Central and South Asia. Its population is small, fragmented, and under threat from poaching, habitat loss, human-wildlife conflict, and climate change. This study aims to understand the long-term survival prospects of the snow leopard by using a Population Viability Analysis (PVA), a modelling tool that predicts how a species might respond to various threats and conservation actions over time. Materials and methods: We built a non-spatial, age-structured PVA model using demographic, genetic, and environmental data. Key biological parameters, including adult survival, cub survival, reproductive age, fecundity, and maximum lifespan, were included. We also added genetic risks, such as inbreeding and low diversity, based on genome-wide data. Threats such as poaching, human-wildlife conflict, and catastrophic events (e.g., disease outbreaks) were modelled to see how they affect the population. The model started with an estimated global population of around 7,400 snow leopards.

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Simulation scenarios showed that adult survival, cub survival, and fecundity are the most important traits affecting population growth. When threats like poaching and rare disasters were added, extinction risk increased significantly, especially when threats occurred together. Scenarios with inbreeding showed even greater risk, suggesting that genetic isolation worsens survival chances. This highlights the need to maintain genetic connectivity between subpopulations. Results: The sensitivity analysis showed that small changes in survival and reproduction could strongly influence population stability. The other factors, such as generation time and carrying capacity, had less impact. Improving the cub survival and protecting adults are important in the long run. It also shows how layering multiple threats, such as poaching plus habitat disturbance, can quickly push populations below safe levels. Conclusion: This study shows that the targeted conservation strategies can determine the Snow Leopard's future. It addresses the most sensitive life traits and most damaging threats. The PVA gives a realistic way to predict future population and guide conservation decisions to prevent extinction by combining the demographic, genetic and threat-based data.

Keywords:

Extinction risk, genetic diversity, population viability analysis, snow leopard (panthera uncia), *survival and reproduction.*

Article history:

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Introduction

The snow leopard (*Panthera uncia*) is a type of big cat and an endangered animal in the world. It normally lived in high altitude and cold places like the Hindu Kush, Tian Shan, Altai, and the Himalayas. The habitat was spread over 12 to 13 nations in the Central and South Asian region. Even though it covers a wide area, the total number of snow leopards is fewer than 8,000 and is still going down (Jackson et al., 2008). This decline is caused by several threats, such as illegal hunting for their fur and bones, farmers killing them after losing their chattels, and humans moving into their natural homes. Climate change is a major problem; it changes the environment, which is unsuitable for the animals and their prey. In many places, snow leopards are now stuck in small, high-mountain areas, which makes it harder for them to survive and have babies. Some main threads to the snow leopard are known, but still, we want to understand how the thread affects the species. Most of the studies focus on only one factor or limited data, which makes it hard to get the full picture. The combination of multiple factors like population trends, habitat conditions, and genetics into one clear approach (McCarthy et al., 2017; Mishra et al., 2025). There are still some critical gaps that threaten the high risk, and traits such as rate of survival or reproductive success are most influential. Also, the resilience of the snow leopard to the environment requires care.

This lack of clarity makes it difficult to design effective conservation strategies. Without knowing the key drivers of population decline or which interventions offer the most impact, conservation efforts risk being inefficient, misdirected, or too late. To care for this, a method called Population Viability Analysis (PVA) is used to understand how the snow leopard can survive in the future (Brook et al., 2000). PVA is a type of computer model that looks at different situations and predicts what might happen to a species over time. The model includes the critical factors about the snow leopard, such as how long they live, how often they have babies, how many cubs survive, and when they become adults. And also the threats like poaching, conflict with humans, disease, and the loss of prey (Forrest et al., 2012).

On top of that, it uses new genetic data to study the effects of inbreeding and low genetic diversity, which are major concerns for small, isolated groups of snow leopards. What makes this study different is that it tries to model the snow leopard population as a whole, rather than just looking at one small area. It examines different stimuli of the future, examining how survival traits interact with threats to influence the species' chances of survival. The model shows which traits are the most important, which are more critical threats, and what methods effectively improve the outcomes. In summary, this research addresses a key problem, such as the complex interplay between threats and traits and how it influences the long-term viability of the Snow Leopard, which is not fully understood. This research gives better results and guides to make smarter conservation to protect the species by using a complete and realistic model.

Literature Review

Large carnivores like the snow leopard (*Panthera uncia*) are highly sensitive to fallouts and other deaths that may be caused by humans, especially through poaching and retaliatory killings due to livestock loss (McCarthy et al., 2017). These threats have caused a gradual decline in the population. According to the (IUCN, 2023), the snow leopard is now listed as Vulnerable, with fewer than 8,000 individuals left in the wild.

Demographic models are often used to understand extinction risk. For instance, (Doak et al., 1994) offered a description of how age-structured models, such as the Leslie matrix, are used to determine certain key life-history traits that include cub survival, reproductive age, and adult longevity, which are assigned to predict population growth or decline. Such models have also been employed to aid the conservation planning of other great cats such as tigers and cheetahs.

Apart from demographics, genetic problems are also to be tackled in conservation issues. Recent findings by (Zhou et al., 2024) suggest that snow leopards, especially northern populations, are characterised by poor genetic variability and inbreeding levels. Among other effects, this can cause inbreeding depression that diminishes offspring survival and their reproduction, leading to an extinction of greater probability with time. Habitat fragmentation and alteration of prey availability due to climate change pose other problems.

Presently, tracking technologies have wrought seismic changes in the snow leopard realm. The snow leopard researchers tracked individual members of this cat family across the high Himalayas through satellite telemetry and were able to delineate the different seasonal home range behaviour, mortality pattern, and denning behaviours. These were data necessary to estimate the parameters of survival and reproduction that serve in population modelling. Meanwhile, it was found that camera trapping and GPS collar data together provide robust methodological approaches to the assessment of survival of cubs and evaluation of maternal behaviour, and hence confirm the importance of tracking data in viability assessments (Javaherian et al., 2017). More generically, (Safa et al., 2025) show how the convergence of location and activity sensing technologies embedded within ubiquitous computing platforms enables adaptive context-aware services in domains such as healthcare and intelligent transport technologies approaches that strongly parallel emerging paradigms in wildlife monitoring and conservation surveillance systems. Cloud computing and AI together offer great potential to improve real-time decision-making systems for environmental monitoring. These technologies, originally conceived for disaster response and climate resilience planning, now present opportunities for tracking and conserving wildlife. By processing big telemetry or camera-trap datasets, they could support fast interventions against threats like poaching and habitat disturbances (Choudhary & Deshmukh, 2023).

These problems cause subpopulations to be less connected, thereby affecting genetic exchange between groups. Further, (Shrestha et al., 2025) and (Li et al., 2022) demonstrate that the distribution of prey, female care for offspring, and threats in the area all have an impact on the survival of cubs as well as the health of the populations.

Besides ecological and genetic subjects, in the last couple of decades, the application of modern computational tools has started to endorse some kind of wildlife conservation in the interior zones. The deep learning models had been truly instrumental in curbing elephant-train collisions across the railway networks of India. This completely exposed the path for integrating AI-based solutions within conservation frameworks to mitigate a big factor of human-induced mortality, which is also of serious concern to snow leopards in areas where human encroachment and development of infrastructure are on the way up (Bharathi & Senbagam, 2025).

Animal diversity monitoring forms one of the most important wings of conservation. In a detailed study carried out by (Khyade & Jagtap, 2019), the butterfly diversity of the Mayureshwar Wildlife Sanctuary was investigated, which gave insights into how the species-specific data collection helps in understanding ecological health and stability of the habitat. With the emphasis on the habitat-based studies, this indirectly illustrates the considerations that would be pertinent to the conservation of larger mammals. Such biodiversity baseline information feeds into long-term monitoring frameworks, which become crucial when assessing prominently elusive species, such as snow leopards. Hence, any modifications in habitat quality and ecosystem integrity should directly bear on the ability of the populations to avoid extinction through management.

While these valuable studies provide some understanding, the focal points of the majority of studies lie in one factor: demographics, genetics, or threats. Only a handful combines all three into one model. This study attempts to fill in this gap by using a Population Viability Analysis (PVA), which incorporates demographic, genetic, and threat-based data into one and the same age-structured model. It uses stochastic simulations to test different future scenarios and helps identify the most urgent risks and conservation priorities for the snow leopard.

Materials and Methods

Study Overview

This so-called stochastic age-structured viability analysis is done for the snow leopard (*Panthera uncia*) and aims at forecasting future survival. The objective is to calculate the extinction risk, understand which phases in the snow leopard's life history are most critical for its survival, and see the impacts of various threats or conservation measures (Lacy, 1993; Boyce, 1992). To make things simpler, the model assumes the population to be panmictic-this means it views the snow leopard population as a huge cluster without any attention being paid to how they are distributed, or joined, in different areas. The model does not incorporate any spatial dynamics or movements among subpopulations. In general terms, the study tells what changes in survival, reproduction, or some external threats can affect the long-term survival of the snow leopard, and thus some good conservation planning (Boyce, 1992).

Data Collection

This study used detailed demographic, genetic, threat, and habitat-based data to construct a Population Viability Analysis (PVA) model for the snow leopard (*Panthera uncia*) (Schofield, 2019). The model was designed to simulate long-term population trends and estimate extinction risk under different scenarios.

Tracking and Monitoring Approach

By using the non-invasive tracking and satellite telemetry approaches, snow leopard monitoring generated demographic parameters such as survival rate, fecundity, and dispersal. Very long-term field studies involving

GPS-satellite collaring, camera-trapping and sign-surveys (scat, pugmarks, etc.) were conducted around range countries of Mongolia, Nepal, and India. Satellite telemetry gave fine-scale information on the movement of, and survival in, adult individuals (Janečka et al., 2008; McCarthy et al., 2017). Camera-traps identified reproductive behaviours, cub survival, and denning events. These data were corroborated with local ecological monitoring programs and were vital in estimating and modelling age-specific mortality and reproduction in the PVA.

Demographic Parameterization

The demographic parameters were gathered from credible conservation sources, including the (IUCN, 2023) and peer-reviewed ecological sources. The model comprised various life-history parameters such as age at first reproduction, litter size, survival rate, and lifespan. To simulate survival and reproduction in snow leopards across age groups, a Leslie matrix model was employed by the study. With such a method, age-specific probabilities of survival and reproduction rates were combined. The reproduction was set to begin in early adulthood and increase with age. Ecological field data determined cub and adult survival rates. To account for natural variability and associated uncertainties, the model assigned Beta distributions to survival rates and Gamma distributions to litter size. A generation length of 7.3 years was adopted to set the time scale for the projections.

Integration of Genetic Factors

Wild snow leopard populations are dispersed across several countries, including China, Mongolia, Russia, and Tajikistan; in these countries, samples are collected to study genetic risk using whole-genome sequencing (WGS). The analysis includes estimates and measures of genetic diversity, inbreeding coefficients, and effective population size. They modelled population genetic trends using more traditional methods, such as the Pairwise Sequentially Markovian Coalescent (PSMC) approach, among others derived from the coalescent model (Janečka et al., 2008). While the model considered a panmictic population structure for its baseline scenarios, other simulations were introduced to account for genetic structure and the impacts of inbreeding depression.

Threat Scenario Modelling

Threats as a consequence of humans and nature were modelled on evidence gleaned from wildlife trade monitoring networks, conservation organisations, and published literature. These threats were poaching, human-wildlife conflict, and habitat disturbances (McCarthy et al., 2017; Boyce, 1992). Further, one set of modelled threats was rare yet highly destructive stochastic events, such as disease outbreaks or prey population crashes. These were assigned given probabilities and severity levels dependent on how they would likely affect snow leopard populations in various circumstances.

Carrying Capacity Estimation

Carrying capacity was estimated using a habitat-based approach. Snow leopard density values from some previous works were combined with habitat area estimates from regional distribution maps, one of which included recent data from Pakistan. While the spatial variation in the quality of habitat was not explicitly modelled, this approach allowed density-dependent factors to be incorporated in the population model, thereby allowing for some affected long-term population growth and stability due to environmental constraints (McCarthy et al., 2017). The pathway constituted by demographic and genetic health issues on one end and threats from outside and habitat constraints on the opposite end provides a viable methodological framework within which snow leopard population viability may be evaluated and conservation management guided.

Model Construction and Simulation

Modeling Framework

To evaluate the long-term survival prospects of snow leopards, an age-structured stochastic population model was developed. The model was based on a Leslie matrix framework, which is commonly used in wildlife population studies to describe how individuals progress through age classes over time (Lacy, 1993; Morris & Doak, 2002). In this model, populations were subdivided into numerous age classes, beginning with newborn cubs and ending with the oldest adult stage. This model incorporated demographic and environmental variabilities. Demographic stochasticity implied the randomness inherent in survival and reproduction pertaining to small populations. Whereas, environmental variability treated this issue by giving probability distributions for parameter values of perhaps the most important life-history parameters, so that each simulation run would be able to draw slightly different values within biologically realistic ranges. This approach thus helped account for the natural fluctuations the snow leopard populations may face in the wild.

Simulation Settings

The model was working against a fixed time period considered to extend through many generations of snow leopards. With each run of the simulation, rates of survival and reproduction were alternately drawn out from the distributions they were assigned. To incorporate all uncertainty and variation occurring in the response of populations, these simulations would be run many times (Morris & Doak, 2002; Panthera et al., 2017; Perini & Sicuro, 2025). Two thresholds were applied to decide on a population at extinction risk: one based on the minimum number of individuals remaining and the second based on a decline in the number of mature breeding individuals. These criteria aligned quite well with international conservation assessment standards. Thanks to the structure of the model, life-history traits and environmental factors could be varied to understand their effects on the population trends as a whole with time (Akçakaya & Sjögren-Gulve, 2000).

Scenario Development

A number of scenarios were developed to see how the snow leopard population might be affected by different states of conservation and threat. The base scenario represented a population with no additional direct human-caused threats, with only the demographic parameters being those set forward by scientific sources. The other scenarios incorporated threats to the population that could arise through poaching, human-wildlife conflict, and disturbance to habitat. These threats were modelled by applying increased mortality to the population at different levels of severity. Recovery scenarios were also built to portray an improvement of survival or reproduction that might become realised through conservation interventions to reduce conflict, establish protected areas, or enhance community participation (McCarthy et al., 2017; Janečka et al., 2008). In a few scenarios, the genetic aspects of the populations were considered by simulating the potential effects of inbreeding, condensed into the decreased fitness of the population on the basis of empirical data from genomic studies. Those simulations of genetic risk served to assess how a lack of genetic diversity may affect the long-term stability of the population. Thus, each scenario studied gives variable insight into the degree to which demographic, environmental, or genetic pressures affect extinction risk or recovery potential. Together, these approaches were developed as a comprehensive tool that can be used to inform long-term conservation planning for snow leopards.

Sensitivity Analysis

The sensitivity analysis was performed to establish which biological and ecological parameters most influence snow leopard population dynamics. It helped to identify how small changes in input values affect the outputs of the model, especially the population growth rate (λ) and the probability of extinction. The approach taken was based on the popular methodology of (Morris & Doak, 2002) who integrated elasticity and perturbation analyses within the Leslie matrix model.

Elasticity analysis measures the relative contribution of each matrix element (survival or fecundity) to population growth. The elasticity of λ with respect to a matrix element is calculated by:

$$e_{ij} = \frac{a_{ij}}{\lambda} . \frac{\partial \lambda}{\partial a_{ij}} = \frac{a_{ij} . v_i w_j}{\lambda . \langle v, w \rangle}$$

Here, v_i and w_j are the elements of the left and right eigenvectors of the Leslie matrix, representing reproductive value and a stable age distribution, respectively, and $\langle v, w \rangle$ is their scalar product. The elasticities are dimensionless, allowing comparison across life-history traits.

Complementarily, perturbation analysis was done by systematically modifying, within biologically plausible ranges, each parameter, including adult survival, juvenile survival, fecundity, and carrying capacity. The change in the growth rate of the population after the change of any parameter is recorded as:

$$\Delta\lambda = \lambda' - \lambda$$

Where λ' is the growth rate subsequent to the parameter change, and λ is the original rate. Such an option gave a practical view of the sensitivity of the model to the uncertainty in each parameter. Having worked in partnership, these analyses helped explore what traits most influence population persistence and so help focus management actions and future research efforts (Boyce, 1992).

Results

Geographic Distribution and Habitat Range

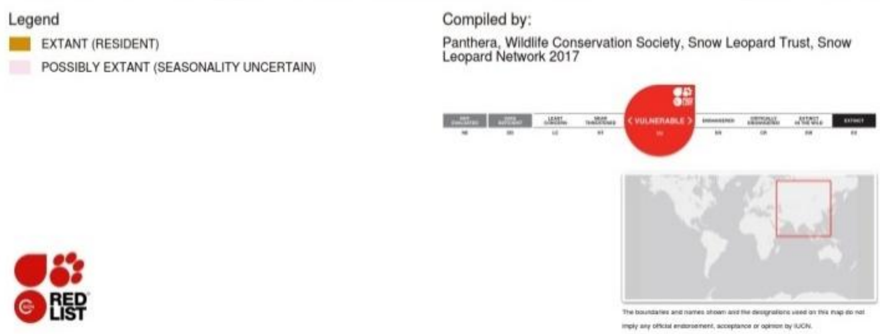

Figure 1. Distribution range of the snow leopard (*Panthera uncia*) across Central and South Asia, based on the (IUCN, 2023). The map shows areas where the species is extant (resident) and regions where its presence is uncertain due to seasonal variation

Figure 1 shows where snow leopards (*Panthera uncia*) are found across Central and South Asia. The species mainly lives in rugged mountain regions such as the Himalayas, Altai Mountains, and Tian Shan range. Countries where snow leopards are known to live include China, Mongolia, India, Pakistan, Nepal, Bhutan, and other parts of Central Asia.

Knowing the combined geographic range of snow leopards is important for several reasons. The first of these is that it offers an estimate of the possible carrying capacity (K), that is, the maximum number of snow leopards that the environment may support. The second is that it provides some indication of subpopulation structure, as these various zones may contain isolated groups of animals. Finally, it enables the identification of certain regional threats, such as poaching, habitat loss, or conflicts with humans, which may differ from one country to the next.

Initial Population and Demographic Trends

The population model for snow leopards started with a worldwide estimate of between 7,367 and 7,884 individuals given by the (IUCN, 2023). These individuals were categorised into 13 different classes by age to study population dynamics. Each age class was assigned different values for survival, reproduction, and maturity that changed with age. The model considered a 7.3-year generation time as the main time frame for all facilities. Most snow leopards were assumed to become reproductively mature by 4 years of age. However, breeding probability changed according to age-roughly 30% of individuals bred at age 2, 65% at age 3, and almost all at age 4 (see Figure 2). Reproductive output was considered at the rate of one litter size of 1.5 cubs per breeding occurrence. This was further modelled by the Gamma distribution to account for natural variation in the litter sizes (Johansson et al., 2025). The survival probability was also age-dependent. Survival of adults was modelled with the Beta distribution and was estimated to be between 0.6 and 0.9, while the survival of cubs tended to be lower, ranging anywhere from 0.5 to 0.6, on the basis of observations from the field (McCarthy et al., 2017).

Table 1. Key demographic parameters used in the snow leopard population viability analysis (PVA)

Parameter	Value / Distribution	Source	Use in PVA
Global Population Estimate	7,367 – 7,884	IUCN Red List Supplement	Initial population size
Reproductive Age	Starts at 2 yrs; 100% by 4 yrs	IUCN Supplement	Maturity thresholds
Maximum Age	13 years	Red List Matrix	Max age in Leslie matrix
Litter Size	Gamma (4.5, 0.3), Mean ≈ 1.5	Red List Supplement	Fecundity input (stochastic)
Adult Survival	Beta (25, 5) → ~0.6–0.9	IUCN Supplement	Adult survival rate
Cub Survival	0.5 – 0.6	Inferred from maternal care	Juvenile mortality
% Breeding by Age	2 yrs: 30%, 3 yrs: 65%, 4+: 100%	Red List Scenarios	Breeding probabilities
Generation Time	7.3 years	Red List	Used to scale model duration

In Table 1, the demographic parameters and probability distributions used in the population viability analysis for snow leopards are summarised. Parameters for the model should primarily be taken from the Red List Supplement (IUCN, 2023) and related ecological studies. They give estimates of initial population size, age-specific reproduction, survival rates, and generation time. Paramount are the inputs into developing an age-structured population model and using it to project population dynamics under stochastic conditions.

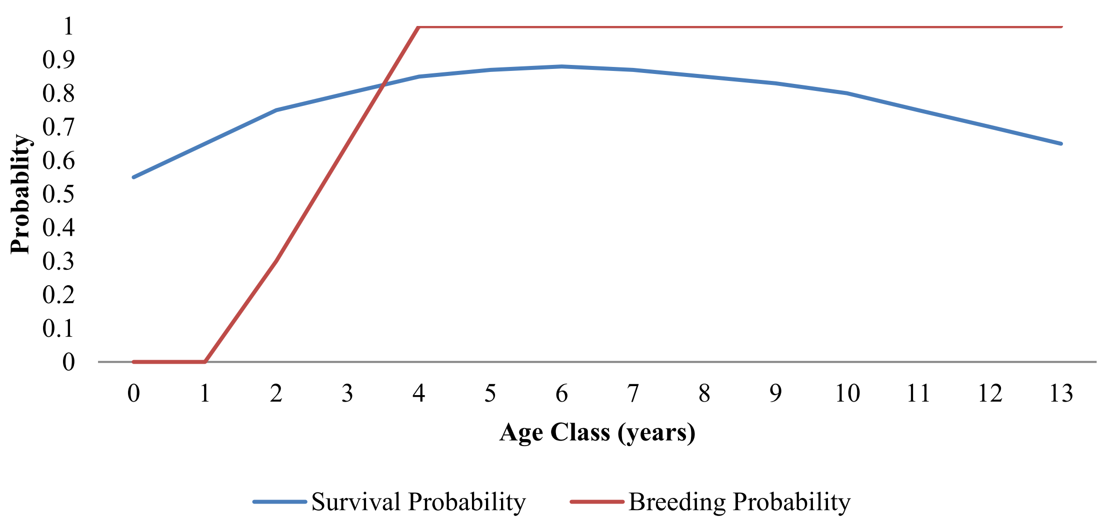

Figure 2. Age-specific survival and breeding probability curve in snow leopard

Genetic Vulnerability

Genetic diversity is very low in wild snow leopards, especially in the northern groups, where more inbreeding was found. The effective population size (Ne) has been getting smaller since the Last Glacial Maximum, around 13,000 years ago, which means they have been losing genetic diversity over a long time. In the simulation model, when inbreeding depression (a drop in the health and survival of offspring due to close relatives mating) was included, the risk of extinction increased. This is because isolated groups had weaker, less fit offspring. The main model assumed random mating among all snow leopards, but other versions of the model included separated populations to see how inbreeding and limited movement between groups affected them. Figure 3 clearly shows that the chance of extinction becomes much higher when inbreeding and population separation are part of the scenario, compared to the random-mating situation (Yang et al., 2025).

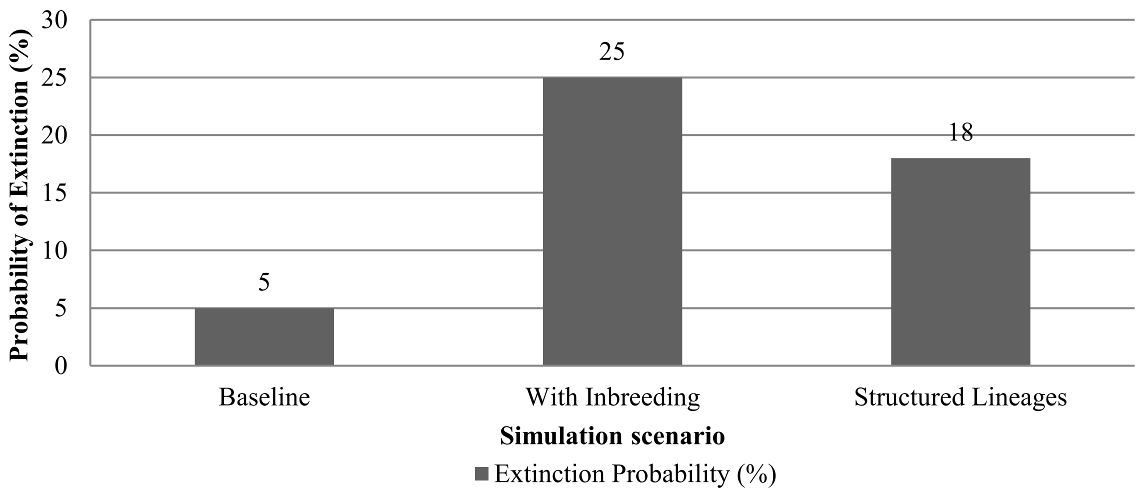

Figure 3. Comparison of extinction probability in snow leopard populations under inbreeding scenarios

Threat-Based Scenarios

The threats done by humans, like poaching and conflict, increase the deaths per year by 2-10 % in the snow leopard from the test (McCarthy et al., 2017). This caused the population to drop over time, especially in small or isolated groups. This trend is clearly shown in Figure 4, where higher poaching rates led to sharper population declines. The other factors, like rare disasters**,** such as disease or prey shortages, happen every 10–15 years and reduce the population by 10–20%. The above factors made a low probability of survival and often pushed the population below safe levels. Figure 5 illustrates how populations exposed to catastrophic events declined significantly compared to those without such disturbances (Johansson et al., 2025). The combined impact of poaching and catastrophic events is further summarised in Table 2, which shows a dramatic increase in extinction probability when both threats are present Figure 6.

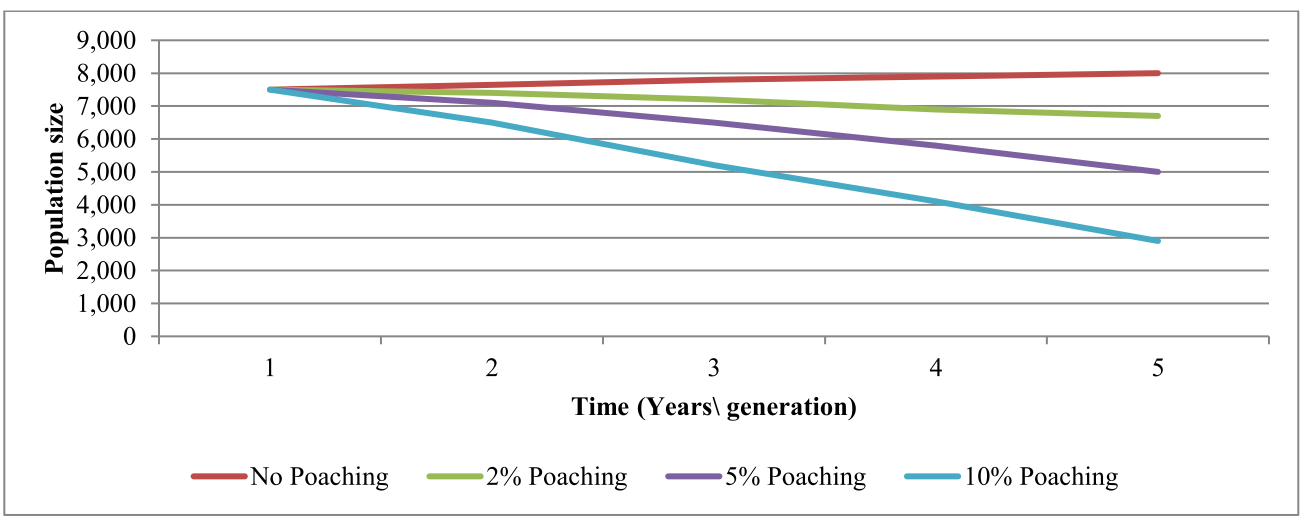

Figure 4. Impact of poaching rates on snow leopard population over time

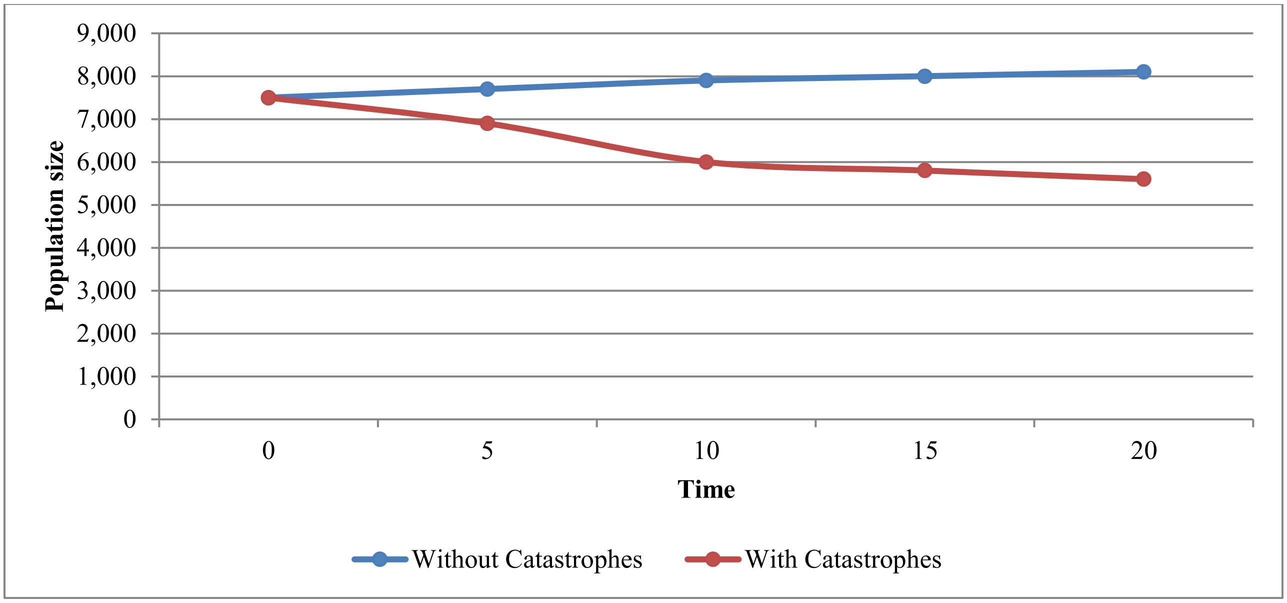

Figure 5. Effect of catastrophic events on snow leopard population dynamics over 20 years

Table 2. Extinction probabilities under different poaching and catastrophic event scenarios

Scenario	Added Mortality (%)	Frequency (if applicable)	Extinction Probability (%)	Notes
Baseline (no threat)	0	—	<5%	Stable population
Low Poaching	2	Annual	10–15%	Gradual decline
Moderate Poaching	5	Annual	30–40%	High risk in fragmented areas
High Poaching	10	Annual	60–70%	Severe population collapse
Catastrophic Events	N/A	Every 10–15 yrs	20–30%	Events reduce recovery potential
Poaching + Catastrophes	5	+Catastrophes	70–90%	Combined effects are highly damaging

Habitat and Carrying Capacity Constraints

Human threats, such as poaching and human-wildlife conflicts, add a 2-10% death annual mortality. It can lead to a population decline in a time period, efficiently in a small or fragmented population (McCarthy et al., 2017). 10-20% of population reduction caused by catastrophic events like disease outbreaks and prey loss every 10-15 years is also added (Brook et al., 2000). It can increase the extinction risk and reduce long-term population stability. Growth stopped when populations got closer to the carrying capacity. However, communities frequently failed to achieve or sustain these levels in situations with significant mortality or environmental perturbations.

Simulation and Extinction Risk Analysis

10,000 simulations were run for each scenario by the model, with extinction defined as the population falling below 2,500 mature individuals based on the IUCN C1 2023 criteria (Lacy, 1993). In the background, where no additional threats were added, the snow leopard population remained stable or showed slow growth. Then, when threats such as poaching, inbreeding, and catastrophic events were included, the population often declined sharply, with many simulations predicting collapse. Sensitivity analysis showed that adult survival, cub survival, and fecundity were the most important factors influencing population growth rate (λ) (UNEP-WCMC & IUCN, 2020; Van De Kerk et al., 2016). These traits had the strongest effect on whether the population could recover or continue to decline. Figure 6 illustrates the highest elasticity value seen in the adult survival; it shows that small improvements in the adult survival can improve the population stability. This is followed by cub survival and fecundity, both of which also play key roles. Table 3 supports this by ranking these parameters according to their effect on growth rate, confirming that they should be prioritised in snow leopard conservation planning (Larsson, 2025).

Table 3. Sensitivity ranking of life-history parameters based on impact on population growth rate (λ)

Parameter	Perturbation Range	Effect on λ (Growth Rate)	Sensitivity Ranking
Adult Survival	0.6 → 0.9	High	1
Cub Survival	0.5 → 0.6	Moderate	2
Fecundity	1.3 → 1.7 cubs/female	Moderate	3
Carrying Capacity	±20%	Low	4
Generation Time	±0.5 years	Very Low	5

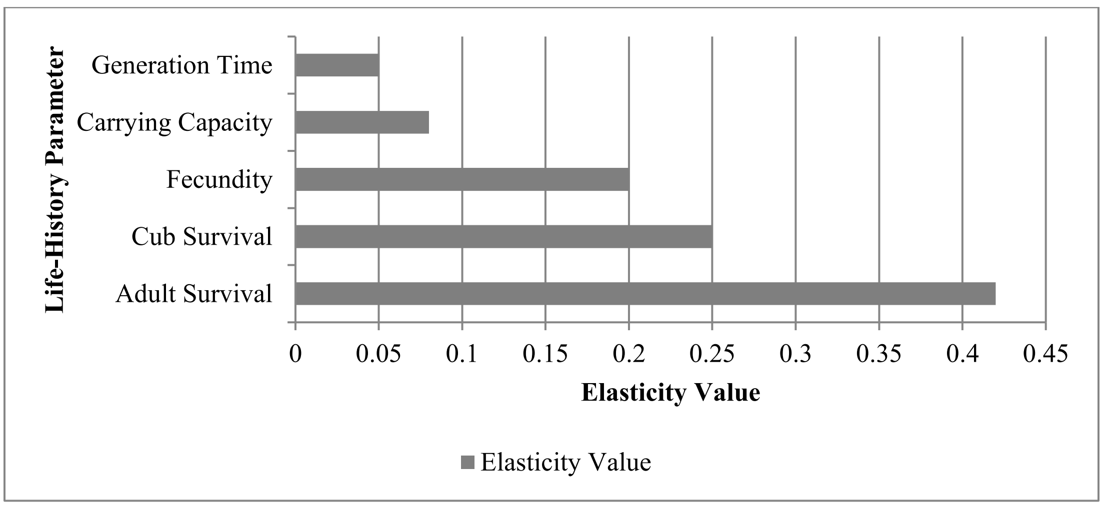

Figure 6. Elasticity analysis of life-history parameters in snow leopard population model

Discussion

This Population Viability Analysis (PVA) provides a useful tool for understanding how the snow leopard (*Panthera uncia*) may survive in the long term under different ecological and threat conditions. The model results show that three life-history traits**,** adult survival**,** cub survival, and fecundity (reproductive rate), have the greatest influence on population growth. The results are similar to other studies on the big cats; protecting adult animals and improving conditions for cub survival are important for species recovery. The risk factors were increased, including threats such as poaching, human-wildlife conflict, and catastrophic events (like disease outbreaks or prey loss), which were added to the model. Populations declined more quickly when multiple threats occurred together. This shows that the combined effect of threats is more damaging than individual threats alone. Therefore, it is important to develop conservation strategies that tackle both direct and indirect pressures on the species. The model also looked at the effect of genetic factors**.** Simulations showed that low genetic diversity (heterozygosity) and inbreeding, especially in northern subpopulations, can lead to reduced offspring fitness and a higher chance of extinction. While the main model assumed a panmictic population (where all individuals can breed freely), scenarios that included structured subpopulations with limited gene flow showed higher vulnerability. This highlights the need to maintain genetic connectivity between regions and to consider transboundary conservation actions. Although this PVA model did not directly include spatial data, it used carrying capacity (K) estimates based on habitat area and population density. This helped define the maximum number of snow leopards the environment could support. When mortality pressures were high, populations did not reach carrying capacity, which caused unstable population dynamics. This suggests that habitat protection, prey availability, and reducing conflict are important for maintaining a stable population. A sensitivity analysis was used to find which traits had the biggest effect on the model's outcomes. It confirms that the survival of the adults, cubs and fecundity have the highest elasticity, it shows that even small improvements in the area can reflect the better population stability. Generation time and carrying capacity are the other factors that have a lower sensitivity, as they require minimal focus in the short term. Overall, the model shows for the future of the snow leopard by both of the biological traits and external threats play a strong role. Conservation efforts should be directed at the traits and threats that matter most to prevent long-term decline and extinction.

Conclusion

From this study, we can understand that the snow leopard (*Panthera uncia*) faces significant long-term risks due to both natural and human-related threats. The survival is directly influenced by the rate of survival in the adults and the cubs, and also by reproductive success. The threads like poaching, human-wildlife conflict, inbreeding, and rare catastrophic events were included in the model; the probability of extinction increased notably, especially when multiple threats were combined. These conditions led to greater population instability and faster declines. Genetic problems, particularly low genetic diversity and inbreeding in isolated populations, further reduced the fitness of offspring, increasing extinction risk. Among the traits studied, adult survival had the biggest effect on population growth. Even small improvements in adult survival could help stabilise the population. Cub survival and the number of offspring (fecundity) were also important. Since habitat and prey availability were not directly included in the model, they still affected the population by limiting how many snow leopards the area could support. These results show which biological and environmental factors matter most for snow leopard populations. They also stress the need for targeted conservation efforts to reduce major threats and help the species survive in the long run.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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