

Master of Science in Biology

Assessing effectiveness of protected area through snow leopard conservation: an interdisciplinary case study of the Sarychat–Eertash Nature State Reserve (Kyrgyzstan)

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Figure front page: Mother snow leopard and her two cubs captured by camera trap installed through OSI-Panthera citizen science programme, in Sarychat-Eertash Nature State Reserve (Kyrgyzstan)

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Abstract

The snow leopard (*Panthera uncia*) is an elusive apex predator of the high-mountain ecosystems of Central Asia. Despite its importance as both a flagship and umbrella species, major knowledge gaps remain regarding the effectiveness of conservation measures designed to protect it. This study assesses the effectiveness of the Sarychat-Eertash Nature State Reserve (SENSR), one of Kyrgyzstan's most important protected areas, through an interdisciplinary framework combining long-term ecological monitoring with a socio-ecological systems approach.

Ecological effectiveness was evaluated using more than ten years of citizen science data collected through the OSI-PANTHERA programme. Spatial capture-recapture (SCR) models estimated snow leopard density, while transect surveys provided complementary information on prey and carnivore populations. Socio-anthropology was investigated through the analysis of 29 semi-structured interviews with stakeholders involved in or affected by snow leopard conservation.

The ecological assessment revealed stable populations of large mammals, recurring evidence of reproduction among both prey and predator species, and comparatively high snow leopard density (7.29 individuals/100 km²; 95% CI: 3.42-15.75). These results suggest that SENSR functions as an effective refuge and likely source population within the Central Tien Shan. Although SCR estimates should be interpreted cautiously because of limitations related to sampling design and data quality, these findings also highlight the scientific value of long-term citizen science monitoring. The socio-anthropological analyses identified two complementary drivers underpinning protected-area effectiveness: the symbolic value of the snow leopard as a flagship species capable of mobilizing political and financial support, and the central role of conservation NGOs in translating this symbolic capital into concrete conservation actions. The systemic analysis demonstrates that protected-area effectiveness is not solely determined by ecological outcomes, but emerges from interactions among governance arrangements, social acceptance, economic incentives, and symbolic values. While SENSR currently generates positive conservation outcomes, its long-term resilience remains constrained by institutional fragilities, land-use conflicts, and competing development priorities.

Beyond its empirical findings, this thesis proposes a framework for evaluating protected-area effectiveness through the lens of an umbrella species. More broadly, it shows that conservation effectiveness should not be understood as an intrinsic ecological property of a protected area, but as a dynamic socio-ecological outcome continuously shaped by interactions among species, people, institutions, and governance systems. Interdisciplinarity therefore emerges not as a methodological option, but as a prerequisite for understanding, evaluating and improving conservation effectiveness.

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General Introduction

The ongoing global biodiversity crisis highlights the urgent need to better understand and evaluate the effectiveness of conservation strategies, particularly protected areas. While protected areas remain one of the most widely used tools for biodiversity conservation, assessing their effectiveness is inherently complex, as it depends on the interaction between ecological dynamics, governance systems, and human behaviour. Traditional approaches often focus primarily on ecological indicators, neglecting the role of social processes and stakeholder perceptions. This limitation is particularly critical for large carnivores, whose survival frequently depends as much on human tolerance as on habitat suitability (Lham et al., 2026; Treves & Karanth, 2003).

Among large carnivores, the snow leopard (*Panthera uncia*) represents a particularly relevant case. This elusive species is the smallest member of the *Panthera* genus, with a head-and-body length ranging from 1.0 to 1.3 m, a tail length of 0.8 to 1.1 m, and a body mass between 20 and 50 kg. It is highly specialized for life in high-altitude montane environments of Central Asia, where it has evolved a range of morphological and physiological adaptations to cope with low temperatures, hypoxic conditions, and the challenges of hunting on steep, heterogeneous terrain (Mallon & McCarthy, 2024). These adaptations have historically led to its classification as taxonomically and phylogenetically distinct from other *Panthera* species. However, recent molecular evidence has confirmed its placement within the genus, identifying the snow leopard as a sister species to the tiger (*Panthera tigris*) (Mallon & McCarthy, 2024). This top trophic-level predator (=apex-predator; Wallach et al., 2015), inhabiting high-mountain ecosystems across Central Asia, plays a key ecological role as both a flagship and umbrella species. Its flagship status stems from its ability to attract conservation attention, funding, and political support, whereas its umbrella function derives from the large areas and ecological conditions required to sustain viable populations, thereby benefiting many co-occurring species and mountain ecosystems (Wilcox 1984 in Ray et al., 2005; Roberge & Angelstam 2004 in Ray et al., 2005; Mallon & McCarthy, 2024). However, despite its importance, it remains one of the least studied large felids due to the remoteness and harshness of its habitat (Macdonald et al., 2010; Mallon & McCarthy, 2024). Across the 12 countries that constitute its range, snow leopard populations are threatened by a combination of pressures, including habitat degradation, climate change, prey depletion, and human–wildlife conflict driven by livestock depredation, what can lead to retaliatory kills (Sharma et al., 2019; Koshkin et al., 2024; Suryawanshi et al., 2017; Chetri et al., 2020). These pressures are exacerbated by the limited availability of reliable population data, which constrains the development of evidence-based conservation strategies (Janečka et al., 2008).

Kyrgyzstan is a landlocked country of approximately 198,500 km² located in Central Asia and is one of the 12 range countries of the snow leopard. Dominated by the Tien Shan and

Pamir mountain systems, more than 90% of its territory lies above 1,000 m elevation, creating extensive high-mountain ecosystems that support snow leopards and their principal prey species (Akimaliev et al., 2013). The country plays a key role in the regional hydrological system of Central Asia and contains a mosaic of alpine, subalpine, and steppe habitats shaped by strong elevational gradients and seasonal snow cover (Tomaszewska et al., 2020). Following its independence from the Soviet Union in 1991, Kyrgyzstan experienced profound socio-economic transformations, including the collapse of collective farming systems, livestock privatization, rural economic restructuring, and changing land-use practices. These transitions have substantially influenced grazing dynamics, wildlife-livestock interactions, and biodiversity conservation across mountain landscapes (Havenith et al., 2017; Nuraliev et al., 2024). Recent national-scale assessments in Kyrgyzstan estimate the snow leopard population at approximately 300 individuals (data based on SCR analyses, with a 95% confidence interval of 246 to 366; Kubanychbekov et al., 2026), with higher densities mostly associated with rugged terrain and protected areas (PASK, 2024). However, no single protected area is large enough to ensure long-term population viability independently (Johansson et al., 2016), highlighting the importance of connectivity, landscape-scale governance, and the integration of human-dominated areas into conservation strategies with mitigation of human-wildlife conflicts to facilitate coexistence (Hacker et al., 2021; Kubanychbekov et al., 2026). These findings reinforce the idea that conservation effectiveness must be understood beyond the boundaries of protected areas and within broader socio-ecological systems.

In this context, the Sarychat–Eertash Nature Reserve (SENSR) in eastern Kyrgyzstan provides a particularly relevant case study. Established in 1995, the reserve covers approximately 1,341 km² of high-mountain ecosystems ranging from 2,000 to 5,500 m elevation and includes one of the largest strictly protected areas in the country. Characterized by broad alpine valleys, rugged mountain ranges, a harsh continental climate, and extensive alpine grasslands, the reserve supports abundant populations of Siberian ibex (*Capra sibirica*) and argali sheep (*Ovis ammon*), the principal prey species of the snow leopard. The reserve hosts one of the most important snow leopard populations in the region within a relatively well-preserved ecosystem (SER, 2007). The entire territory is dedicated to nature conservation and scientific research, and economic activities are prohibited (SER, 2007). At the same time, it is embedded in a complex socio-ecological context, involving local communities, conservation non-governmental organisations (NGOs), and external pressures such as mining, pastoralism, and tourism. Uniquely, the reserve has been monitored for more than 15 years through a citizen science programme (OSI-PANTHERA), providing a rare long-term dataset on snow leopard presence and ecological dynamics. The programme is coordinated by Objectif Sciences International (OSI), a Swiss NGO dedicated to science education and participatory research in support of sustainable development. OSI-PANTHERA aims to promote the

study and conservation of mountain wildlife in Kyrgyzstan and Nepal, with a particular focus on snow leopards. The first expedition was organized in Kyrgyzstan in 2006, and annual citizen science expeditions have been conducted in SENSr since 2007. These expeditions generate long-term ecological and camera-trap data following an adaptive monitoring framework that has been progressively refined through field experience and scientific advances.

Despite considerable progress in snow leopard research over recent decades, important knowledge gaps remain regarding both ecological dynamics and conservation effectiveness. Reliable long-term demographic trends remain incompletely understood across much of the snow leopard's range. Although recent nationwide assessments have considerably improved knowledge in some countries, notably Kyrgyzstan where SCR analyses estimated an adult population of approximately 300 individuals (95% CI: 246-366; Kubanychbekov, 2026), important knowledge gaps persist regarding population dynamics, survival, reproduction, connectivity, and long-term trends both within Kyrgyzstan and across large parts of the species' distribution (Janečka et al., 2008; McCarthy et al., 2008). Indeed, robust population estimates about the species are available only from less than 2% of their entire distribution range, which are also biased in resulting from sampling mostly best habitats. This makes any projections about the populations across the landscapes, countries or range unreliable (Sharma et al., 2019). These deficiencies largely stem from the species' elusive behaviour and the remoteness of its high-mountain habitat, which make ecological and behavioural studies particularly challenging (Macdonald et al., 2010). At the same time, recent research has highlighted that conservation success cannot be explained by ecological factors alone (Lham et al., 2026). Although community-based conservation approaches are increasingly promoted, their effectiveness remains highly context-dependent and may be constrained by unequal participation, social exclusion, and local governance dynamics (Agrawal & Gibson, 1999; Alexander et al., 2022; Berkes, 2004; Keane et al., 2016; Mishra et al., 2017; Roe, 2008). Furthermore, growing evidence indicates that protected areas alone are unlikely to ensure the long-term persistence of snow leopard populations. The species depends on extensive interconnected landscapes (Azizan et al., 2023; Johansson et al., 2016), while only a small proportion of its current distribution is formally protected (Kubanychbekov et al., 2026), and most protected areas remain smaller than the spatial requirements of a viable population (Johansson et al., 2016; McCarthy et al., 2017). Consequently, conservation efforts increasingly emphasize the need for integrated approaches combining protected areas, ecological connectivity, and community involvement (PASK, 2024; Kubanychbekov et al., 2026). In response to these knowledge gaps, this thesis proposes an exploratory interdisciplinary assessment of conservation effectiveness in the SENSr. By combining ecological monitoring, citizen science data, and socio-anthropological analyses, it seeks not only to contribute to the understanding of snow leopard conservation, but also to reduce the gap between scientific knowledge and

conservation practice (Fabian et al., 2019; Pullin & Knight, 2001). Beyond the case of Sarychat–Eertash, the study aims to explore how an interdisciplinary socio-ecological perspective can contribute to evaluating conservation effectiveness in complex mountain landscapes. The central research question being:

How effective is the Sarychat–Eertash Nature State Reserve as a socio-ecological system for conservation, when assessed through the lens of snow leopard conservation?

The ecological component of the study focuses on the temporal evolution of snow leopard population density and related indicators, using camera-trap data collected between 2016 and 2024 and analysed through spatial capture–recapture models (Efford & Boulanger, 2019). A key feature of this work is the use of citizen science data, which, although not originally designed for rigorous statistical analysis, could offer valuable insights when carefully processed. In data-limited contexts, such approaches represent an important opportunity to advance knowledge and support evidence-based conservation (Sharma et al., 2019)

The second component mobilizes a socio-anthropological perspective, based on semi-structured interviews with actors involved in snow leopard conservation and/or in proximity of SENSAR. It combines ecological and socio-anthropological analyses within a conceptual framework inspired by Ostrom’s social-ecological systems (SES) theory (Ostrom, 2009). This analysis draws on the sociology of translation and Actor-Network Theory, as well as governance frameworks such as PARTNERS (Mishra et al., 2017) and SPECCS (Brichieri-Colombi et al., 2018), to examine how conservation measures are perceived, negotiated, and implemented. Accordingly, the snow leopard, considered a flagship species (Yue et al., 2024) and widely used to mobilize funding, policy support, and public engagement, can be used as a focal species to investigate the effectiveness of conservation interventions. Nevertheless, this approach relies on the assumption that snow leopard conservation is sufficiently representative of wider conservation processes. While such a lens offers important analytical advantages, it may also oversimplify the research question by underrepresenting other species, ecosystem functions, and socio-ecological dynamics that shape overall conservation effectiveness.

The originality of this research lies in the integration of ecological monitoring, citizen science, socio-anthropological inquiry, and socio-ecological systems analysis to evaluate conservation effectiveness through the lens of snow leopard conservation. Rather than treating ecological and social dimensions separately, the study assumes that conservation outcomes emerge from interactions between ecological processes and the broader governance, institutional, and socio-economic context in which conservation takes place.

To address the research question, this thesis evaluates a set of complementary hypotheses concerning the ecological, social, and socio-ecological dimensions of conservation effectiveness. First, if Sarychat-Eertash Nature State Reserve (SENSR) functions as an effective protected area for snow leopard conservation, ecological indicators should reveal stable or improving conditions over time. Snow leopard density estimates, prey population indices, and evidence of recruitment are expected to remain stable or increase throughout the monitoring period.

The study also assumes that, despite limitations related to sampling design and data standardization, long-term citizen science monitoring can provide scientifically relevant information for conservation assessments when analysed using methods that explicitly account for variation in monitoring effort and detectability. Under this assumption, ecological patterns derived from citizen science datasets should be biologically coherent and suitable for informing conservation decisions.

Beyond ecological performance, the thesis hypothesizes that conservation effectiveness depends on social mechanisms that facilitate the implementation of conservation actions. Snow leopard conservation is therefore expected to be supported not only by ecological conditions but also by stakeholder engagement, local participation, and social processes influencing conservation behaviour. Consequently, perceptions of conservation are expected to reflect both ecological concerns and broader socio-anthropological factors, including livelihoods, local values, and relationships with conservation institutions.

The study further assumes that conservation outcomes are influenced by the symbolic role of the snow leopard as a flagship species. Under this hypothesis, conservation effectiveness depends not only on formal governmental institutions but also on the ability of stakeholders to mobilize resources, coordinate actions, attract support, and maintain legitimacy within the conservation system. The symbolic value of the species is therefore expected to play an important role in shaping conservation dynamics.

Finally, the thesis hypothesizes that if SENSR functions as an effective socio-ecological system, positive ecological outcomes should be accompanied by governance arrangements capable of managing tensions between conservation objectives and competing social and economic interests. Conservation effectiveness is therefore expected to emerge from the interaction between ecological and social dimensions rather than from either component alone.

Together, these hypotheses move the study beyond a purely descriptive assessment of biodiversity and protected-area management. Rather than analysing ecological, social, and institutional dimensions independently, the thesis evaluates whether different sources of evidence converge toward a common interpretation of conservation effectiveness. The interdisciplinary approach is thus used not as an additional descriptive layer, but as a means of assessing whether ecological outcomes, stakeholder

perceptions, governance arrangements, and socio-ecological dynamics collectively support the functioning of SENSR as an effective conservation system.

Chapter 1: Ecological effectiveness of the Sarychat-Eertash Nature State Reserve

1.1. Introduction

Evaluating the ecological effectiveness of protected areas is a central challenge in conservation science. Beyond their legal designation, effective protected areas are expected to maintain biodiversity, preserve ecological processes, and ensure the long-term viability of species populations (Gaston et al., 2006; Geldmann et al., 2013). More specifically, an effective reserve should maintain representative biodiversity features, sustain ecological interactions, buffer ecosystems from anthropogenic pressures, and preserve habitat quality and connectivity through time (Gu et al., 2024; Nord et al., 2019; Wang et al., 2024). Assessing whether these objectives are achieved requires robust ecological indicators capable of detecting changes in population status and ecosystem functioning over time. Among the different indicators available, large carnivores are often considered particularly informative because of their high trophic position, extensive spatial requirements, and sensitivity to environmental changes. However, monitoring these species remains challenging. Large mammals and apex predators generally occur at low densities, occupy vast territories, and exhibit elusive behaviours that make direct observations unreliable, and abundance estimates difficult (Balme et al., 2009). Traditional methods based on trace surveys, track counts, or opportunistic observations are highly sensitive to variations in detection probability and can therefore lead to biased conclusions regarding population trends.

Despite these challenges, this study adopts the snow leopard *Panthera uncia* as the principal ecological entry point for evaluating conservation effectiveness. This choice is justified not only by the species' conservation status but also by its ecological and symbolic importance. The snow leopard is widely recognized as a flagship species, mobilizing public support, funding, and political attention for biodiversity conservation (Xu et al., 2022). Beyond this communication role, it is frequently described as an umbrella species, whose conservation may benefit numerous co-occurring species through habitat protection (Mallon & McCarthy, 2024; Solari et al., 2025), and as a potential keystone species because of its position as an apex predator (Lovari et al., 2009; Weckworth, 2021). However, unlike for species such as the tiger, no formal food-web analysis has yet demonstrated a keystone effect for the snow leopard (Sun et al., 2024). Much of its presumed ecological influence remains inferred from theoretical

expectations and comparisons with other well-studied apex carnivores (LaBarge et al., 2022; Mallon & McCarthy, 2024), like puma (*Puma concolor*).

This uncertainty does not diminish the relevance of the snow leopard as an indicator. On the contrary, its dependence on extensive territories, healthy wild prey populations, and relatively low levels of human disturbance makes it a particularly useful lens through which to evaluate the broader ecological condition of high-mountain ecosystems. If a protected area successfully maintains ecological integrity, such success should be reflected, at least in part, in the status of its snow leopard population. Conversely, changes in snow leopard abundance may reveal underlying ecological pressures affecting the wider ecosystem. The species can therefore be viewed as a practical proxy for assessing the ecological effectiveness of conservation measures, while recognizing that it does not capture all dimensions of biodiversity.

Monitoring snow leopard populations has long been constrained by the logistical challenges associated with studying a secretive species inhabiting remote mountain environments (Janečka et al., 2008; Macdonald et al., 2010). Recent technological advances have nevertheless transformed wildlife monitoring. Camera trapping combined with spatially explicit statistical approaches now allows the collection and the analysis of standardized data over large areas while accounting for imperfect detection (Burton et al., 2015; Nawaz et al., 2026). For species with identifiable coat rosettes patterns at the individual level (Jackson et al., 2006), such as the snow leopard, camera traps provide the foundation for capture–recapture analyses, such as the use Spatial Capture–Recapture (SCR) modelling (Efford & Boulanger, 2019).

Snow leopards occupies territories that often exceed the boundaries of individual protected areas and relies on extensive interconnected landscapes (Johansson et al., 2016; McCarthy et al., 2017). Consequently, evaluating the effectiveness of the Sarychat–Eertash Nature State Reserve (SENSR) requires not only estimating snow leopard density, but also examining whether the ecological conditions supporting the species are maintained through time and how it is improving the status of the snow leopard in the region. Assessing conservation effectiveness through snow leopard conservation assumes that the status of this apex predator reflects, at least partially, the broader ecological conditions maintained within the protected area.

The ecological component of this thesis therefore addresses the following question:

Does the Sarychat–Eertash Nature State Reserve modify the ecological trajectory of the system in a manner consistent with effective nature conservation?

The general hypothesis is that strict protection promotes ecological conditions favourable to the long-term persistence of snow leopards and their prey. Accordingly, if the reserve functions effectively, snow leopard populations should remain stable or increase over time, prey populations to be maintained or enhanced. More broadly, a

successful reserve should contribute to preserving the ecological processes and trophic interactions necessary to sustain viable populations over the long term (Gaston et al., 2006).

To evaluate these predictions, this chapter combines several complementary ecological approaches. Data collected through the citizen science OSI-PANTHERA programme will be valorised and analysed to answer those questions. First, transect survey data were analysed to assess temporal trends in direct observations and indirect signs of presence of large mammals, providing a relative indicator of species occurrence over ten years of summer citizen science expeditions. Second, long-term camera-trap records were analysed to evaluate changes through time in snow leopard detection rates and the number of identified individuals, while considering differences in sampling effort among monitoring periods. Third, spatial capture–recapture (SCR) models are applied to estimate population density and investigate temporal trends in snow leopard abundance. Finally, citizen science transect-based observations of wild ungulates are analysed to provide an overview of prey dynamics within the reserve. Together, these indicators make it possible to assess whether the ecological trajectory observed within SENSr is consistent with the expected outcomes of effective conservation management and to evaluate the extent to which snow leopard conservation reflects the ecological effectiveness of the reserve as a whole.

1.2 Ecological Methods

1.2.1 Study Area

The study was conducted in the Sarychat–Eertash Nature State Reserve (SENSr), located in eastern Kyrgyzstan ($41.7^{\circ} \sim 42.2^{\circ}\text{N}$, $78.1^{\circ} \sim 79.1^{\circ}\text{E}$). The reserve covers approximately 1 341 km², including a 720.8 km² strictly protected core zone and a 620.6 km² buffer zone (Figure 1). This is a regional nature conservation scientific research since 1995, in there economic use of the area is prohibited and the entire territory is secured for scientific research and nature conservation (SER,2007) .

The landscape of the largest Kyrgyz protected area is characterized by large, flat valleys (approximately 1 km wide) surrounded by high mountain ranges, with elevations ranging from 2,000 to 5,500 m. The region experiences a continental climate, with harsh winters and low temperatures throughout the year (mean January temperature at 3000 meter above sea level (masl): -21.5°C ; mean June temperature at 3000 masl: $+4.2^{\circ}\text{C}$). Vegetation is dominated by arid grasslands and alpine meadows, adapted to cold, dry, and windy conditions. Annual precipitation is 295 mm with 164 mm falling between June and August. The number of days per year with snow cover fluctuates between 200 and 210 days in the upper high-altitude zones (SER, 2007).

The mountains of Central Asia contain a rich and diverse flora and fauna, and the area have been recognized as one of the Global 200 Ecoregions by WWF, a centre of plant diversity by IUCN/WWF, and a biodiversity hotspot by Conservation International. This reserve was established with major purpose to conserve snow leopard (*Panthera uncia*) (Red Book of the Kyrgyz SSR, 1985). Four other species listed in the Red Book of the Kyrgyz republic are living in this reserve: snow leopard (*Panthera uncia*), brown bears (*Ursus arctos isabellinus*), Pallas's cat (*Otocolobus manul*), stone marten (*Martes foina*) and argali sheep (*Ovis ammon*) (Suyundukov & Choduraev 2022). The establishment of protected area lead to shift of ecological pattern to a more low-human-impact original and natural state, where argali sheep and Siberian ibex (*Capra sibirica*) are able to thrive (Jumabay-Uulu et al., 2014). The reserve hosts also a diverse assemblage of mountain fauna, including wolves (*Canis lupus*), Eurasian lynx (*Lynx lynx isabellinus*), red fox (*Vulpes vulpes*) and key prey species including marmots (*Marmota baibacina*), Tolai hare (*Lepus tolai*), Altai weasel (*Mustela altaica*) and other small mammals. There are also important and diverse birds of those biomes, including bearded vulture (*Gypaetus barbatus*), Eurasian Griffon (*Gyps fulvus*), Himalayan griffon (*Gyps himalayensis*), Golden eagle (*Aquila chrysaetos daphanea*), Himalayan snowcock (*Tetraogallus himalayensis*) and Eurasian eagle owl (*Bubo bubo*). This trophic structure makes SENSR a critical habitat for snow leopard conservation (Nyhus et al., 2016; Rode et al., 2024).

Ecological sampling focused on a ~500 km² (annual average of the effective state-space area used for SCR analyses = 521km²) area within the core zone, corresponding to the primary camera-trap monitoring network.

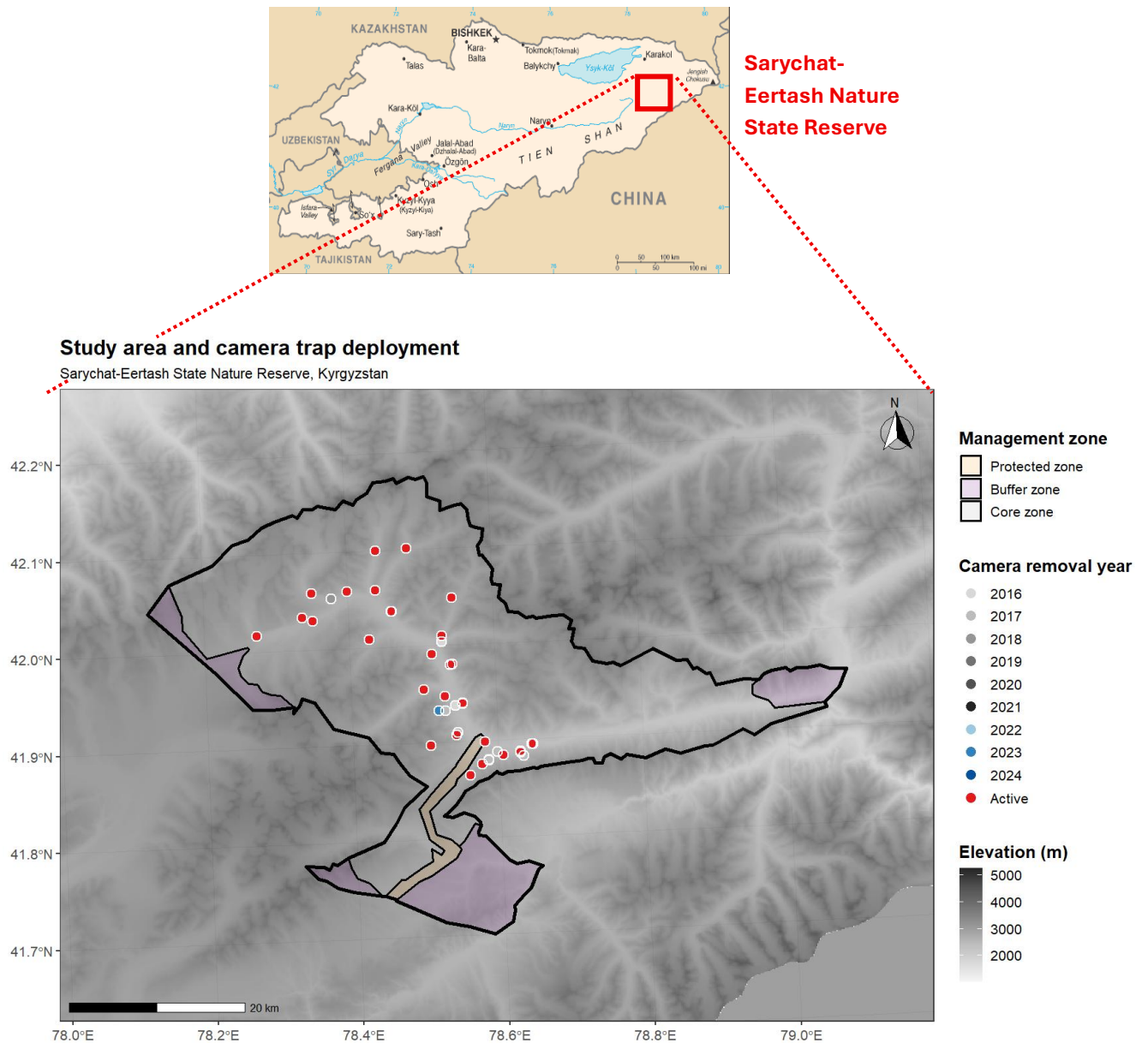


Figure 1: Study area within the Sarychat-Eertash Nature State Reserve, showing elevation, management zones, and the spatial distribution of OSI-Panthera camera traps used for snow leopard monitoring. Camera symbols indicate the final year of operation, whereas red symbols represent camera traps that remained active at the end of the study period (August 2024). The grey area in the southeastern portion of the map represents China's territory and is intentionally included to illustrate the international boundary.

1.2.2 Data Collection

1.2.2.1 Camera-trap deployment through citizen science monitoring programme

The OSI-PANTHERA citizen science programme has monitored snow leopards and its environment, in the SENSR, since 2007. During the early years of the programme, camera-trap coverage was limited because only a small number of cameras were available and deployments were generally restricted to a few months. Monitoring effort progressively increased over time due to technological advancements, the availability of additional cameras, and the expansion of the study area's spatial coverage. The camera-trap network reached a relatively stable configuration from 2016 onwards. Therefore, to ensure greater consistency in sampling effort and spatial coverage among years, only data collected from 2016 to 2024 (2025 data were not treated when I started my master thesis) were retained for analysis. Camera-trap maintenance was carried out during annual summer expeditions organised by OSI-PANTHERA, with the participation of experts, volunteers, and reserve rangers. Rangers contributed their knowledge of the reserve and assisted field operations during these expeditions, but camera traps were not routinely checked outside this monitoring framework. Expeditions took place between June and August and lasted approximately three weeks. During each expedition, batteries and memory cards were replaced, camera functioning was checked, camera alignment was adjusted when necessary, and some units were occasionally relocated to improve monitoring efficiency. As the principle of citizen science, the monitoring protocol is continuously refined based on accumulated field experience, scientific advances, and application of scientific guidelines published by expert (Sharma et al., 2019).

In order to increase the probability of detecting the same individual at multiple sites, spacing distance within camera trap are set up little bit smaller than snow leopard's territories range: approximately 3-4 km (Jackson et al., 2006; Sharma et al., 2019). Respecting those recommendations, camera traps were deployed at sites considered likely to be used by snow leopards, including marking sites, travel routes, ridgelines, saddles, cliffs and other prominent landscape features. Cameras were typically positioned at an angle of approximately 45° to the expected direction of travel to maximise the duration of animal presence within the field of view and increase the probability of obtaining photographs suitable for individual identification.

The monitoring material consisted primarily of Bushnell Trophy Cam HD Essential (E2 and E3) and Browning Spec Ops Elite HP5 camera traps equipped with passive infrared sensors and low-glow infrared flash. Cameras were programmed to acquire bursts of three photographs per trigger event, with a 0.3-second interval between photographs and a one-second delay between consecutive trigger events. Time-lapse and field-scan functions were disabled.

Camera traps remained active year-round between annual maintenance visits. In this study, monitoring years correspond to the interval between two successive summer expeditions. For instance, the 2024 monitoring season refers to data collected between the summer expeditions of 2023 and 2024 rather than the calendar year 2024. Information recorded for each camera-trap station included geographic coordinates, elevation, station name, deployment and control date and, when applicable, relocation or removal date. A detailed summary of camera-trap deployments is provided in Appendix 1, including the place name and operational period of each of the 48 camera-trap stations, together with the number of raw snow leopard photographic records.

1.2.2.2 Ecological data collection along transects

Ecological data are collected annually during the summer field expedition, which coincides with the maintenance of camera traps and the retrieval of camera-trap data. During these expeditions, participants of the OSI–Panthera citizen science programme, together with trained educators, systematically recorded all observations related to fauna. The repeated annual survey of the same transects provides valuable long-term information on species occurrence and population trends within the study area. In addition to transect surveys, observations made around camps during morning and evening periods were also recorded and incorporated into the dataset.

Data collection consisted of a systematic inventory of all direct wildlife observations and indirect evidence of animal presence encountered while moving between survey locations. Particular attention was given to carnivore monitoring through dedicated transect surveys conducted across ridgelines and valleys within the reserve. The following signs of presence were systematically searched for and recorded: Tracks (pugmarks); Scrapes; Urine marks; Rubbing sites; Faeces; Hair samples; Kill sites. Each observation or sign of presence was georeferenced using a GPS device.

Data on ungulates were primarily obtained through direct visual counts conducted during transect walks within the reserve, as well as start and end of day observation with binocular. In contrast, carnivore data were predominantly based on indirect signs of presence, as direct observations of carnivores were rare and represented only a small proportion of the records. This distinction reflects the cryptic behaviour and low detectability of large carnivore species in the study area.

No ecological transect surveys were conducted in 2020 because all field expeditions were cancelled because of the COVID-19 pandemic. As a result, the ecological monitoring dataset is not continuous throughout the study period.

1.2.2.3 Individual identification

The camera-trap network generated a total of 17,737 usable snow leopard photographs over more than a decade of monitoring. Although the first photographic capture was obtained in 2008, systematic image collection began in 2015. Until recently, all

photographs were manually screened to identify and extract snow leopard images from the complete camera-trap dataset. This process was highly time-consuming and relied on the contribution of trained volunteers. More recently, the OSI-PANTHERA programme developed the artificial intelligence tool *Manas*, which automates much of the image-sorting, metadata (date and hour) and data-entry process. As the training dataset expands, the performance of the model continues to improve, progressively reducing classification errors and processing time.

Because automated recognition tools remain insufficiently reliable for accurate individual identification of snow leopards (Miguel et al., 2019), individual identification was conducted manually using the unique rosette patterns of each animal (Alexander et al., 2015; Augugliaro et al., 2025; Jackson et al., 2006). Each image is independently reviewed by three trained volunteers following standardized identification guidelines adapted from felid monitoring protocols. Discrepancies were resolved through review by an experienced observer or through consensus among reviewers, ensuring a high level of confidence in individual assignments.

For data management, each detected individual was recorded as a separate entry in the monitoring database, even when several snow leopards appeared in the same photograph. A standardized protocol was developed to ensure consistent recording among observers. For each detection, the database included the photograph identifier, the image code, date, time, geographic coordinates of the camera trap, visible body profile, number of individuals present, collar presence, sex and age when identifiable, landscape and marking-site characteristics, behavioural observations, and the identity of the animal whenever reliable identification was possible. These records were compiled into annual datasets and continuously used to build individual photographic histories, creating a long-term reference database that greatly facilitates subsequent identification work. The recent development of *Manas* has progressively automated part of this workflow, although expert validation remains essential for individual identification.

1.2.3 Datasets construction

1.2.3.1 Capture–Recapture dataset construction

To construct the capture–recapture dataset, all annual monitoring records were merged into a single consolidated database. Extensive data cleaning and quality-control procedures were performed, including verification of dates, geographic coordinates, individual identities, camera locations, and potential typing or formatting errors. The resulting standardized dataset provided a reliable basis for subsequent capture–recapture analyses.

The objective was to create a dataset in which each row represented a single independent detection event (hereafter referred to as a passage) of a known snow leopard individual while retaining all relevant information associated with that event. A passage was defined

as the occurrence of an identified individual passing in front of a camera trap during a discrete detection event. A new event starts if there is a gap of more than 15 minutes since the last detection of the same individual. Particular attention was paid to photographs containing multiple snow leopards, such as females accompanied by cubs, social interactions, or simultaneous detections of several individuals. As these photographs had already been separated into individual-level records in the original database, they were preserved as distinct detections during data processing. This approach ensured that each identified animal contributed independently to the capture history, accurately reflecting the biological reality of multiple individuals being recorded within the same event.

Only detections associated with a confirmed individual identity were retained for capture–recapture analyses. Records labelled as unidentified snow leopards ("NA") were excluded because they could not be incorporated into individual encounter histories required for model estimation. Consequently, only a small proportion of the original photographic records (approximately 6%) were ultimately suitable for capture–recapture analyses. In addition, unidentified cubs and subadults that could not be reliably associated with a known adult individual were excluded to avoid potential biases in individual counts and capture histories.

All available metadata associated with the original photographs were retained whenever possible. These included sex, age class (cub <1 year, subadult =1–2 years, and adult >2 years), collar presence, behavioural observations, elevation, habitat description, observer comments, and image identifiers. When several consecutive photographs belonged to the same passage, metadata were aggregated using conservative decision rules. For categorical variables, the first non-missing value was retained when inconsistencies occurred among photographs. For temporal information, the timestamps of both the first and last images of the passage were recorded, allowing the duration of each detection event to be calculated.

Age and sex information were further standardized at the individual level using the individual identification records maintained by OSI–Panthera (all details concerning individuals are available in Appendix 1, section 2.1). When available, age classes derived from estimated birth years were prioritized over field observations. Similarly, sex information derived from individual identification sheets was considered more reliable than field-based assessments and was therefore given priority. When sex could not be confidently determined, the value was recorded as missing (NA).

In sum, the complete data-processing workflow reduced the original database from 17,737 photographs to 970 independent passages involving identified snow leopard individuals. The resulting dataset contains only scientifically usable records and is fully formatted for capture–recapture and spatial capture–recapture analyses.

All data processing and aggregation procedures were conducted in R version 4.5.2 (R Core Team, 2025), ensuring transparency, traceability, and full reproducibility of the analytical workflow.

1.2.3.2 Transect dataset construction

All transect records collected throughout the monitoring programme were merged into a single database. Prior to analysis, records were checked for typographical errors, cleaned and quality-control procedures were performed, including verification of dates, geographic coordinates. The resulting transect database was divided into three categories corresponding to the main types of information collected during field surveys: (i) ungulate observations, (ii) snow leopard signs and observations, and (iii) observations of other large carnivores. Because monitoring effort varied through time, the data were standardized to account for differences in survey intensity. Specifically, for ungulates, as no direct measure of sampled area was consistently available across years. A proxy of spatial survey effort was calculated using the number of distinct locations (place names) where ungulates were recorded. Annual counts were standardized by this measure of spatial effort. In addition, observations were aggregated at the location level to provide an index of the average herd size recorded at each site throughout the monitoring period.

For snow leopard and other large carnivore observations and signs, annual records were standardized by field effort. To account for variation in monitoring intensity among years, observations were divided by the total number of field days in the year. Each survey mission with OSI-PANTHERA represent 11 field days in the reserve.

All data processing were also conducted in R version 4.5.2 (R Core Team, 2025).

1.2.4 Data Analysis

1.2.4.1 Informative analysis of camera-trap and transect datasets

Prior to density estimation, exploratory analyses were conducted to characterize the structure of the camera-trap and transect datasets, evaluate temporal patterns in detections, and identify potential sources of variation likely to influence spatial capture–recapture (SCR) analyses.

Transect data were analysed to provide complementary information on broad ecological trends within the reserve. Annual indices were calculated separately for ungulate observations and carnivore signs. Observations were grouped by species and sign type, and temporal trends were visualised using effort-standardised indices. Standardisation followed the procedure described in Section 1.2.3.2 to account for annual variation in survey effort. These indices were used to examine long-term variation in prey and large carnivore observations throughout the monitoring period.

For camera-trap data, all validated snow leopard detections were retained, including observations of cubs, subadults, and individuals of uncertain identity that were not subsequently used in density modelling. Following the cleaning and aggregation procedures described above, exploratory analyses were performed on the processed capture dataset covering the 2016–2024 monitoring seasons. Monitoring seasons were defined from August of the previous calendar year to July of the labelled year (e.g. the 2023 season corresponds to August 2022–July 2023).

Dataset overview visualisations were first produced to describe the temporal evolution of monitoring effort and available capture–recapture information. For each monitoring season, the number of active camera traps, processed detection events, and unique identified snow leopards were calculated and visualised. These summaries provided an overview of data availability and annual variation in sampling effort throughout the monitoring programme.

Population structure was then explored using identified individuals for which age and sex information were available. Sex structure was described from adult individuals only, and the relative representation of males and females was evaluated through descriptive statistics and a binomial test against an expected 1:1 sex ratio. Temporal variation in sex ratio was further assessed using generalized linear models and chi-square tests. Age structure was examined by summarising the number of identified individuals assigned to cub, subadult, and adult age classes within each monitoring season. To avoid overrepresentation of frequently photographed individuals, each identified snow leopard was counted only once per monitoring season within a given age class.

Temporal patterns in capture data were further investigated through seasonal exploration of detections and recaptures. Detection events were grouped according to biologically meaningful periods of the annual cycle: breeding (January–March), birth and cub-rearing (April–August), and a comparatively stable period (September–December). Spatial recaptures were defined as detections of the same identified individual at more than one camera-trap location within a given biological period. Heatmaps were used to visualise the distribution of recaptures among seasons and monitoring years, providing an assessment of the availability of recapture information across different periods of the annual cycle. These analyses were intended to complement biological knowledge of snow leopard ecology and assist in the selection of biologically relevant sampling periods for SCR modelling.

Although not constituting a primary objective of the study, these exploratory analyses provide important contextual information for interpreting the SCR results. They offer a descriptive overview of the available data, highlight temporal variation in monitoring effort and detection processes, and justify the selection of modelling choices adopted in the subsequent analyses.

1.2.4.2 Spatial capture–recapture framework and modelling

Spatial capture–recapture (SCR) models explicitly incorporate the spatial locations of detections to estimate animal density while accounting for imperfect detection. SCR has become a standard approach for camera-trap studies of elusive carnivores (for example Jaguar: Alves et al., 2024; snow leopard: Li et al., 2025; Tiger: Karanth et al., 2006) because it uses individual encounter histories and spatial information simultaneously to infer population density and abundance (Efford & Boulanger, 2019). Because density is generally considered the most robust demographic metric for evaluating population status and trends in wide-ranging carnivores, SCR provides an appropriate framework for assessing the ecological effectiveness of protected areas (Borchers & Efford, 2008). In this study, SCR analyses were conducted using the R (version 4.5.2; R Core Team 2025) package *secr* version 5.3.0 (Efford et al., 2025) with the primary objective of estimating annual snow leopard density within the SENSR and evaluating temporal trends in density as an indicator of long-term population status and conservation effectiveness.

A multi-session framework was adopted, with each monitoring year representing a separate session. Multi-session SCR models allow information from repeated surveys to be combined while estimating density independently.

SCR models assume that the probability of detecting an individual decreases as the distance between a detector and the individual's activity centre increases (Efford, 2019). Density was estimated using maximum-likelihood SCR models implemented in *secr*, assuming a hazard half-normal detection function. This function is parameterized by (i) the baseline encounter probability (λ_0 / g_0), representing detection probability when the detector coincides with the activity centre, and (ii) a ranging spatial scale parameter (σ) describing animal movement and space use (Efford, 2019). Detection parameters may vary among individuals, sessions, and detectors due to behavioural, ecological, or methodological factors. Such heterogeneity can influence capture probabilities and, if ignored, may bias density estimates or confound temporal comparisons by reflecting changes in detectability rather than true population dynamics. Camera traps were specified as proximity detectors, whereby an individual could be recorded only once per detector per sampling occasion.

1.2.4.3 Definition of sessions and occasions

A key characteristic of the OSI-PANTHERA dataset is the absence of predefined sampling sessions. Camera traps were deployed continuously throughout the year and checked annually during citizen science expeditions. While continuous monitoring maximizes detection opportunities, spatial capture-recapture (SCR) analyses require clearly defined sampling periods that approximate demographic closure.

To address this issue, the continuous dataset was first restricted to a biologically relevant period of the year. Following previous snow leopard studies (Li et al., 2025), the selection

of this sampling window was guided by ecological considerations. The January-March period was excluded because the breeding season is associated with increased movements, particularly among males, which may artificially inflate encounter probabilities and movement estimates (Mallon & McCarthy, 2024). The May-July period was also excluded because female movements may be constrained by parturition and cub rearing, potentially generating sex-specific differences in detectability and violating closure assumptions. Consequently, only detections recorded between September and December were retained for SCR analyses. This period, hereafter referred to as the stable period, was considered the most suitable because it is characterised by relatively stable movement behaviour and more homogeneous detection probabilities among individuals (Mallon & McCarthy, 2024).

Once this four-month sampling window had been defined, alternative occasion structures were evaluated within it. Three temporal aggregations of the same September-December dataset were compared: (i) a single occasion encompassing the entire four-month sampling period, (ii) two occasions of equal duration, and (iii) four monthly occasions. This comparison was undertaken because SCR estimates can be sensitive to occasion definition, particularly in long-term monitoring programmes based on continuous camera-trap deployment. The objective was therefore to assess whether density estimates, and biological conclusions remained robust across different temporal discretisation of the same biologically selected sampling period.

1.2.4.4 Capture-history construction

SCR analyses require the construction of capture histories (in form of *capthist* objects) linking individual detections to specific detectors and sampling occasions. Annual sessions were created from the selected monitoring period, and capture histories were generated using the dedicated functions available in the *secr* package (Efford et al., 2025).

To ensure consistency with SCR assumptions, only identified individuals were included in the analyses. Unidentified cubs not associated with a known adult female were excluded because they could not be reliably tracked among occasions and would introduce uncertainty into encounter histories. Cubs observed together with identified females were retained when their identity could be inferred within the sampling period.

1.2.4.5 State-space and habitat mask construction

SCR models infer the spatial distribution of individual activity centres using a latent state-space. This state-space consists of the sampled area plus a surrounding buffer sufficiently large to encompass the activity centres of all individuals exposed to sampling (Alves et al., 2024; Augugliaro et al., 2025).

Habitat masks were generated from camera-trap locations after projection of geographic coordinates into a metric coordinate system (UTM). Mask spacing was fixed at 500 m,

following recommendations for snow leopard SCR studies (Sharma et al., 2021), under the assumption that finer resolutions would not substantially alter density estimates.

Buffer width was determined using the optimization procedures implemented within the *secr* package and ranged from 6.13 to 18.8 km among sessions, with an average value of approximately 12 km. Similar buffer values have been reported in recent snow leopard SCR studies (Augugliaro et al., 2025). Although some authors have cautioned against relying exclusively on automated buffer selection procedures (Sharma et al., 2019), the resulting values were consistent with those reported in the literature and were therefore retained. Unlike Chetri et al. (2019), no additional habitat restrictions were required because the state-space did not include extremely low-elevation or high-elevation areas considered unsuitable for snow leopards.

1.2.4.6 Environmental covariates

Environmental covariates were incorporated into the habitat masks to explore ecological drivers of snow leopard density and detection probability.

The following spatial variables were considered:

- Elevation derived from SRTM data;
- Normalized Difference Vegetation Index (NDVI) derived from MODIS imagery and averaged across the growing season (Didan, K. 2021);
- Terrain Ruggedness Index (TRI);
- Topographic Position Index (TPI).

Covariate selection was based on both ecological hypotheses and previous snow leopard studies. Rugged terrain is known to facilitate snow leopard movement and habitat use (Mallon & McCarthy, 2024), and both TRI and TPI have been identified as important predictors in previous SCR analyses (Augugliaro et al., 2025). Consequently, TRI, TPI, and elevation were considered candidate predictors of density and ranging parameter (σ).

Previous studies have reported a non-linear relationship between snow leopard density and elevation, with peak density generally occurring between 3 500 and 5 000 masl (Chetri et al., 2019; Suryawanshi et al., 2017). Because elevations within the sampled area remained below this presumed optimum, a positive relationship between elevation and density was expected.

Elevation data were obtained from the Shuttle Radar Topography Mission (SRTM) digital elevation model using the *elevatr* package in R and reprojected to the coordinate reference system used for the study area.

TRI and TPI were derived from a 30-m resolution digital elevation¹ model following standard procedures. Continuous covariates were standardized to a mean of zero and a variance of one prior to modelling in order to improve numerical stability, facilitate model convergence, and allow direct comparison of parameter estimates (Schielzeth, 2010 in Augugliaro et al., 2025). Correlations among environmental covariates were examined before model fitting to avoid over-parameterization.

NDVI was included as a proxy for prey availability because primary prey species such as Siberian ibex and argali depend on vegetation productivity. We therefore hypothesized an indirect positive relationship between NDVI and snow leopard density.

Sex was also tested as a predictor of detection parameters because preliminary analysis shows significant difference within sex detections. Moreover, previous SCR studies on felids have demonstrated sex-specific differences in movement and detection processes (Alves et al., 2024 with jaguar). Finally, TPI was evaluated as a predictor of encounter probability because snow leopards frequently use ridgelines, saddles, and valley corridors as travel routes and marking locations (Sharma et al., 2021; Chetri et al., 2019; Weiss, 2001).

1.2.4.7 Model selection

Model selection followed a hierarchical three-step procedure based on Akaike's Information Criterion corrected for small sample sizes (AICc; Burnham and Anderson, 2002). Models were ranked according to their AICc values, which balance improvements in model fit against increased model complexity associated with additional parameters (Burnham et al., 2010). The best-supported model from each step was subsequently retained and used as the reference model for the next stage of model selection.

Following the approach adopted by Alves et al. (2024), our primary objective was to estimate temporal variation in snow leopard density among monitoring sessions. Therefore, the first step evaluated temporal effects by comparing a null model ($D \sim 1$, $g_0 \sim 1$, $\sigma \sim 1$) with models allowing baseline detection probability (g_0), movement scale (σ), or both parameters to vary among sessions.

In the second step, the potential influence of sex on detection parameters was investigated. Models allowing g_0 , σ , or both parameters to vary according to a latent heterogeneity class (h2) were compared. The h2 formulation does not directly assume that sex affects detection probability; rather, it represents unobserved individual heterogeneity that may be partially explained by sex. The estimated mixing proportion ($pmix$) provides information on the relative contribution of each latent class to the population. Sex-specific models were considered because exploratory analyses

¹ Copernicus Digital Elevation Model (DEM) was accessed on 20.04.2026 from <https://registry.opendata.aws/copernicus-dem>.

suggested differences in detection frequencies between males and females, consistent with previous studies reporting sex-related variation in movement and detection processes in large felids (for jaguar: Alves et al., 2024; for snow leopard: Oberosler et al., 2022).

In the third step, environmental covariates were incorporated into density and detection models to evaluate their potential influence on snow leopard distribution and detectability. Candidate covariates included elevation, NDVI, terrain ruggedness (TRI), and topographic position (TPI).

To evaluate the contribution of environmental covariates, density estimates obtained from the null model were compared with those from the best-supported covariate model and, when appropriate, with model-averaged estimates derived from all models with $\Delta AIC_c < 2$. In addition to model ranking, model performance was assessed using the precision of density estimates. Precision was quantified using the coefficient of variation (CV), calculated as the ratio between the standard error (SE) and the density estimate. Lower CV values indicate greater precision. According to Efford and Boulanger (2019), a CV of approximately 20% is desirable for reliable SCR density estimation, and the inclusion of ecologically relevant covariates may reduce CV and improve estimator performance, particularly when sample sizes or detection rates are limited (Palmero et al., 2023). Density estimates, associated confidence intervals, and derived population size estimates were obtained from the best model predictions for each monitoring session.

1.2.4.8 Comparison of alternative occasion structures

Each occasion structure (as a reminder: one occasion covering the entire table sampling window, two occasions of equal duration, and four monthly occasions) was analysed independently following the same SCR modelling workflow. Because these models were based on different temporal organizations of the data (as some include finite-mixture structures: *hcov*), direct comparison using AIC was not appropriate. Models including finite-mixture structures (*hcov*) were not compared directly with standard models using AIC because the likelihood formulations differ. Instead, model performance was evaluated using complementary criteria, including:

- biological realism of parameter estimates (density D , baseline encounter probability g_0 , and ranging parameter σ);
- precision of estimates, assessed through standard errors and confidence intervals;
- model identifiability and convergence;
- ecological interpretability of estimated parameters.

To assess the robustness of density estimates, annual density predictions obtained under the three occasion structures were compared using Pearson correlations. Mean density

estimates, population size estimates, ranging parameters, and relative confidence interval widths were also compared among models.

Further inference regarding density variation, ranging scale (σ), and baseline encounter probability (g_0) was based and extracted from the best model.

1.2.4.9 Modelling assumptions and conceptual framework

The analyses were conducted under the standard assumptions of SCR models, including demographic closure within sessions; fixed detector locations during each session; equal exposure of individuals to detection processes; correct individual identification.

The analytical workflow progressed from exploratory analyses to model-based inference. Initial descriptive analyses were used to characterize capture patterns and evaluate data structure, while SCR models provided estimates of density after accounting for imperfect detection and spatial variation in encounter probability. This sequential approach was adopted to maximize both biological realism and statistical robustness.

1.3. Results

1.3.1 Index of population trend over 10 years monitoring along transect

1.3.1.1 Ungulate monitoring

Annual transect surveys revealed substantial interannual variation in the number of argali (*Ovis ammon*) and Siberian ibex (*Capra sibirica*) recorded across the study area (Figure 2). After accounting for survey effort, both species showed generally stable or increasing observation events between 2015 and 2025.

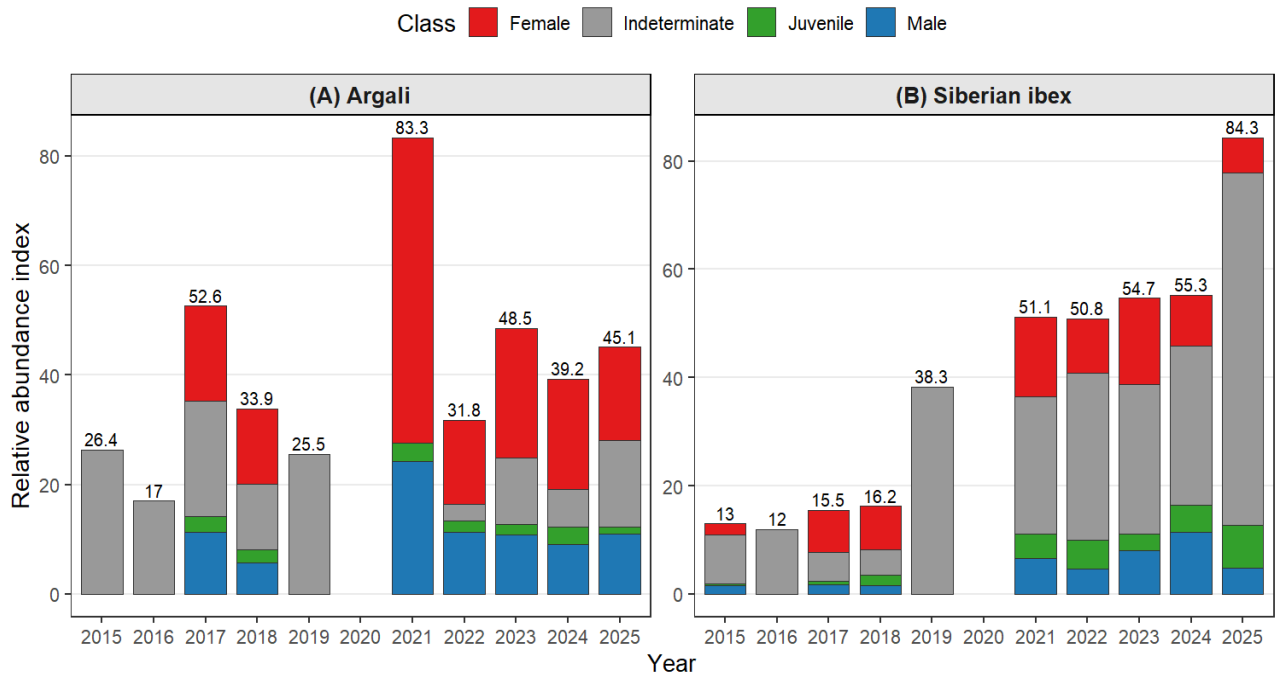
For ibex, observations were consistently dominated by females and individuals of indeterminate age or sex. Juveniles were detected throughout most years, with no indication of a sustained decline. In several recent years, juvenile records remained stable or increased, suggesting regular recruitment within the population.

Argali displayed a similar pattern, with females representing the largest proportion of identified individuals. Juvenile observations persisted throughout the study period, although annual fluctuations were observed. A notably high number of argali observations was recorded in 2021, particularly among identified males and females.

Some years, particularly 2019, were characterized by an unusually high proportion of individuals classified as indeterminate for both species. This likely reflects inconsistencies in data recording or age-sex classification rather than a biological phenomenon. Consequently, direct comparisons of age and sex structure involving this year should be treated with caution.

Relative abundance and population structure of wild ungulates

Individuals observed per surveyed site



No surveys were conducted in 2020 due to COVID-19 restrictions.

Figure 1: Temporal variation in the relative abundance and demographic structure of the two principal wild ungulate prey species of the snow leopard in the Sarychat-Eertash State Nature Reserve: (A) Siberian ibex (*Capra sibirica*) and (B) Argali (*Ovis ammon*). Bars represent the annual relative abundance index expressed as the number of individuals observed per surveyed site, partitioned into sex and age classes (male, female, juvenile, and indeterminate). Values above bars indicate total relative abundance. No surveys were conducted in 2020 due to restrictions associated with the COVID-19 pandemic.

1.3.1.2 Carnivore signs

The relative abundance index of large carnivore signs recorded along transects increased over the monitoring period after standardization for survey effort (Figure 3). Snow leopard (*Panthera uncia*) signs were consistently the most frequently recorded carnivore evidence throughout the study. The effort-corrected detection rate increased from 1.05 records per field day in 2015 and 1.00 in 2016 to a peak of 9.32 records per field day in 2022, remaining high in 2024 (9.05 records per field day).

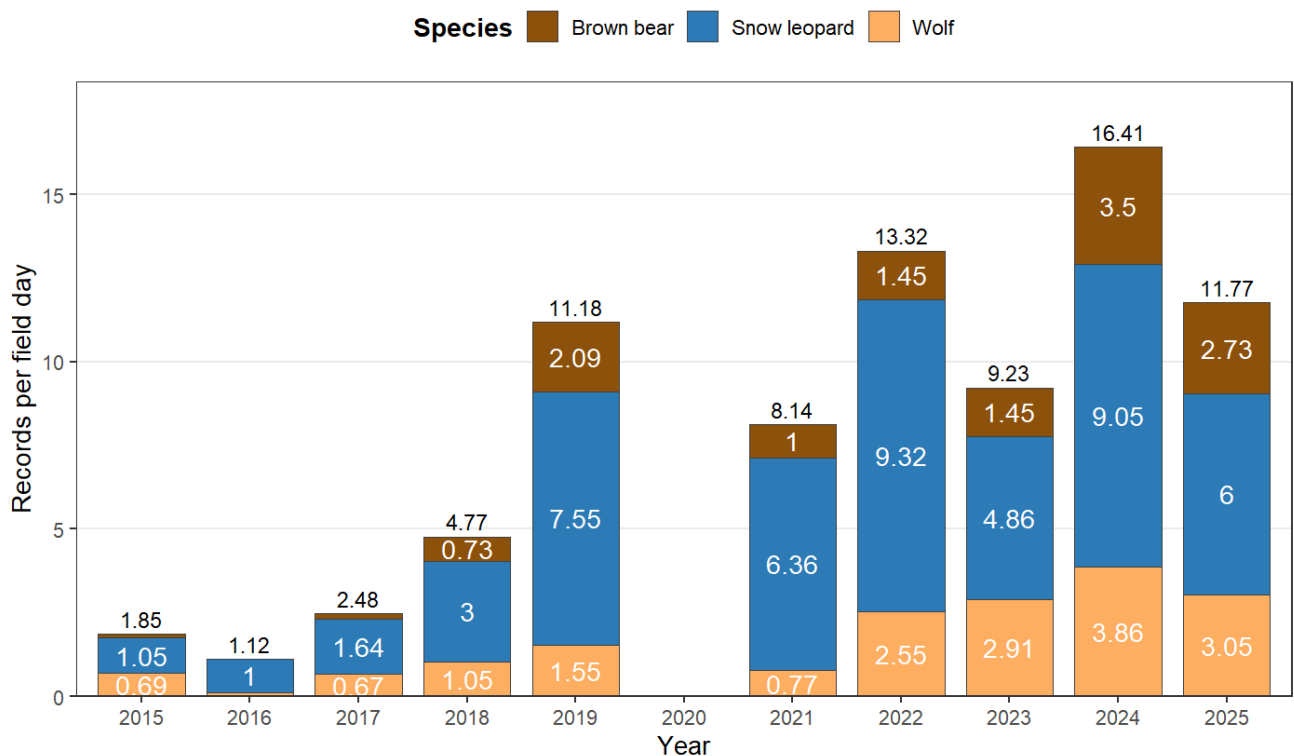
Wolf (*Canis lupus*) signs were detected every survey year and showed a progressive increase through time. The relative abundance index rose from 0.69 records per field day in 2015 and 0.12 in 2016 to 3.86 records per field day in 2024, representing the highest value recorded during the study period.

Brown bear (*Ursus arctos isabellinus*) signs were recorded at lower frequencies than snow leopard signs throughout the survey period. Effort-corrected detections increased from 0.11 records per field day in 2015 to 3.50 records per field day in 2024. Values exceeded 1 record per field day from 2021 onwards, except for 2021 itself when exactly 1.00 record per field day was recorded.

Most records consisted of scrapes and scats, with occasional paw prints, rubbing sites, hair samples. Direct observations remain very rare (see Appendix 1, Figure 15, 16 and 17).

Temporal dynamics of large carnivore sign detections

Detection rates standardized by annual survey effort (records per field day)



No field surveys were conducted in 2020 due to COVID-19 restrictions.

Figure 2: Annual relative abundance index of the three principal large carnivore species recorded during transect surveys in the Sarychat-Eertash State Nature Reserve between 2015 and 2025. Values were standardized by annual survey effort and calculated as the number of signs recorded per field day. Stacked bars represent the contribution of snow leopard (*Panthera uncia*), wolf (*Canis lupus*), and brown bear (*Ursus arctos isabellinus*) to total annual detections. Values above bars indicate annual totals. No surveys were conducted in 2020 due to restrictions associated with the COVID-19 pandemic.

1.3.2 Camera trap dataset overview

A total of 1729 snow leopard detection events (1014 from identified individuals) were retained for analysis between the 2016 and 2024 monitoring seasons. The number of active camera traps, which represent the monitoring effort, increased from 6 cameras in 2016 to a maximum of 27 cameras in 2022 before declining to 14 cameras in 2024 (Figure 3). Across the study period, 86 individual snow leopards were identified based on their

unique coat patterns visible on camera-trap images. Among these, 60 were classified as adults, while the remaining individuals were recorded as cubs or subadults. Younger age classes were not consistently monitored through time because many individuals were either not detected again after their initial observation or could not be reliably reassigned to known adults at later stages of development. Of the 33 adult individuals for which sex could be determined, 19 were identified as males and 14 as females (Table 7, Appendix 1).

The number of processed detection events varied substantially among monitoring seasons, ranging from 38 detections in 2017 to 433 detections in 2022. Similarly, the number of unique identified snow leopards increased from 7 individuals in 2017 to a maximum of 47 individuals in 2022. Following this peak, both the number of detections and the number of identified individuals decreased in 2023 and 2024.

Overall, monitoring effort, expressed as the number of active camera traps, increased progressively throughout most of the study period. Detection events and identified individuals generally followed a similar temporal pattern, with the highest values recorded during the 2022 monitoring season (Figure 3; for further detail on full raw camera trap dataset see Appendix 1, section 3).

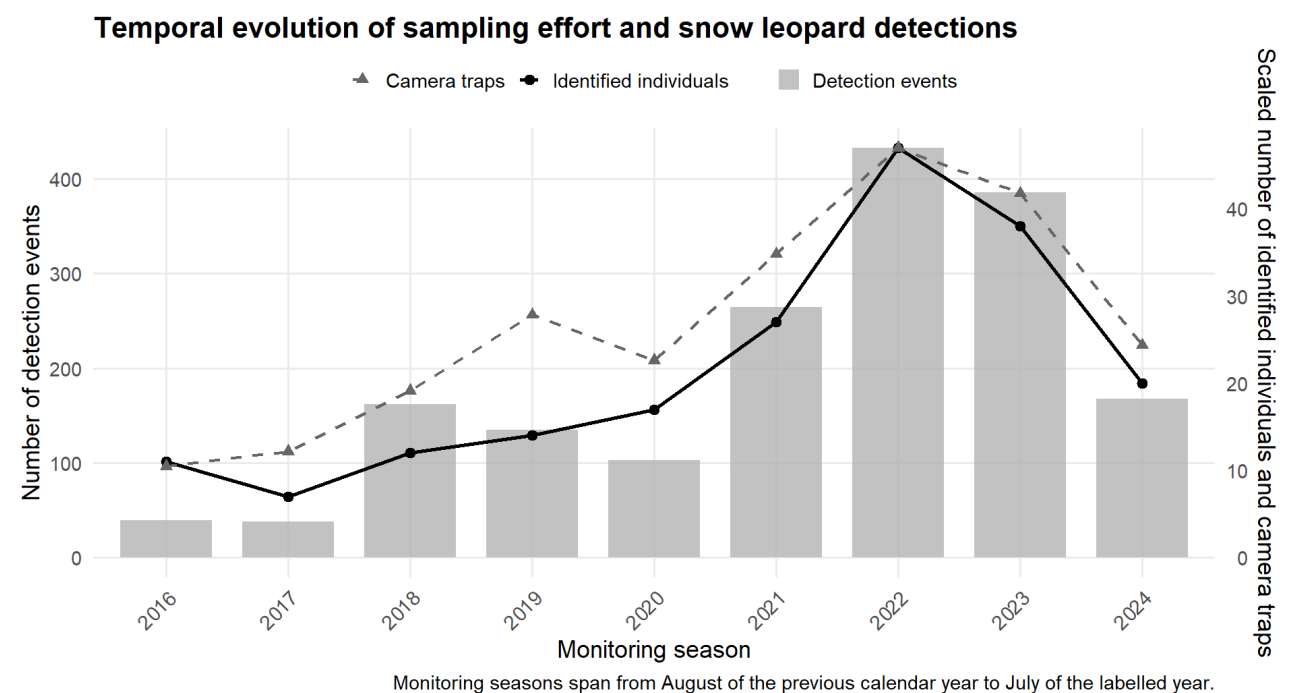


Figure 3: Temporal evolution of snow leopard detection events, identified individuals, and camera-trap monitoring effort across monitoring seasons (2016–2024). Grey bars represent processed detection events, the solid black line indicates the number of unique identified snow leopards, and the dashed grey line represents the number of active camera traps. For visualisation purposes, the latter two variables were rescaled using the ratio between their maximum value and the maximum number of detection events. This figure provides an overview of the increase in monitoring effort and available capture–recapture data through time.

1.3.2.1 Seasonal distribution of spatial recaptures

Spatial recaptures were recorded during all biological periods throughout the monitoring programme (Figure 5). Recapture rates varied considerably among monitoring seasons, ranging from 0 to 4.33 spatial recaptures per month.

Prior to 2021, recapture rates generally remained below one recapture per month regardless of biological period. From 2021 onwards, higher values were recorded in all seasons, coinciding with an increase in monitoring effort.

The highest monthly recapture rate was observed during the breeding period in 2022 (4.33 recaptures per month), followed by the birth period in 2023 (3.25 recaptures per month). The stable period (September–December) showed relatively consistent recapture rates among years, varying from 0.40 to 2.40 recaptures per month.

Spatial recaptures occurred during all biological periods, indicating that individuals were repeatedly detected at multiple camera-trap locations throughout the annual cycle.

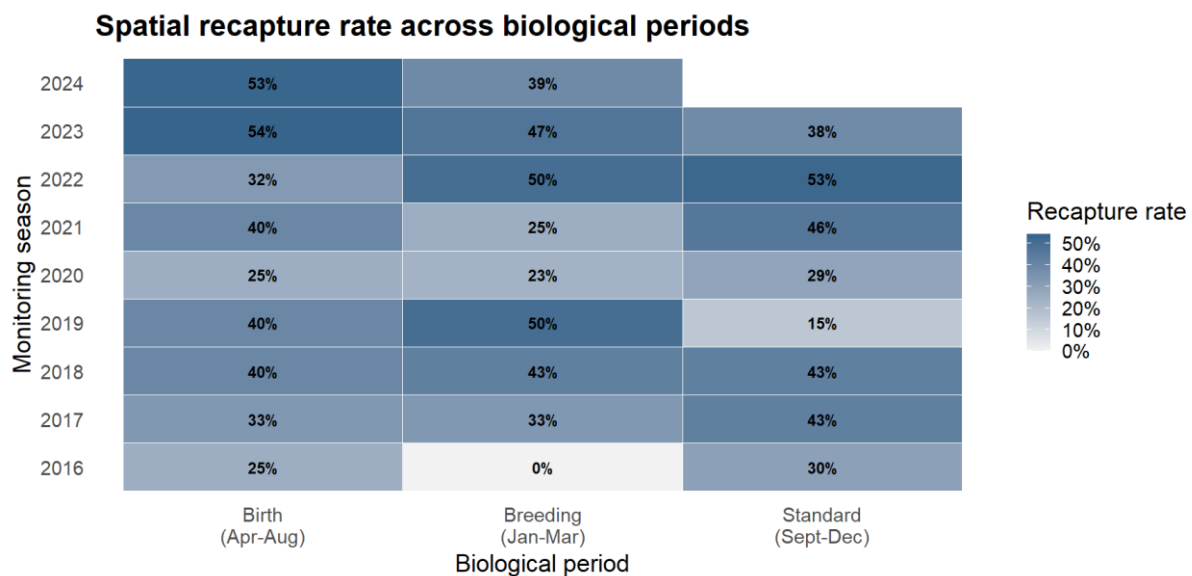


Figure 4: Heatmap of spatial recapture rate across biological season of snow leopard in Sarychat-Eertash Nature State Reserve

1.3.3 Population structure

Camera-trap data provide insights into the demographic structure of the detected population. Across the full camera trap survey period (2016-2024), detections exhibited a strong male-biased sex ratio, with 76.3% (IC 95%: 73.31-79.31%, see Appendix 1) of identified detections corresponding to males (ratio $\approx$ 3:1). Among adults captured, 570

were males and 170 were females and 113 with indeterminate sex identification (Figure 6).

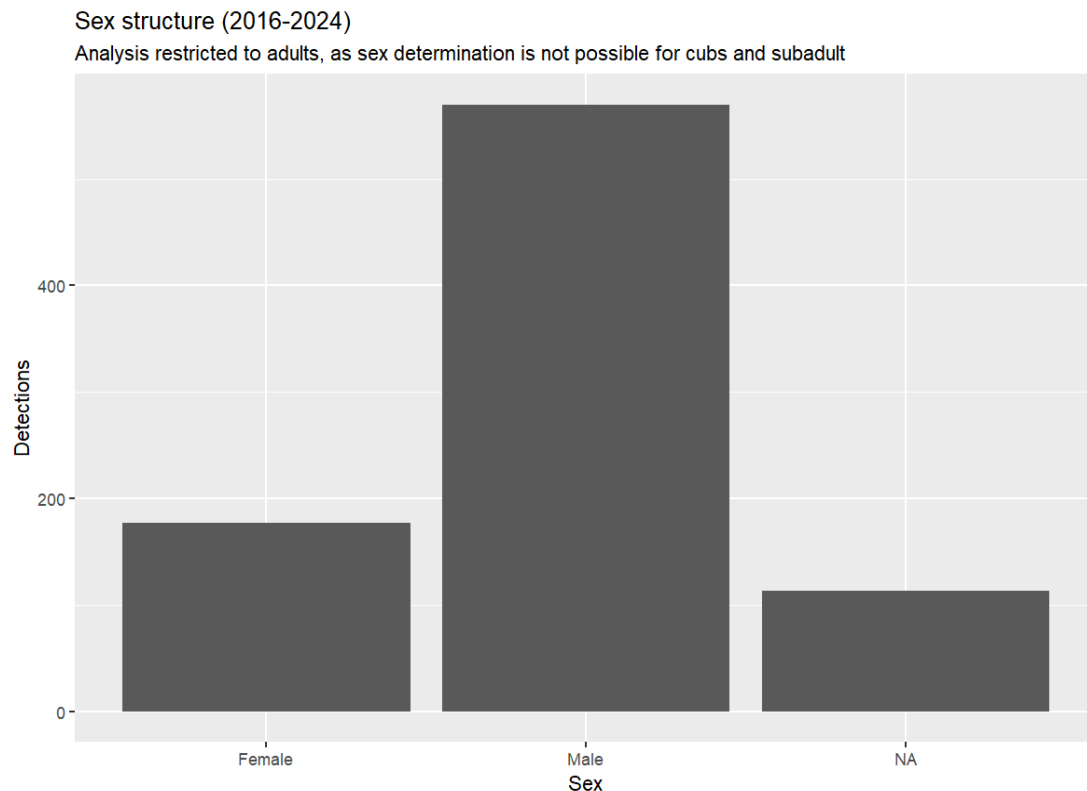


Figure 5: Sex structure of snow leopard camera trap detections, through the 2016-2024 citizen science OSI-PANTHERA programme in the Sarychat-Eertash Nature State Reserve

Figure 7 shows the annual distribution of identified snow leopards among age classes. To reduce the influence of repeated camera-trap detections, each individual contributed a maximum of one observation per year within its recorded age class.

Adult snow leopards represented the majority of identified individuals during all years of monitoring. Cubs and subadults were recorded throughout the study period, although annual counts varied among years. From 2019 onwards, at least one cub and one subadult were documented each year. The number of identified cubs ranged from one individual in 2020 to fourteen individuals in 2023. The number of identified subadults also

varied among years, reaching a maximum of seventeen individuals in 2022 and declining to four individuals in 2024.

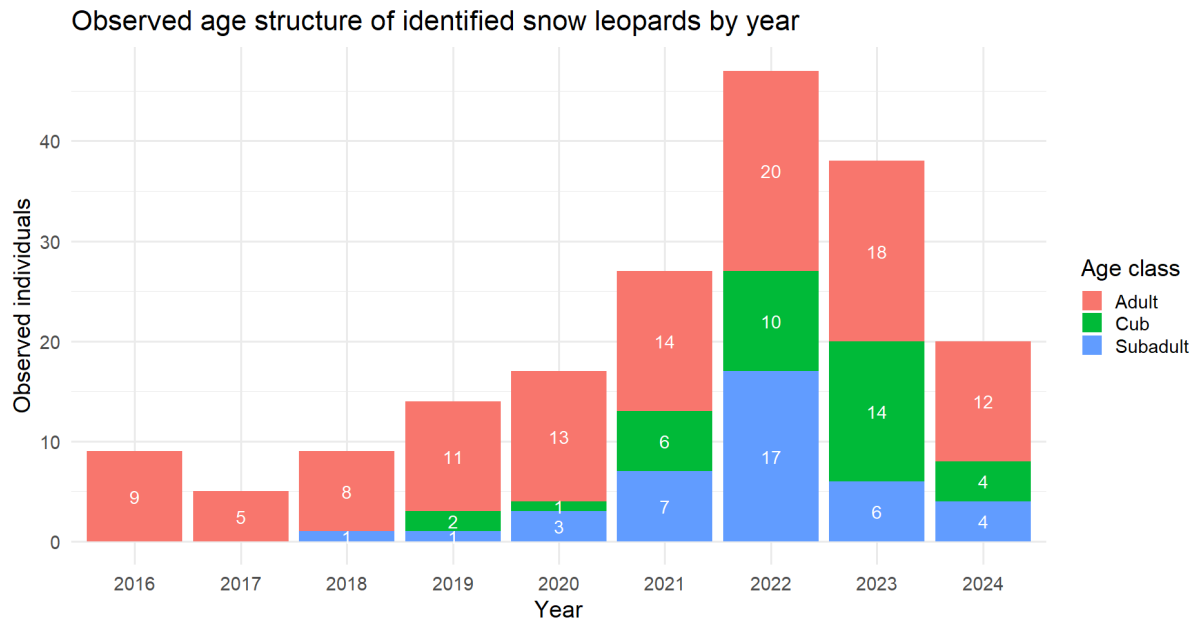


Figure 6: Observed age structure of identified snow leopards recorded by camera traps in Sarychat-Eertash State Nature Reserve. Each identified individual was counted only once per year within a given age class (with cub <1 year, subadult =1–2 years,

1.4 Spatial capture-recapture results

1.4.1 Evaluation of occasion structure and model robustness

1.4.1.1. Influence of occasion structure on density estimates

To evaluate the influence of occasion definition on spatial capture–recapture (SCR) estimates, annual density estimates obtained from models using one, two, and four occasions per session were compared. Density estimates were highly consistent among the three occasion structures, with pairwise correlations ranging from 0.925 to 0.989. The strongest agreement was observed between the one- and four-occasion models ($r = 0.989$), followed by the comparison between the one- and two-occasion models ($r = 0.953$). Correlation remained high between the two- and four-occasion models ($r = 0.925$).

The temporal trajectories of density estimates were therefore highly similar across all occasion structures, indicating a strong agreement among modelling frameworks.

1.4.1.2 Comparison of model performance

Although models based on different occasion structures cannot be directly compared using AIC because they rely on different capture-history formulations, several model characteristics were compared, including ranging parameter estimates (σ), mean density estimates, mean population size, and the relative width of confidence intervals (Table 1).

Table 1: Summary statistics for SCR models fitted using alternative occasion structures.

Model Occasions	Years	Parameters	Sigma_m	Sigma_SE	Mean_Density	Mean_Population	Mean_Relative_CI
1	2016-2023	12	21952.32	0.318	0.073	27.303	1.646
2	2016-2023	17	13805.91	0.108	0.057	24.379	1.886
4	2020-2023	8	6532.7	0.067	0.139	33.049	1.221

Estimated ranging scale (σ) varied considerably among occasion structures, ranging from 6.53 km in the four-occasion model to 21.95 km in the one-occasion model. Mean density estimates remained within the same order of magnitude across models despite differences in temporal structure.

The precision of density estimates also varied among occasion structures. The four-occasion model produced the narrowest confidence intervals (mean relative confidence interval width = 1.22), whereas the two-occasion model produced the widest confidence intervals (1.89). The one-occasion model showed intermediate precision (1.65).

Model complexity differed substantially among frameworks. The two-occasion model included the largest number of parameters ($n = 17$), followed by the one-occasion model ($n = 12$), whereas the four-occasion model was the most parsimonious ($n = 8$).

Based on these comparisons, the one-occasion framework was retained for subsequent analyses because it incorporated sex-specific detection probabilities, allowed the use of

the complete 2016–2023 monitoring dataset, and produced density estimates consistent with those obtained under alternative occasion structures (Figure 8).

Sensitivity of snow leopard density estimates to occasion structure

SECR density estimates obtained using one, two and four sampling occasions

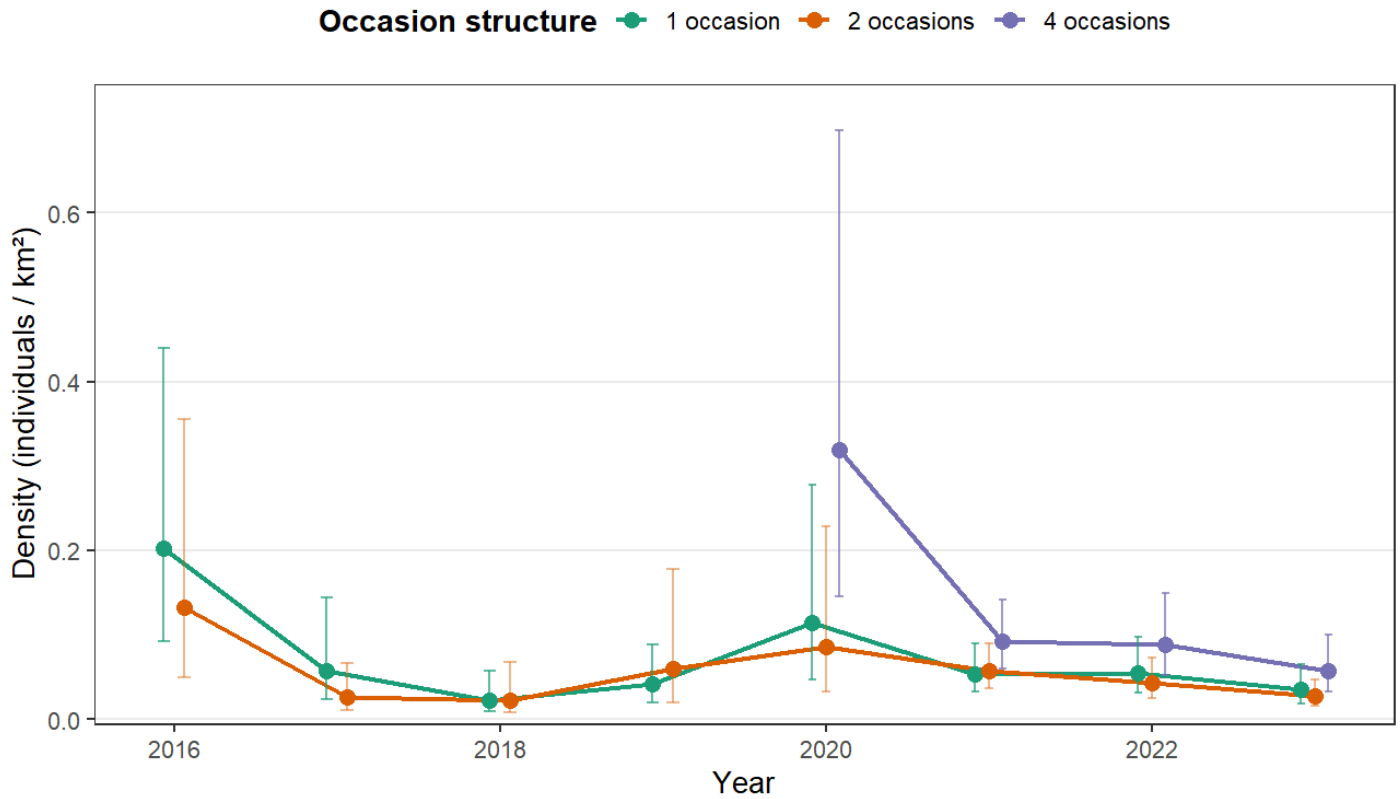


Figure 7: Comparison of annual snow leopard (*Panthera uncia*) density estimates obtained using three alternative sampling occasion structures in spatially explicit capture-recapture (SECR) models. Density estimates were derived from camera-trap detections aggregated into (i) a single sampling occasion spanning the entire survey period, (ii) two occasions corresponding to early and late survey phases, and (iii) four monthly sampling occasions. Points represent annual density estimates and error bars indicate 95% confidence intervals. The figure illustrates the consistency of density estimates across alternative temporal aggregation schemes.

1.4.1.3 Selection of the one-occasion framework

Density estimates were highly consistent across alternative occasion structures ($r = 0.92$ – 0.99), indicating that biological conclusions were largely insensitive to the temporal subdivision of capture histories. Because the one-occasion framework retained the complete 2016–2023 dataset, allowed incorporation of sex-specific detection probabilities and remained relatively parsimonious, it was selected for all subsequent analyses.

1.4.2 Model selection within the selected one-occasion framework

1.4.2.1 Temporal variation in detection parameters

The first stage of model selection evaluated whether detection parameters varied among monitoring sessions (Table 2). The model allowing baseline detection probability (g_0) to vary between sessions while maintaining a constant ranging parameter (σ) received overwhelming support (AIC = 903.11, Δ AIC = 0). Models assuming constant detection probability across years received considerably less support (Δ AIC = 28.17), while models allowing both g_0 and σ to vary among sessions showed even poorer support (Δ AIC = 40.61).

These results indicate strong evidence for temporal variation in baseline detection probability among monitoring sessions, whereas a constant ranging parameter across years was sufficient to describe the data.

1.4.2.2 Individual heterogeneity: sex effect

The second stage of model selection investigated whether individual heterogeneity associated with sex improved model performance (Table 2). Models incorporating sex-specific detection probabilities received substantially stronger support than models assuming homogeneous detection processes.

The best-supported model included sex-specific baseline detection probability while maintaining a constant ranging parameter ($D \sim \text{session}$, $g_0 \sim h2$, $\sigma \sim 1$, AIC = 642.54). Competing models allowing sex-specific variation in ranging parameter (σ) received considerably less support (Δ AIC = 3.61; Δ AIC = 4.24 when combining effect of sex on g_0 and σ), while models without sex effects performed poorly (Δ AICc ≥ 8.25).

The selected finite-mixture model estimated that males represented 60.3% (95% CI: 39.7–77.8%) of the population and females 39.7% (95% CI: 22.2–60.3%), corresponding to an estimated sex ratio of approximately 1.5 males per female.

Baseline detection probability differed markedly between sexes. Females exhibited a higher estimated detection probability ($g_0 = 0.230$, 95% CI = 0.111–0.417) than males (g_0

= 0.069, 95% CI = 0.027–0.166) (Figure 9). In contrast, no support was found for sex-specific variation in ranging scale (σ).

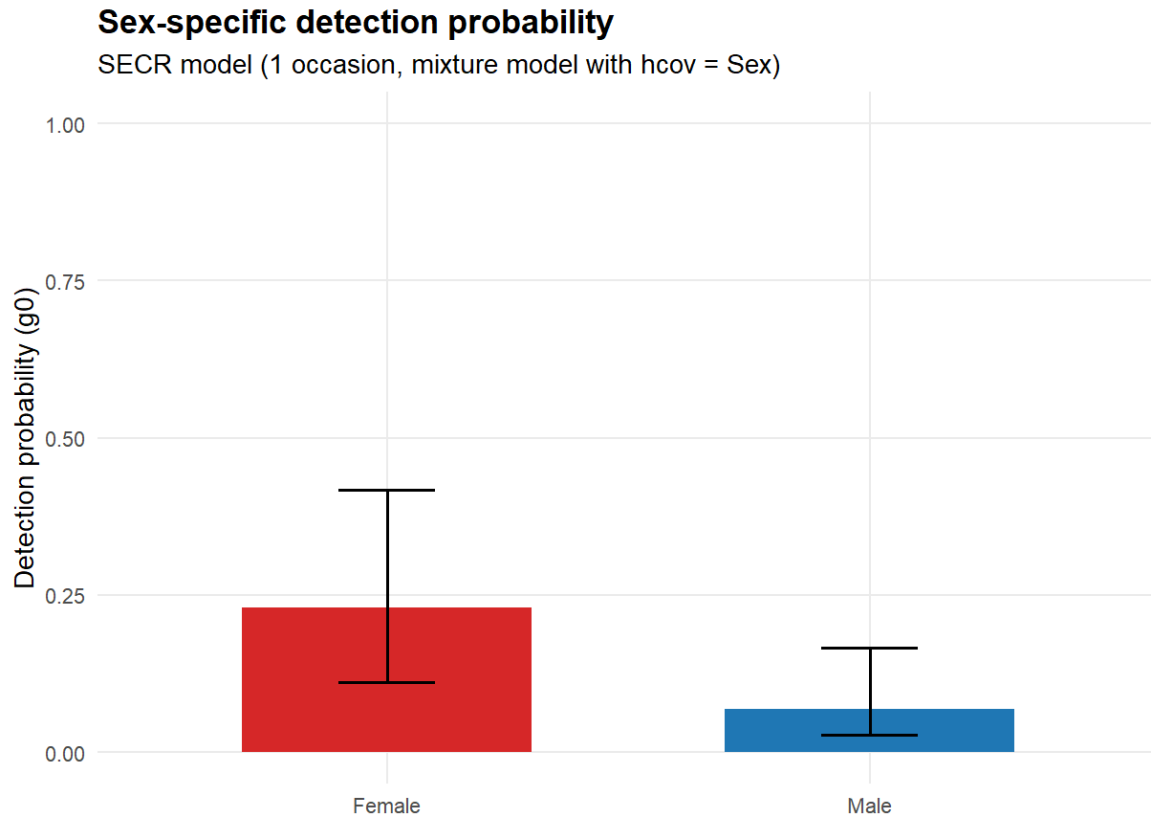


Figure 8: As the best model make variation of detection depending on sex, we can see the difference of detection by comparing boxplot of 2 sex. Data obtained by extraction estimation of $g0$ from best 1 occasion model framework.

1.4.2.3 Environmental covariates

The third stage of model selection evaluated the influence of environmental covariates on snow leopard density (Table 2). Environmental predictors produced only marginal improvements in model fit relative to the reference model containing session effects and sex-specific detection probabilities.

Among the covariates considered, NDVI provided the strongest support, although model improvement remained limited ($\Delta AIC = 0.38$). Models including growing-season NDVI ($\Delta AIC = 1.21$), topographic position index (TPI; $\Delta AIC = 1.85$), elevation ($\Delta AIC = 1.98$), and terrain ruggedness index (TRI; $\Delta AIC = 2.07$) all received comparable support.

No environmental covariate clearly outperformed the reference model. Furthermore, several more complex models produced unstable parameter estimates or undefined standard errors, indicating limited support for additional ecological complexity within the available dataset.

Overall, model selection identified the following structure, as the best-supported model for subsequent analyses:

$D \sim \text{session}, g0 \sim h2, \sigma \sim 1, pmix = h2 = \text{sex}$

This model estimated density independently for each monitoring session, incorporated sex-specific variation in detection probability, and assumed a constant ranging scale throughout the study period.

Model selection followed the three-step procedure described in the Methods. The best-supported model from each step was retained and used as the reference model for the subsequent selection stage (Table 2).

Table 2: AIC of three step selection of model within 1 occasion framework

model	Detect_f ctn	N_p ara m	logLik	AIC	AICc	dAIC	AIC wt
Step 1: Among-session variation							
<i>D~session g0~session sigma~1</i>	halfnor mal	17	-430.732	895.46 4	903.1 14	0.000	1
<i>D~session g0~1 sigma~1</i>	halfnor mal	10	-451.819	923.63 8	926.1 67	28.174	0
<i>D~session g0~session sigma~ses sion</i>	halfnor mal	24	-444.039	936.07 8	952.5 17	40.614	0
Step 2: Sex-specific detection parameters							
<i>D~session g0~h2 sigma~1 pmix~h2</i>	halfnorm al	12	-307.343	638.687	642.5 39	0.000	0.75 17
<i>D~session g0~1 sigma~h2 pmix~h2</i>	halfnorm al	12	-309.147	642.293	646.1 45	3.606	0.12 39
<i>D~session g0~h2 sigma~h2 pmix~h2</i>	halfnorm al	13	-308.463	642.926	647.4 76	4.239	0.09 03
<i>D~session g0~session + h2 sigma~1 pmix~h2</i>	halfnorm al	19	-303.877	645.754	656.0 24	7.067	0.02 20
<i>D~session g0~1 sigma~1 pmix~h2</i>	halfnorm al	11	-312.468	646.937	650.1 56	8.250	0.01 22
<i>D~session g0~session sigma~1 pmix ~h2</i>	halfnorm al	18	-308.408	652.817	661.9 37	14.130	0.00 00
Step 3: spatial covariates on density							
<i>D~session g0~h2 sigma~1 pmix~h2</i>	halfnorm al	12	-307.344	638.687	642.5 39	0.000	0.28 6
<i>D~session + raster.NDVI g0~h2 sigma ~1 pmix~h2</i>	halfnorm al	13	-306.533	639.066	643.6 16	0.379	0.23 7
<i>D~session + raster.NDVI_growing g0~ h2 sigma~1 pmix~h2</i>	halfnorm al	13	-306.947	639.894	644.4 44	1.207	0.15 6

$D \sim \text{session} + \text{raster.TPI } g_0 \sim h_2 \text{ sigma} \sim 1$ $pmix \sim h_2$	halfnormal	13	-307.267	640.535	645.085	1.848	0.113
$D \sim \text{session} + \text{raster.altitude } g_0 \sim h_2 \text{ sigma} \sim 1$ $pmix \sim h_2$	halfnormal	13	-307.334	640.668	645.218	1.981	0.106
$D \sim \text{session} + \text{raster.TRI } g_0 \sim h_2 \text{ sigma} \sim 1$ $pmix \sim h_2$	halfnormal	13	-307.379	640.759	645.309	2.072	0.101

1.4.3 Annual density estimates and population trends

Annual snow leopard density estimates derived from the selected SCR model ($D \sim \text{session}$, $g_0 \sim h_2$, $\sigma \sim 1$) varied substantially throughout the study period (Figure 10). Estimated density ranged from 0.023 individuals/km² (95% CI = 0.009–0.058) in 2018 to 0.202 individuals/km² (95% CI = 0.092–0.440) in 2016.

Population size estimates within the monitored area ranged from 15.3 individuals (95% CI = 9.1–35.5) in 2018 to 38.1 individuals (95% CI = 29.2–61.9) in 2021. The number of detected individuals per year varied between six and seventeen. The effective state-space area used for SCR analyses varied among monitoring seasons, ranging from 171 km² in 2016 and 2020 to a maximum of 819 km² in 2019. Across all sessions, the monitored area averaged 521 km² and reflected annual variation in camera-trap deployment and spatial coverage (Table 3).

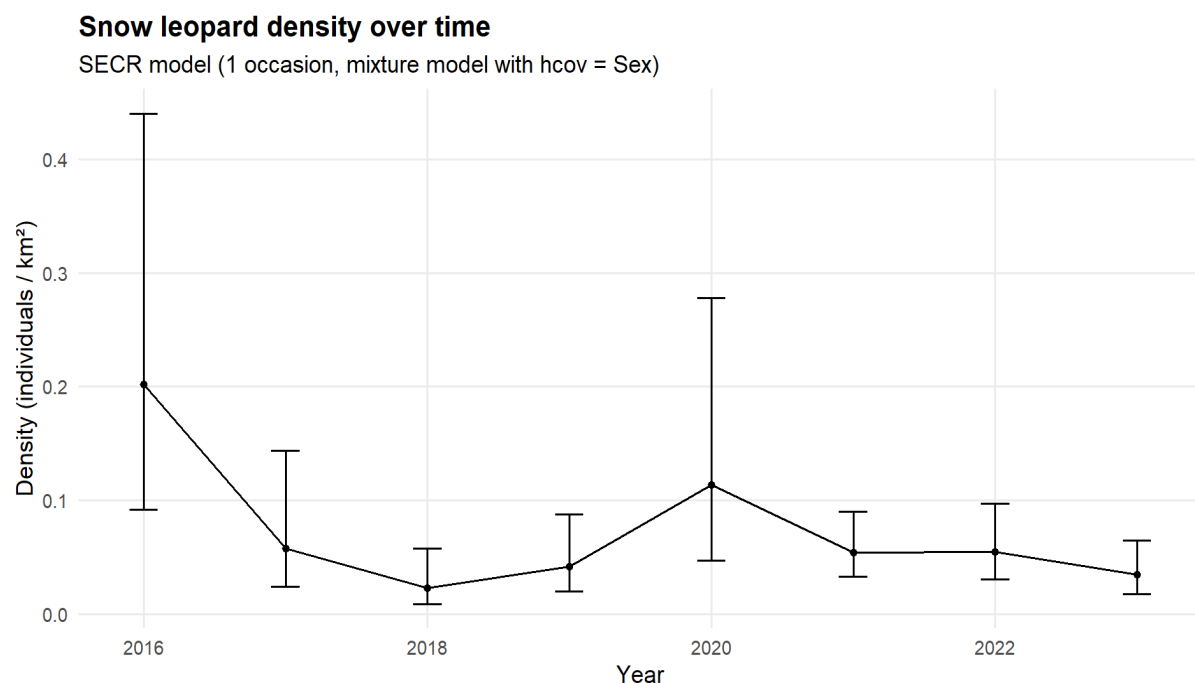


Figure 9: Annual snow leopard density estimates derived from a multi-session spatial capture–recapture model. Points and connecting lines represent annual density estimates, while vertical bars indicate 95% confidence intervals.

Temporal variation in estimated density was characterized by a marked decline between 2016 and 2018, followed by an increase between 2018 and 2020. From 2021 onwards, density estimates remained relatively stable, fluctuating between 0.035 and 0.055 individuals/ km². Confidence intervals overlapped substantially among years, although all annual density estimates remained significantly above zero (for more detail see supplementary material in appendix 2).

The best-supported model estimated a constant ranging scale parameter of 21.95 km throughout the study period.

Table 3: Extraction of value from best spatial capture-recapture model ($D \sim \text{session}$, $g0 \sim \text{sex}$, $\sigma \sim 1$) selected through 3 step AIC. $\text{detectfn} = \text{halfnormal}$; $\log\text{Lik} = -307.3437$; $\text{AIC} = 638.687$; $\text{npar} = 12$. Constant value through study period: $g0 \text{ male} = 0.069$ (IC 95% = 0.027-0.166); $g0 \text{ female} = 0.230$ (IC 95% 0.111-0.417); $\sigma = 21.952 \text{ km}$; $\text{pmix Male} = 0.603$; $\text{pmix Female} = 0.397$

Year	Density_k m2	Density_L CL	Density_U CL	N_detect ed	Population_e st	Population_L CL	Population_U CL
2016	0.202	0.092	0.440	9	34.48	19.594	72.191
2017	0.058	0.024	0.144	6	21.553	11.305	49.537
2018	0.023	0.009	0.058	6	15.337	9.065	35.476
2019	0.042	0.020	0.088	17	34.435	20.526	69.849
2020	0.114	0.047	0.278	9	20.565	11.176	46.708
2021	0.054	0.033	0.090	6	38.068	29.165	61.925
2022	0.055	0.031	0.097	6	31.531	22.329	53.807
2023	0.035	0.018	0.065	17	22.459	17.174	40.983

1.5. Discussion

1.5.1 Ecological monitoring and temporal patterns in wildlife observations

The transect surveys provided a complementary perspective to camera-trap monitoring by documenting long-term patterns in ungulate and carnivore observations across the reserve. Although these data cannot be interpreted as direct estimates of abundance, they provide valuable indicators of wildlife presence, activity, and broad ecological trends. For ungulates, observations were standardized to account for variation in monitoring effort; however, these data were not collected using a survey design specifically intended to estimate population size. Unlike official ungulate counts, which

are generally conducted over a short and standardized period across the entire reserve, transect data were collected opportunistically during field expeditions and therefore provide indices of occurrence rather than robust estimates of abundance. For mountain ungulates in Central Asian landscapes, Suryawanshi et al., (2012) recommend the use of double-observer approaches, involving two independent surveys separated in time or space, to improve the reliability of population estimation and monitoring.

One of the most striking observations was the apparent absence of a strong signal associated with the severe winter event ("jut" in Kyrgyz) reported during spring 2022. As expressed by Kubanychbekov et al. (2016), extreme weather events have already caused large-scale prey mortality, such as the 2022 die-off in Issyk-Kul oblast, with potential cascading effects on snow leopard survival. According to reserve rangers and OSI-PANTHERA field reports, exceptional snowfall accumulated across the high plateau during early June 2022, reaching depths of approximately 1.5–1.8 m in some valleys. Numerous argali (*Ovis ammon*) carcasses were observed during subsequent fieldwork and anecdotal evidence suggested substantial mortality among both wild ungulates and livestock. Nevertheless, no clear decline in transect observations of either argali or juvenile ungulates was detected in the years immediately following this event. Several explanations may account for this discrepancy. Mortality may have been geographically concentrated, leaving a large proportion of the monitored area relatively unaffected. It is also possible that transect observations respond more slowly to demographic perturbations than true population size, particularly when observations are aggregated over large spatial and temporal scales. Consequently, the absence of a clear decline in observations should not be interpreted as evidence that the jut had no ecological impact. Instead, it suggests that either the demographic consequences were insufficient to produce a detectable population-level signal, or that the effects could not be adequately captured by the transect-based monitoring approach.

The continued detection of juvenile Siberian ibex (*Capra sibirica*) throughout the monitoring period suggests that recruitment persisted despite interannual climatic variability. Although transect observations cannot be used to derive robust demographic parameters, the recurrent observation of juveniles indicates continued recruitment throughout the monitoring period. Similar patterns were observed in both Siberian ibex and argali, suggesting that these populations remained reproductively active over the duration of the study.

For argali, the marked increase in detections observed in 2021 should be interpreted cautiously. While it could reflect a genuine increase in local abundance, alternative explanations include temporary aggregation of animals, favourable observation conditions, or observer-related effects. Because transect surveys provide indices rather than abundance estimates, distinguishing among these mechanisms remains difficult.

For large carnivores, most records consisted of indirect signs such as scrapes, scent marks, tracks, scats, or feeding remains rather than direct observations. Direct sightings of snow leopards, wolves, and bears were rare, which is expected given the elusive behaviour of these species and their tendency to avoid human presence. The higher frequency of snow leopard signs relative to wolf and bear signs should therefore be interpreted cautiously. Snow leopards frequently use conspicuous marking sites along ridgelines, saddles, cliffs, and travel routes where signs can accumulate and remain detectable for extended periods (Mallon & McCarthy, 2024). In contrast, wolves tend to concentrate scent marking at territory boundaries, crossroads, and travel corridors (Stępnia et al., 2020), while bears generally use specific trees or movement routes as marking locations (Sergiel et al., 2017). Furthermore, transects were originally designed to maximize the detection of snow leopard signs, creating an inherent sampling bias towards the target species. Consequently, differences in sign frequencies among carnivore species should not be interpreted as differences in abundance. Nevertheless, the repeated detection of carnivore signs throughout the monitoring period indicates a continuous use of the reserve by these species and supports the presence of relatively stable predator populations across the study area.

More generally, temporal variation in transect observations is likely influenced by both ecological and methodological factors. Increased observer experience, improvements in data recording procedures, changes in survey intensity, and enhanced field supervision may all have contributed, even with the effort-correction of the data, to the rise in observations recorded after 2018. As a result, citizen science transect data should primarily be interpreted as indices of presence and activity rather than direct measures of abundance or population fluctuations. Their principal value lies in documenting the long-term occurrence and spatial distribution of wildlife within the reserve, while providing complementary ecological information alongside more rigorous monitoring approaches such as camera trapping and spatial capture–recapture analyses.

1.5.2 Snow leopard detections with camera trap and population structure

The rapid increase in snow leopard detections over time closely paralleled the expansion of the camera-trap network. As camera numbers increased, spatial coverage improved, generating greater opportunities both for detecting individuals and for obtaining spatial recaptures. Consequently, trends in raw detections cannot be interpreted directly as trends in population size. This highlights the importance of accounting explicitly for variation in sampling effort when assessing population dynamics. Raw detections are influenced simultaneously by ecological processes, camera-trap deployment, image processing effort, and observer capacity. The substantial increase in capture-recapture information through time therefore justified the use of spatial capture-recapture modelling to separate detection processes from variation in density.

The recurrent detection of cubs, subadults, and adults throughout the monitoring period also provides valuable information regarding population functioning. While camera-trap data do not allow robust reconstruction of age structure because of imperfect identification and repeated observations of the same individuals, the recurrent detection of all age classes strongly suggests that reproduction and recruitment have occurred regularly within the reserve. This pattern supports the interpretation that SENSr currently hosts a reproductively active snow leopard population.

Nevertheless, caution is required when interpreting age-related patterns. Cubs and subadults are more difficult to identify reliably than adults, and historical recording protocols did not systematically document young individuals. Consequently, age classes were likely affected by stronger detection and identification biases than adults. Future monitoring protocols specifically targeting cub and subadult identification could considerably improve understanding of recruitment, dispersal, and apparent survival.

Sex-related patterns showed stronger and more consistent signals than age-related patterns. Males were detected more frequently in the raw dataset, suggesting sex-specific differences in movement behaviour, home-range use, and territorial marking activity. This result is consistent with existing knowledge of snow leopard spatial ecology, which indicates limited intrasexual home-range overlap, particularly among adult males, supporting the view that the species exhibits territorial behaviour (Johansson et al., 2016). Although important aspects of snow leopard behaviour remain insufficiently documented (Mallon & McCarthy, 2024), these observations suggest that detection processes are likely to differ between sexes. This provided a strong biological rationale for including sex as a detection covariate in the subsequent SCR modelling framework.

1.5.3 Snow leopard density estimation and SCR modelling

A major result of this study is the robustness of density estimates across alternative definitions of sampling occasions. Density trajectories obtained using one, two, and four occasions per session were highly correlated ($r = 0.92\text{--}0.99$), indicating that the overall temporal pattern was largely insensitive to the temporal subdivision of capture histories. Furthermore, although the estimated ranging parameter (σ) varied substantially among occasion structures, density estimates remained remarkably consistent. This suggests that density estimates were more robust to modelling choices than movement-related parameters, increasing confidence in the biological pattern observed across years.

The SCR analyses revealed considerable annual variation in density estimates but no evidence of a sustained long-term decline between 2016 and 2023. Despite interannual fluctuations, confidence intervals largely overlapped and all density estimates remained clearly above zero. Taken together, these results suggest that the snow leopard population persisted throughout the study period and remained broadly stable at the scale of the reserve.

When compared with published SCR studies across the species' distribution range (Table 4), the density estimates obtained in this study were markedly higher than most values

reported elsewhere. Across Central Asia, the Himalayas, Mongolia, China, and Russia, published densities generally range between 0.19 and 3.31 individuals per 100 km² (Table 4). By contrast, the average density estimated in this study reached 7.29 individuals per 100 km². Independent monitoring conducted by the Snow Leopard Trust (SLT) within the Sarychat-Eertash Nature State Reserve provides a useful point of comparison². Analysis of SLT camera-trap data led to the identification of 15 adult snow leopards, including at least one female accompanied by a cub, providing evidence of successful reproduction within the reserve. In the present study, annual camera-trap records identified up to 17 individual snow leopards and the SCR analyses estimated an annual mean population size of approximately 27 individuals within the monitored portion of the reserve. Although derived from different methodologies and therefore not directly comparable, these results are broadly consistent and support the interpretation that SENSr sustains one of the most important and dense snow leopard populations in Kyrgyzstan. Furthermore, the longer temporal coverage provided by the OSI-PANTHERA citizen science dataset documented multiple reproductive events and repeated observations of cubs and subadults, suggesting sustained recruitment throughout the monitoring period. Snow leopards are well known for occupying large territories in low-productivity mountain ecosystems (Mallon & McCarthy, 2024), but the estimated ranging parameter ($\sigma \approx 22$ km) remained substantially larger than most published values, which generally range between 2 and 9 km (Table 4). Detection probabilities were also comparatively high, particularly for females ($g_0 = 0.23$), whereas published estimates typically range between 0.004 and 0.05 (Table 4). Together with the elevated density estimates, these differences suggest that methodological factors, in addition to ecological characteristics of the reserve, may contribute to the observed divergence from previously published studies.

Although methodological limitations may have contributed to the relatively high-density estimates obtained in this study, these results should not be dismissed entirely as artefacts of the monitoring design. These differences do not necessarily imply that the estimates obtained here are unrealistic. SENSr is the largest protected area in Kyrgyzstan and represents one of the most intact high-mountain ecosystems in Central Asia (Khanyari et al., 2021). The reserve benefits from long-term protection, relatively low human disturbance, and abundant populations of wild ungulates, all factors expected to favour snow leopard persistence. Consequently, it is plausible that the reserve supports one of the most important snow leopard populations in the region and potentially higher local densities than landscapes subjected to greater anthropogenic pressure.

At the same time, comparison with the literature suggests that part of the observed differences may arise from methodological factors rather than ecological conditions alone. Augugliaro et al. (2025) noted that the highest snow leopard density estimates published to date are often associated with studies covering less than 500 km², raising

² https://www.zoobasel.ch/uploads/files/website/Zoo_Basel_2023-2024_Snow_Leopard_Trust_Report_1.pdf, (accessed on 10 May 2026)

concerns about positive bias resulting from limited spatial coverage and an incomplete representation of individual movements across heterogeneous landscapes. Similarly, Suryawanshi et al. (2019) found a negative relationship between estimated density and study area size, suggesting that many studies preferentially sample the most suitable habitats for the species. The monitoring area used in the present study was close to the minimum spatial extent recommended by the PAWS guidelines, which may contribute to the elevated density estimates obtained.

Interestingly, density estimates remained highly consistent across the alternative occasion structures tested in this study despite large differences in the estimated ranging parameter (σ). This result suggests that density estimates were relatively robust to modelling choices, whereas movement-related parameters were considerably more sensitive (Efford & Boulanger, 2019). Consequently, differences among studies may partly reflect variation in SCR parameterization and sampling design rather than purely biological differences among populations. The agreement between the SLT photographic inventory (15 identified adults)³ and the minimum numbers detected by this study suggests that the reserve indeed supports a relatively large snow leopard population. This interpretation is further supported by genetic analyses conducted through the OSI-PANTHERA citizen science programme, which identified a cumulative minimum of 17 individual snow leopards between 2011 and 2019 (Rode et al., 2024). However, the discrepancy between identified individuals and model-derived population estimates highlights the importance of evaluating potential sources of bias associated with camera-trap placement, spatial coverage, and SCR model parameterization.

The limited contribution of environmental covariates to model performance was somewhat unexpected, given that previous snow leopard studies have frequently reported significant relationships between density or habitat use and topographic and environmental variables (Augugliaro et al., 2025; Bayandonoi et al., 2021; Kachel, 2021; Sharma et al., 2021). Several explanations may account for this result. First, environmental variation within the monitored portion of SENSr may be relatively limited compared with larger-scale studies conducted across broader ecological gradients. If most camera traps are located within already suitable snow leopard habitat, the contrast required to detect strong habitat effects may be reduced. Second, the complexity of the SCR models relative to the available sample size may have limited the statistical power to identify subtle environmental relationships. Finally, as this study represents a first exploration of long-term citizen science data using the *secr* framework, additional methodological developments and alternative model structures may help better capture environmental effects in future analyses. The NDVI covariate was included as an indirect proxy for prey availability because direct long-term estimates of wild ungulate abundance

³ https://www.zoobasel.ch/uploads/files/website/Zoo_Basel_2023-2024_Snow_Leopard_Trust_Report_1.pdf (accessed on 24 April 2026)

were not available at the spatial resolution required for SCR modelling. Although this approach has limitations, it remains ecologically relevant. Kachel (2021) reported a positive spatial relationship between NDVI and snow leopard distribution and suggested that vegetation productivity may indirectly influence snow leopard occurrence through its effects on prey resources. Similarly, Lu et al. (2016 in Kachel et al., 2021) demonstrated that NDVI is a good predictor of marmot distribution, which are also prey for snow leopard during summer (Mallon & McCarthy, 2024), in comparable mountain ecosystems. Nevertheless, direct measures of prey abundance would likely provide a more biologically meaningful predictor than NDVI alone and should be prioritised in future studies. The weak support obtained for terrain-related covariates was also somewhat surprising given the ecology of the species. Previous studies have shown that snow leopards generally prefer rugged landscapes that facilitate movement, concealment, and hunting opportunities (Li et al., 2025; Sharma et al., 2021). In Mongolia, Bayandonoj et al. (2021) found that habitat use was best explained by a combination of rugged terrain, NDVI, and a quadratic relationship with elevation, indicating a preference for intermediate elevations rather than the highest or lowest parts of the landscape. Likewise, TRI and TPI have been identified as important predictors of snow leopard distribution and density in several SCR studies (for example: Augugliaro et al., 2025). Although the models presented here showed weak support for these covariates, the ranking of candidate models nevertheless suggested that NDVI, elevation, and topographic variables may still contribute to explaining spatial variation in snow leopard density. Their ecological importance is therefore not rejected by this study but rather appears difficult to detect with the available data and modelling framework.

Overall, the results indicate that SENSr likely constitutes a major snow leopard stronghold within Kyrgyzstan and potentially within Central Asia. However, whether the exceptionally high-density values reported here reflect true ecological conditions or are partially influenced by methodological factors remains uncertain. Additional surveys specifically designed according to PAWS recommendations would therefore be valuable to confirm these estimates and refine our understanding of population size and density within the reserve (Sharma et al., 2019). Such improvements would strengthen the precision and comparability of density estimates while preserving the exceptional long-term value of the OSI-PANTHERA citizen science programme. Likewise, further development of analytical workflows and more advanced use of the *secr* package could improve the treatment of detection heterogeneity, sampling effort, and spatial processes. The present analyses should therefore be viewed as a first large-scale application of SCR methods to this unique citizen science dataset, providing an informative baseline for future methodological refinement and long-term population assessment. Nevertheless, the long-term citizen science dataset clearly demonstrates the continued presence of a reproductively active snow leopard population and supports the role of SENSr as a key refuge and conservation reservoir for the species.

Table 4: non-exhaustive representative existing snow leopard camera trap density studies based on spatially explicit capture-recapture modelling

Reference	Location	Estimated area (km ²)	Density (inds/100km ²)	Ranging parameter (km)	Encounter probability
Kachel et al., 2017	Madiyan, Tajikistan	Around 1000	0.46 (95% CI: 0.20 ~ 0.83)	5.18	Did not report
Kachel et al., 2017	Murghab, Tajikistan	Around 1000	0.74 (95% CI: 0.57 ~ 0.95)	7.27	Did not report
Bian et al., 2023	Tibet, China	7604	1.40 (95% CI: 1.06 ~ 1.84)	Male: 4.02 (95% CI: 3.50–4.61); Female: 1.84 (95% CI: 1.56–2.17)	0.054
Suryawanshi et al., 2021	Himachal Pradesh, India	26 112	0.19 (95% CI: 0.12 ~ 0.31)	8.50 (95% CI: 6.9–10.41 km)	0.018 (95% CI: 0.013–0.025)
Li et al., 2025	Sanjiangyuan, China	116 570	0.90 (95% CI: 0.68 ~ 1.21)	4.349 (95% CI: 3.906~4.844 km)	0.015 (95% CI: 0.012 ~ 0.019)
Bayandonoi et al., 2021	Mongolia	326 617	0.31 (did not report 95% CI)	Did not report	Did not report
Augugliaro et al., 2025	Western Mongolian Altai	811	0.93 (95% CI: 0.45 ~ 1.8)	1.978 (95% CI: 669~2840)	0.02 (95% CI: 0.01–0.05)
Karnaukhov et al., 2024	Chikhachev Ridge, Russia	3175	0.43 (95%CI: 0.32~0.54)	Did not report	Did not report
(Khanal et al., 2020)	Upper Dolpa, Nepal	~800	2.51	2.17 (95% CI: 1.88~2.46)	0.04 (95% CI: 0.03~0.05)
Alexander et al., 2015	Tibetan Plateau and northern China	480	1.40-3.31	4.138km (95% CI: 3.265~5.131)	0.0036 (95% CI: 0.0015~0.0060)
Oberosler et al., 2022	Sutai Range in Altai, Mongolia	850	1.31 (95% CI: 1.15~ 1.50)	79 (95% CI: 56–112) for females and 329 (95% CI: 154–706) km ² for males	g0female = 0.03 [95% CI: 0.02–0.04]); g0male = 0.02 [95% CI: 0.01–0.02]
My study	Sarychat-Eertash Nature State Reserve, Kyrgyzstan	521 (mean over 8 years multi-session study)	7,287 (95% CI: 3,425~ 15,75) (mean over 8 years multi-session study)	22.801 km (95% CI: 11.125~46.731)	g0 male = 0.069 (IC 95%= 0.027-0.166); g0 female= 0.230 (IC

					95% 0.111-0.417);
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1.5.4 Limitations of the citizen science monitoring framework

Several limitations should be considered when interpreting the density estimates obtained in this study. Although the OSI-PANTHERA monitoring programme generated a uniquely long-term dataset, its initial objective was not to produce spatial capture-recapture density estimates. Consequently, the monitoring design only partially followed the recommendations developed within the Population Assessment of the World's Snow Leopards (PAWS) framework, which was specifically designed to standardize snow leopard abundance estimation across the species' range (Sharma et al., 2019). In particular, camera-trap deployment was primarily optimized to maximize snow leopard detections and facilitate individual identification rather than to ensure spatial representativeness of the study area. Cameras were preferentially installed at known marking sites, ridgelines, saddles, cliffs, and travel routes. While this strategy is highly efficient for documenting snow leopard presence and generating capture histories, it may favour areas of high activity and therefore contribute to positive bias in density estimation. Such concerns have previously been highlighted in snow leopard studies, where estimated density showed a negative relationship with study-area size, suggesting that surveys often concentrate on the most suitable habitats (Suryawanshi et al., 2019).

Additional limitations are linked to the citizen science nature of the programme. Observer experience varied among years, protocols evolved progressively through time, and some camera-trap sessions experienced documented equipment failures or incomplete information regarding periods of inactivity. Variability associated with camera models may also influence encounter rates. Furthermore, although substantial effort was invested in quality control and individual identification, identification errors remain a recognised source of uncertainty in camera-trap studies of individually identifiable felids (Johansson et al., 2020). This issue is particularly relevant for cubs and subadults, whose coat patterns are often less distinctive and whose photographic histories are generally less complete than those of adults.

1.5.5 Recommendations for future monitoring

Several improvements could strengthen the scientific value of future citizen science monitoring efforts. A progressive transition towards a partially gridded sampling design would improve compliance with PAWS recommendations while maintaining the long-term monitoring value of historical marking sites. Increasing the number of simultaneously active camera traps would improve spatial coverage and better represent environmental variability across the reserve, in order to insure a monitored surface much greater than 500km².

Standardization of data management could also be strengthened through greater use of digital data-collection open-source tools such as *EarthRanger* and through closer collaboration among the different organisations operating within the reserve. Improving volunteer training and documentation for image identification would further reduce uncertainty in individual assignments. More broadly, establishing long-term partnerships with universities, research institutions, and conservation organisations would help ensure the continuous curation, validation, and scientific exploitation of monitoring data. Such collaborations would facilitate the maintenance of a standardized, well-documented, and interoperable database that remains readily accessible for future statistical or capture-recapture analyses and conservation assessments. Ensuring that data are consistently archived in formats compatible with evolving analytical tools is essential for maximizing their long-term scientific value and for supporting adaptive evidence-based conservation management. Finally, developing a specific protocol for monitoring cubs and subadults would allow future analyses of recruitment, dispersal, apparent survival, and population turnover.

1.5.6 Conservation implications

The principal conservation implication of this study is not the precise density estimate itself, but rather the confirmation that SENSr functions as a major snow leopard stronghold in Kyrgyzstan. Whether the estimated densities represent the exact magnitude of the population or are partially influenced by methodological biases, all available evidence points towards the presence of a large, persistent, and reproductively active snow leopard population within the reserve.

Consequently, future conservation efforts should not focus solely on maintaining local abundance within reserve boundaries. Snow leopards occupy large home ranges, occur naturally at low densities, and depend on landscape connectivity to maintain demographic and genetic viability (Johansson et al., 2016; Mallon & McCarthy, 2024). The long-term persistence of the population therefore depends not only on protection within SENSr but also on maintaining functional connections with neighbouring mountain systems.

In this context, conservation actions should prioritize the preservation of ecological corridors facilitating dispersal, particularly of young males, and maintaining genetic exchange among neighbouring populations. Although recent genetic analyses conducted within the OSI-PANTHERA citizen science programme found no evidence of significant heterozygote deficiency, population structuring, or inbreeding among a cumulative minimum of 17 identified snow leopards between 2011 and 2019 (Rode et al., 2024), this result should not be interpreted as reducing the importance of connectivity. On the contrary, the apparent genetic health of the population may partly reflect the continued existence of demographic and genetic exchanges with surrounding mountain systems. Such landscape-scale conservation approaches are consistent with contemporary snow

leopard conservation strategies, which emphasize connectivity and coexistence across multiple-use landscapes rather than relying exclusively on protected areas (Sharma et al., 2021; Augugliaro et al., 2025). SENSr should therefore be viewed not only as a refuge population but also as a potential source population contributing to the persistence of snow leopards across the wider Central Asian mountain network.

1.6 Conclusion

This study combined long-term camera-trap monitoring, ecological transect surveys, and spatial capture–recapture (SCR) modelling to assess snow leopard population dynamics and the ecological effectiveness of the Sarychat–Eertash Nature State Reserve (SENSr).

Overall, the ecological indicators examined provide no evidence of major ecosystem degradation within the reserve. Transect surveys documented the continued presence of wild ungulates and large carnivores throughout the study period, while repeated observations of juveniles, cubs, and subadults suggest ongoing reproduction and recruitment. Although these datasets should be interpreted as indices of presence and activity rather than direct measures of abundance, they consistently point toward a relatively intact high-mountain ecosystem capable of supporting viable populations of large mammals and their predators.

Spatial capture–recapture analyses further suggest that the snow leopard population remained broadly stable between 2016 and 2023. Density estimates were robust to alternative occasion structures, highlighting the consistency of the observed temporal pattern despite methodological differences. The inclusion of sex-specific detection heterogeneity significantly improved model performance, suggesting that sex should be more systematically considered in future snow leopard SCR studies (Alves et al., 2024). Environmental covariates showed limited explanatory power, although this likely reflects both the ecological homogeneity of the reserve and limitations of the available dataset.

Estimated densities were substantially higher than most values reported elsewhere across the snow leopard range. While these results may partly reflect methodological biases linked to sampling design, spatial coverage, and SCR implementation (Sollmann et al., 2012; Suryawanshi et al., 2019), they are also consistent with the hypothesis that SENSr represents one of the most important snow leopard strongholds in Kyrgyzstan. Future monitoring efforts would benefit from closer alignment with PAWS recommendations (Sharma et al., 2019), including increased camera-trap coverage, improved spatial representativeness, and further refinement of analytical approaches.

One of the most important contributions of this work is to demonstrate that long-term citizen science monitoring can generate datasets capable of supporting advanced ecological analyses and informing conservation decisions. Taken together, the maintenance of wild prey populations, recurring evidence of snow leopard reproduction,

and the absence of clear negative population trends suggest that SENSr currently functions as an effective sanctuary and likely source population within the wider Tien Shan landscape, reinforcing the importance of ecological connectivity and corridors to maintain demographic and genetic exchange among populations.

However, biodiversity monitoring alone cannot fully evaluate the effectiveness of a protected area. Ecological indicators provide only one dimension of conservation outcomes. To understand whether SENSr is truly effective as a conservation system, it is also necessary to examine the broader socio-ecological context in which protection occurs, including governance, local communities, human activities, and human–nature relationships. It is precisely at this interface between ecological processes and social dynamics that the concept of protected-area effectiveness becomes most meaningful, and therefore the focus of the following socio-anthropological chapter.

Chapter 2: Socio-anthropological analysis of the interviews

2.1 Introduction

The previous chapter assessed the ecological state of the Sarychat–Eertash Nature State Reserve (SENSR) through wildlife monitoring, ecological surveys, and spatial capture–recapture modelling. Although ecological indicators provide essential information on species persistence and population dynamics, they alone cannot fully explain why conservation succeeds or fails. Increasingly, conservation scientists recognize that protected-area effectiveness emerges from interactions between ecological, social, economic, institutional, and political processes (Frietsch et al., 2023).

The integration of social sciences into conservation research has therefore become a central requirement for understanding conservation outcomes. Beyond measuring biodiversity indicators, effective conservation requires understanding the perceptions, behaviours, institutions, power relations, and governance systems that shape human interactions with nature (Bennett, 2018). Taking social dimensions into account has been shown not only to improve conservation effectiveness but also to support more equitable and socially legitimate conservation practices (Sanborn & Jung, 2021). Consequently, evaluating the effectiveness of a protected area requires adopting a broader socio-ecological perspective rather than relying exclusively on biological indicators.

This perspective is particularly relevant in the case of SENSR. Although the reserve is one of the largest protected areas in Kyrgyzstan, it is embedded within a complex socio-economic landscape. The reserve is surrounded by hunting concessions, livestock grazing areas, and the Kumtor gold mine, one of the country's most important economic activities (SER, 2007). Additional mining projects are currently being developed near the western and southern boundaries of the reserve. At the same time, SENSR plays a strategic role within a larger ecological network connected to the Khan Tengri region through mountain corridors that may facilitate wildlife movements (Figure 11). The effectiveness of the reserve therefore depends not only on internal protection measures but also on broader regional dynamics affecting land use, resource management, and ecological connectivity.

More generally, snow leopard conservation in Kyrgyzstan is strongly influenced by the country's socio-economic context. Agriculture, pastoralism, and mineral extraction remain major components of rural livelihoods, while governance systems continue to evolve following the country's post-Soviet political transformations (Isaev, 2014; Lempp et al., 2024; Nuraliev et al., 2024). Rural poverty limited economic opportunities, and

growing pressures on natural resources may directly affect wildlife conservation through grazing intensity, poaching risks, and local perceptions of protected areas. In parallel, climate change is expected to place increasing pressure on mountain socio-ecological systems through its effects on water resources, pasture productivity, and natural hazards (Lempp et al., 2024).

Within SENSr, several conservation challenges have already been identified, including limited financial resources, insufficient staffing and technical capacity, illegal hunting of wild ungulates in areas adjacent to the reserve, and concerns regarding mining developments near critical wildlife habitats (SER, 2007). However, evaluating conservation effectiveness requires looking beyond current pressures alone. Future threats may emerge from changing economic priorities, evolving governance systems, infrastructure development, demographic dynamics, or climate-related transformations of mountain ecosystems. For instance, there are growing concerns that economic interests could increasingly outweigh conservation objectives, as mining companies are already exploring areas bordering the reserve (SER, 2007). Likewise, the conservation of SENSr remains closely connected to the socio-economic conditions of surrounding rural communities. At the time of the reserve management plan, more than 60% of the rural population in Kyrgyzstan lived below the poverty line, creating conditions that can favour unsustainable resource use, including poaching and other forms of environmental degradation (SER, 2007).

Location and surroundings of the Sarychat–Eertash Nature State Reserve (SENSR)

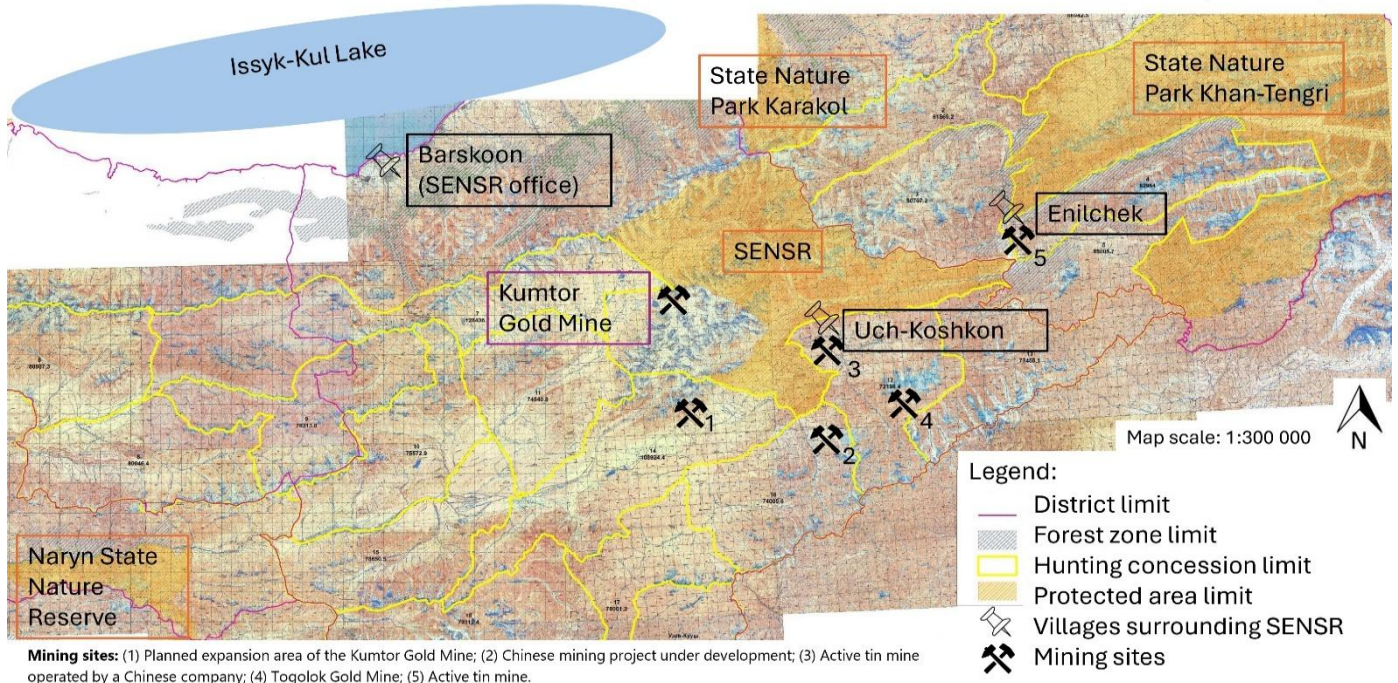


Figure 10: map of the Issyk-Kul region with important features to understand the Sarychat–Eertash State Nature Reserve system. This context maps show the mining developments in the region and how the reserve is surrounded by hunting concession area. Together, these features provide the geographical context necessary to understand the socio-ecological factors influencing conservation effectiveness within SENSr. (Map produced by the author using information compiled from official reserve documents, conservation reports, and publicly available geographic sources. The final cartographic layout was assembled in Microsoft PowerPoint.)

Understanding how present and future pressures interact with conservation actions therefore requires an analytical framework that extends beyond ecological monitoring alone. A socio-ecological perspective not only helps explain current conservation outcomes but also allows the identification of emerging vulnerabilities, potential conflicts, and future trajectories that may ultimately shape the long-term effectiveness of the reserve. To address this challenge, the present chapter analyses SENSr as a socio-ecological system using a framework inspired by Ostrom's Socio-ecological Systems Framework (Ostrom, 2009). Conservation effectiveness is considered as an outcome emerging from interactions among ecological components, governance arrangements, conservation organizations, local communities, and broader political and economic drivers (Ghoddousi et al., 2022). The analysis is primarily based on semi-structured expert interviews combined with participant observation and documentary sources. Following the problem-centred expert interview approach (Döringer, 2021), interviews were conducted with a diverse range of stakeholders involved in snow leopard conservation, including scientists, conservation NGOs, reserve rangers, protected-area managers, and policy actors. This approach enables exploration not only of explicit knowledge but also of implicit understandings regarding conservation challenges, opportunities, and decision-making processes.

Through the analysis, two recurrent dimensions emerged as particularly influential for conservation effectiveness: the symbolic role of the snow leopard and the central position occupied by conservation NGOs within the Kyrgyz conservation landscape.

By combining ecological and socio-anthropological perspectives, this chapter seeks to move beyond a purely biological evaluation of protected-area performance. Rather than asking only whether snow leopard populations persist within SENSr, the objective is to understand how social, institutional, and political processes contribute to, or constrain, the long-term effectiveness of conservation efforts. Ultimately, this broader socio-ecological approach provides a more comprehensive assessment of protected-area effectiveness and offers insights that cannot be obtained through ecological indicators alone.

2.2 Methods

2.2.1 Data collection and interviews

To investigate the socio-ecological system surrounding the Sarychat-Eertash Nature State Reserve (SENSr), two months of fieldwork were conducted in Kyrgyzstan. More than one month was spent within the reserve and its surrounding areas, while the remaining time was dedicated to meeting stakeholders involved in snow leopard conservation and biodiversity management at local, national, and international levels.

Participants were selected using a combination of purposive and snowball sampling approaches. Initial contacts were established through the OSI-PANTHERA network, which has developed long-term collaborations with local communities, reserve staff, researchers, and conservation organizations through more than ten years of citizen science activities in Kyrgyzstan. At the end of each interview, participants were invited to suggest additional individuals who could provide relevant perspectives on snow leopard conservation and the management of SENSR. This approach facilitated access to a broad diversity of actors and viewpoints. Overall, very few individuals declined participation; most non-participation resulted from scheduling constraints during the fieldwork period rather than unwillingness to contribute.

The objective was to capture the widest possible range of stakeholders involved in, or affected by, snow leopard conservation and SENSR management. Interviewees therefore included scientists, conservation NGO staff, reserve rangers, residents, and other actors directly connected to the socio-ecological system of SENSR.

Semi-structured interviews were conducted using an interview grid specifically developed for this study (Appendix 3, section 2.2). The guide was prepared in collaboration with the thesis supervisor and pre-tested with wildlife conservation experts in Switzerland, notably specialists working on lynx conservation. Although the ecological contexts differ, both species are elusive large felids that generate comparable conservation challenges, including human-wildlife interactions, monitoring difficulties, and protected-area management issues. Feedback obtained during this preliminary phase contributed to the refinement of the interview guide before field implementation.

The semi-structured format allowed questions to be adapted according to interviewee profiles while ensuring that core themes were systematically addressed. Interviews typically lasted approximately 1 hour and 15 minutes, although duration varied depending on the participant and interview context.

Most interviews with NGO representatives and scientists were conducted directly in English or French. For interviews involving residents and some reserve personnel, a professional interpreter translated between Kyrgyz, Russian, and English. Prior to each interview, preparatory discussions were conducted with the interpreter to explain the objectives of the research and the themes of interest. This preparation enabled the interpreter to facilitate exchanges actively and ensure continuity of the discussion while minimizing disruptions caused by translation. In practice, the interpreter fulfilled a role that extended beyond simple translation and contributed to communication and contextual understanding throughout the interviews.

Interviews were generally conducted either at the participant's workplace or home. Before each interview, participants were informed about the objectives of the study, the voluntary nature of their participation, and the anonymization of all collected information (texts of presentation are available in Appendix 3, section 2.1). Participants were also

asked for permission to record the interview to facilitate subsequent analysis. Only one interviewee declined audio recording.

In total, 29 semi-structured interviews were conducted and constituted the primary source of qualitative data for the socio-anthropological component of this research.

2.2.2 Categorizations of interviewees

For the purposes of analysis, and to clarify the terminology used throughout the following chapters, I propose a distinction between two broad analytical categories of actors. This categorization emerged inductively during the analysis, as differences in perceptions, modes of reasoning, and ways of expressing knowledge appeared repeatedly across interviews. These differences seemed to be shaped by a combination of factors, including profession, level of formal education, place of residence (urban versus rural), age, and access to information. It functions as an analytical tool to clarify the standpoint from which generalized statements are made in the analysis. The purpose of this distinction is to be transparent about how patterns emerged during the analytical process, how I interpreted the data, and how these interpretations were influenced by my own perceptions while working with the interviews (Details of each analytical category for each actor is described in Appendix 3, section 1).⁴

The first analytical category brings together actors whose inclusion in my network of interviewees is primarily linked to their direct involvement in snow leopard conservation. For these actors, conservation constitutes a central professional focus, whether through research, programme coordination, environmental governance, or NGO activities. Although their roles and institutions vary, they share the fact that their engagement with the snow leopard is structured through dedicated professional mandates. Many of them have higher levels of formal education and regular access to international scientific, institutional, or policy-oriented information⁵. Their perspectives are often shaped by

⁴ A reflexive note is necessary regarding my own position in the field and its influence on the analytical process. I acknowledge that I may initially attribute greater epistemic legitimacy to interviews with scientists and conservation professionals, whose modes of reasoning, information verification practices, and vocabulary closely resemble my own academic training. This proximity can unconsciously shape how I evaluate statements, particularly when assessing the plausibility of certain claims or narratives. At the same time, this awareness encourages a more cautious and reflexive interpretation of all data. While I may remain sceptical toward some information that appears inconsistent with established scientific knowledge, I recognize that such scepticism constitutes a form of analytical bias linked to my own positionality. This bias may intersect with broader social factors, including education level, language (English vs. non-English interviews conducted through an interpret), and urban versus rural backgrounds. Rather than attempting to eliminate these biases (an impossible task) I seek to make them explicit and to treat different forms of knowledge as situated and partial. This reflexive stance aims to preserve analytical openness while maintaining critical distance, and to avoid privileging one group of actors solely based on its proximity to academic or scientific norms.

⁵ This criterion is inherently subjective and was derived from information voluntarily provided by interviewees regarding their educational and professional backgrounds. It should not be interpreted as a measure of intelligence, expertise, or personal value. Rather, it is used as a proxy for differential access to formal education, scientific knowledge, and institutional networks. Furthermore, interviewees frequently

transnational exchanges, collaborations beyond Kyrgyzstan, and familiarity with global conservation discourses. This position tends to provide greater analytical distance and hindsight when discussing conservation issues, allowing them to situate local dynamics within broader ecological, political, and institutional contexts. For the sake of analytical clarity, I refer to this first group as conservation-centred actors. This analytical category is called further as **conservation-centred actors**.

The second analytical category includes actors whose inclusion in the study is primarily linked to their proximity to protected areas, their everyday interactions with the environment, or their locally grounded knowledge of snow leopard conservation and its consequences. For these actors, snow leopard conservation is not a central professional activity, but rather one element among others within a broader socio-professional and livelihood context. This group encompasses residents living near protected areas, livestock herders, local teachers, rangers, and other locally embedded actors whose knowledge emerges from lived experience, long-term presence, and practical engagement with the landscape. Their socio-professional trajectories often provide fewer opportunities to access international information or develop analytical hindsight beyond the local or regional scale. As a result, their perceptions tend to be rooted in immediate realities, personal experience, and locally circulating narratives rather than global conservation frameworks. I refer to this second group as locally embedded actors, while fully recognizing the diversity of positions and viewpoints within it. This analytical category is called further as **locally embedded actors**.

These two categories should be understood as analytical reference points rather than fixed social groups; they serve to clarify the standpoint from which statements are made in the analysis. Importantly, this analytical distinction does not imply a difference in the validity, relevance, or richness of knowledge held by the two groups. On the contrary, both forms of knowledge proved indispensable for understanding snow leopard conservation as a socio-ecological system.

2.2.3 Qualitative data analysis

Qualitative data were analysed using an inductive thematic approach inspired by the methodology described by Blais and Martineau (2006). The objective of this approach is to identify patterns, meanings, and themes emerging from the data while remaining guided by the research objectives and the researcher's interpretation.

The 29 interviews constituted the primary dataset. The analysis began with repeated readings of interview notes and transcripts to gain familiarity with the material. During this first stage, preliminary categories were identified and progressively refined. A second

emphasized that educational attainment was influenced by broader socio-economic factors, including financial constraints, geographical distance from educational institutions, and unequal access to opportunities. As such, this category reflects differences in socio-economic and institutional contexts more than differences in individual capacities.

review of the audio recordings was then conducted to verify interpretations and assign relevant quotations to the emerging categories.

The resulting categories were subsequently organized into broader analytical themes corresponding both to the research questions and to concepts identified in the literature. These themes formed the basis of the analytical framework used to interpret stakeholder perceptions of snow leopard conservation and protected-area effectiveness. Five main analytical dimensions emerged from the interviews: (1) perceptions of the snow leopard, (2) perceived threats to the species, (3) conservation measures and their effectiveness, (4) governance and institutional dynamics, and (5) concepts of occupations.

Across these themes, two recurrent elements emerged as particularly influential in shaping conservation outcomes: the symbolic role of the snow leopard and the central position occupied by conservation NGOs within the Kyrgyz conservation landscape. These two dimensions appeared repeatedly throughout the interviews and acted as structuring factors linking many of the social, political, and ecological processes discussed by participants.

To better understand these relationships, a stakeholder network was progressively reconstructed from interview material. The interpretation was informed by the sociology of translation and Actor-Network Theory (ANT) developed by Callon (1986). This perspective considers social and ecological realities as the product of heterogeneous networks composed of both human and non-human actors, whose interactions, negotiations, alliances, and conflicts shape collective action. Rather than seeking fixed causal explanations, ANT focuses on how actors, institutions, species, objects, places, and discourses influence one another and contribute to the construction of conservation processes. This approach was particularly useful for identifying actor relationships, enrolment processes, power asymmetries, areas of cooperation, and sources of tension within the snow leopard conservation network.

The actor-network analysis subsequently provided the foundation for a broader socio-ecological interpretation based on Ostrom's Socio-ecological Systems Framework (Ostrom, 2009). This framework made it possible to situate actors, governance arrangements, ecological components, and external drivers within a common analytical structure. Conservation effectiveness was then examined through the lens proposed by Ghoddousi et al. (2022), which conceptualizes effectiveness as an outcome emerging from interactions among ecological, social, institutional, and governance components of a socio-ecological system.

This perspective was further complemented by governance-oriented frameworks inspired by PARTNERS (Mishra et al., 2017) and the SPECCS criteria (Brichieri-Colombi et al., 2018). These approaches facilitated the evaluation of stakeholder participation, collaboration, legitimacy, institutional performance, and other dimensions relevant to conservation effectiveness. Together, these frameworks helped identify synergies,

tensions, governance gaps, areas of fragility, and less visible "shadow zones" within the conservation system that may ultimately influence conservation outcomes.

Finally, the overall analytical strategy and synthesis of these different frameworks were strongly inspired by the work of Frietsch et al. (2023), who similarly combined Ostrom-based socio-ecological approaches with governance analyses to evaluate conservation outcomes in complex protected-area systems.

Through this combination of inductive qualitative analysis and complementary theoretical frameworks, the study aims to provide an interdisciplinary assessment of snow leopard conservation and the effectiveness of SENSR, while identifying the principal social, institutional, and governance mechanisms shaping conservation outcomes within the reserve and its broader socio-ecological context.

2.3 Results and discussion about socio-anthropological analysis

2.3.1 Overview of conservation governance in Kyrgyzstan

This section provides a contextual overview of the governance framework within which snow leopard conservation and the SENSR case study are embedded. Its purpose is not to offer an exhaustive analysis of Kyrgyzstan's political system, but rather to present the institutional and territorial arrangements that shape conservation practices on the ground. Most of the information presented here draws from field observations, interviews with Kyrgyz actors, and explanations provided by people directly involved in conservation, local governance, and land management. While some elements may lack full juridical precision, cross-checking was conducted to avoid misinterpretation or analytical bias. This contextualization is essential for understanding the dynamics developed more deeply in the following analytical chapters.

Following the collapse of the Soviet Union, Kyrgyzstan faced the challenge of reorganizing both its economy and governance structures, moving away from the communist system toward market-oriented models, as in many post-Soviet states. Kyrgyzstan's governance system is characterized by a formal republican structure, a strong presidency, and ongoing efforts at decentralization (Lempp et al., 2024). Since independence, the country has oscillated between presidential and parliamentary models, with recent reforms (2020–2021) reasserting presidential dominance (Bawa & Singh, 2022). The country is divided into regions composed of self-governed entities ("ailakmotö"), which constitute the first level of local decision-making. Within these entities, pasture committees ("jayit komiteti") are responsible for managing grazing lands, allocating pasture access, and collecting livestock-related fees. The 2009 Law on pastures established Pasture Users Associations (PUAs) and Pasture Committees to decentralize pasture management, but

their autonomy is constrained by informal practices and limited capacity (Zhumanova et al., 2016). This arrangement provides a degree of local autonomy in everyday land-use management. However, major environmental and economic decisions, such as the designation of protected areas, mining concessions, or large infrastructure projects, remain highly centralized, with final authority concentrated at the national level within ministries and the presidency: while decentralization is a policy goal, the reality is a reassertion of presidential dominance, with local governments playing a secondary, often symbolic, role (Bawa & Singh, 2022; Lempp et al., 2024). It is also something felt by interviewee: “NGOs are losing power and the parliament is also kind of nothing now with the new president, it’s always the decision of the president because everybody is afraid to hold against president’s opinion. He is doing pression on their activity and can put you in prison” (Arthur, biodiversity management specialist, affiliated with an international conservation NGO active in Central Asia).

2.3.1.1 The role of the state in conservation

The state’s role in biodiversity conservation is widely perceived as limited. Vladimir (senior administrative officer, involved in biodiversity conservation and protected area governance at the national level) was assessing that protected areas currently cover approximately 11.7% of the national territory, with official plans to increase this proportion to 15% by 2030. Moreover, interviews consistently highlight significant challenges in enforcement and management. Ranger salaries are low, equipment is often insufficient, and training opportunities are limited (development in section 3.1.2.4). Frequent administrative rotation further undermines institutional continuity and long-term planning.

Several institutions are formally responsible for conservation governance, notably the Ministry of Natural Resources, Ecology and Technical Supervision and the Kyrgyz Academy of Sciences, which oversee regulation, monitoring, and scientific expertise: though coordination challenges persist. In practice, their effectiveness is constrained by limited funding, bureaucratic inertia, and relatively weak engagement in field-level implementation: though the extent and effectiveness of this oversight are subject to ongoing debate (Heinen et al., 2001). As a result, institutional presence on the ground often remains symbolic rather than operational. It is also informative to consider the historical evolution of conservation governance in Kyrgyzstan. Hunting restrictions aimed at protecting snow leopards and other threatened wildlife have existed since the Soviet period, and recent increases in financial penalties for poaching demonstrate the continued importance of biodiversity conservation within national legislation⁶.

⁶ Fines for following animals with 100 som ~ 1US\$: Snow leopard – 2,000,000 soms. Argali (mountain sheep), maral (stag), brown bear, and goitered gazelle – 1,500,000 soms. Red wolf, Pallas's cat, and lynx – 50,000 soms. The fine for poaching an ibex has been tripled to 300,000 soms, while illegal hunting of roe deer now carries a penalty of 100,000 soms. In addition, specific fines have been introduced for the first time for harming rare bird species: killing a white or black stork will result in a fine of 30,000 soms.

Nevertheless, conservation governance remains shaped by competing objectives. Alongside the strict protection of threatened species, the state continues to authorize trophy hunting of argali and Siberian ibex (see section 3.1.1.6), through quota systems justified by wildlife management and economic considerations. As a result, state conservation policy reflects an ongoing tension between preservation, sustainable use, and economic development (see Section 3.2.3). The creation of the Sarychat–Eertash Nature State Reserve in 1995 constituted an important institutional response to growing biodiversity concerns. Nevertheless, recommendations formulated in the Red Book of the Kyrgyz SSR (1985), including strengthening wildlife law enforcement, increasing public awareness, and expanding protected areas, closely resemble many issues still highlighted by interviewees today. This suggests that the challenge may lie less in the identification of conservation priorities than in the long-term capacity to implement and sustain them effectively (Red Book of the Kyrgyz SSR, 1985).

In this context, other actors increasingly fill gaps left by the state and contribute to the implementation of conservation measures. These dynamics and the central role of non-state actors are developed in detail in section 2.3.3.

2.3.1.2 Land tenure, territorial use, and conservation tensions

Questions of land ownership and territorial use play a critical role in shaping conservation outcomes. Local communities do not formally own most land, even in areas where they hold long-standing knowledge of the territory. As Arthur (biodiversity management specialist for Central Asia, international NGO) explains, private individuals often keep land titles with the expectation of selling them at high prices to mining companies, reinforcing speculative dynamics and weakening local control. Although vast territories remain formally state-owned, land can be leased for periods of 10 to 15 years for purposes such as pastoralism, hunting, or conservation. One conservation-oriented arrangement within this system is the establishment of sanctuaries (“zakaznik”), where pastoral activities are more strictly regulated in favour of biodiversity protection. Through interviews I also perceived the lack of enforcement in that territory due to limited staff, but associations are created to fill this gap and are helped by NGO (discussed further in chapter 3.3.5)

Another significant leasing arrangement concerns hunting companies, which operate primarily in remote and wildlife-rich areas. These companies obtain territorial concessions for up to 15 years and must comply with certain biodiversity obligations, including the establishment of “quiet zones” covering approximately 20% of their territory. However, these obligations intersect with pastoral governance systems, creating frequent land-use conflicts: “We are working separately [with pasture committees] and that

<https://24.kg/english/369657/>

<https://egov.kg/en/ministry/environment/news/23312>

(accessed on 12 July 2026)

creates arguments when sometimes shepherds go into the quiet zone saying they have permission from the pasture committee. That's why I choose difficult-to-access places as quiet zones.” (Yann, director of a hunting company operating close to a protected area context). A more detailed analysis of hunting company practices and their implications for snow leopard conservation is provided in section 3.1.1.6.

Mining concessions introduce an additional layer of complexity. Mining companies benefit from special authorizations that can override both conservation and hunting concessions. As Yann (director of a hunting company operating close to a protected area) notes: “They have special permission from the ministry so as hunting companies we are powerless... sometimes we even need special papers to go through our own land because there is mine activity.” While mining is not the central focus of this thesis, it remains an important background factor shaping land-use conflicts and a threats for wildlife, it will be discussed in section 3.1.2.2.

Overall, conservation governance in Kyrgyzstan can be characterized as a hybrid system, where formal decentralization coexists with strong central authority and persistent informal practices (Shigaeva et al., 2016). The state establishes formal policies and legal frameworks but provides limited operational support and local communities remain central to the practical success of conservation on the ground. These interactions generate constant negotiation between economic development, centralized political authority, and environmental stewardship. This overview, while not exhaustive, highlights the institutional complexity within which both snow leopard conservation and Kyrgyz protected area management unfolds and illustrates the space in which conservation programs are developed, contested, and adapted.

2.3.2 The snow leopard as a symbolic keystone of conservation

The snow leopard occupies a central position in the socio-ecological system of SENS, functioning simultaneously as a symbolic, ecological, political, and economic anchor of conservation effectiveness.

First, this perception is the result of a relatively recent transformation. Historically, the snow leopard was actively persecuted and hunted for its fur, reflecting a utilitarian relationship with wildlife that prevailed across much of Central Asia. According to several interviewees, such practices are now largely associated with past generations and are increasingly regarded as incompatible with contemporary conservation values. Respondents further highlighted the role of conservation policies introduced since the early 2000s, including the creation of *zakazniks* (wildlife sanctuaries), strengthened legal protection, and growing conservation outreach efforts, in reshaping public attitudes toward the species (Mael, vice-director, involved in protected-area management). Consequently, the snow leopard has gained unprecedented visibility within conservation narratives and public discourse. As one respondent noted, “Before 2010, people were not

very aware of the snow leopard” (Arthur, biodiversity management specialist, affiliated with an international conservation NGO active in Central Asia). The species has thus undergone a process of symbolic revalorization, becoming an increasingly important emblem of national and international conservation efforts.

As it appears from the word cloud produce based on interviewees perception of snow leopard (Figure 12; original answers are presented in Appendix 3, section 3), across all actor groups, the dominant perception is strongly aesthetic and symbolic, structured around notions of beauty, rarity, elegance, and mysticism. Its elusive behaviour, rarity of direct encounters, and winter coat blending into snow contribute to associations with purity and invisibility. Many respondents describe dreaming of seeing a snow leopard, and for some, the value of the experience lies precisely in its improbability. This fascination goes beyond simple curiosity and can be interpreted as a form of symbolic reverence. For some, the connection is almost spiritual: living in the same mountains as this species creates a sense of shared territory and quiet privilege⁷

This symbolic framing generates powerful emotional attachment and constitutes a key driver of social legitimacy, facilitating widespread acceptance of conservation measures. At the national scale, this symbolism is further institutionalized through its designation as a national emblem⁸, reinforcing its role as a marker of identity, pride, and territorial belonging. This strategy aims to make the snow leopard visible in everyday representations: calendars, airplanes, and souvenirs, so that people would immediately associate the species with Kyrgyzstan. In this sense, the snow leopard operates as a cultural and political object, shaping how conservation is perceived, justified, and promoted.

⁷ This aspect is difficult to analyse rigorously, yet it was deeply present in my field experience and in conversations with local communities. Observing a snow leopard is often described as a quest: a rare and meaningful encounter. The qualities attributed to the animal (purity, elegance, silent movement) echo traits commonly associated with sacred or higher beings. Even watching videos of the species can evoke a powerful emotional response. After spending three weeks in snow leopard habitat, I personally felt its presence without ever seeing it. Paradoxically, not seeing it seemed almost normal, reinforcing the idea that this is an animal that reveals itself only if it chooses to. In that sense, it appears to “decide” within its own mountains. This dimension is hard to articulate, but it seems to touch something universal. The snow leopard, through its rarity and particularity, awakens a deep emotional and symbolic sensitivity that gives it a unique kind of power.

⁸ https://kaktus.media/doc/493316_snejnyy_bars_stal_nacionalnym_simvolom_kyrgyzstana.html (accessed on 24 March 2026)

Word Cloud – Perception of Snow Leopard (All Actors)

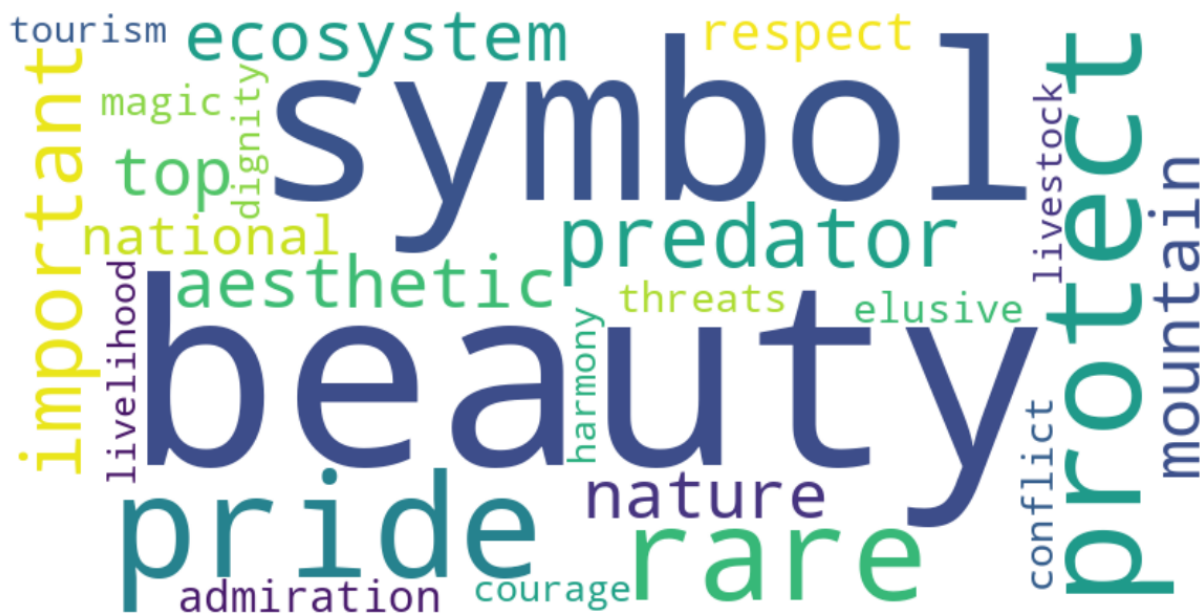


Figure 11: Word cloud from the actor's answer to the question: "what are the three first word that come to your mind when you think about the snow leopard?" (Original answers are presented in Appendix 3, section 3) to visualise the snow leopard perception of all actors. (generated by Copilot IA)

At the same time, this symbolic power is reinforced by a scientific framing that presents the snow leopard as both a keystone species and an umbrella species. As a top predator regulating ungulate populations and structuring trophic dynamics, it provides ecological justification for conservation interventions. Vladimir (senior administrative officer, involved in biodiversity conservation and protected area governance at the national level) similarly frames conservation as both an economic opportunity for local communities and a moral responsibility toward future generations, stating that "protecting snow leopards equals protecting entire mountain ecosystems". This dual status is strategically mobilized by conservation actors to legitimize investment, attract international funding, and align actions with global frameworks such as the Sustainable Development Goals. However, while this narrative facilitates mobilization and action, it raises an important question regarding actual ecological effectiveness, since the emphasis on a flagship species may oversimplify ecosystem dynamics. Indeed, the centrality of the snow leopard produces analytical blind spots. Several actors point to the risk that excessive focus on this charismatic species leads to the marginalization of less visible but equally critical processes, such as climate change impacts, glacier dynamics, or broader biodiversity. This "flagship bias" highlights a tension between symbolic efficiency and ecological complexity, suggesting that effectiveness cannot be fully assessed through a single-species lens (developed further in chapter 4.2).

These dynamics are deeply embedded in political ecology and governance processes. The snow leopard's symbolic value is actively mobilized at the national and international

levels to attract funding, strengthen diplomatic positioning, promote tourism development, and long-term institutional engagement. The sustained involvement of organizations such as the Snow Leopard Trust, as well as transnational initiatives like the Global Snow Leopard and Ecosystem Protection Programme (GSLEP), the international snow leopard day on 23 October, and the 2013 Bishkek Declaration⁹, give the species a unique geopolitical dimension. While this creates important opportunities to attract funding, expertise, and political attention, it also raises questions about the extent to which international visibility translates into effective conservation outcomes on the ground, particularly when conservation objectives interact with competing economic interests such as mining and infrastructure development. Indeed, this situation illustrates the potential risk of symbolic conservation, whereby species may acquire a strong political and communicative value without necessarily being accompanied by equivalent investments in governance, enforcement, or field-based conservation actions (Horsley et al., 2020; Tälle et al., 2023). In parallel, as expected for umbrella species, the snow leopard is also framed as an economic resource, central to conservation finance and development strategies. Its charisma facilitates donor engagement, tourism initiatives, and livelihood diversification programs, linking conservation efforts to local economic opportunities. This economic dimension reinforces long-term engagement but also contributes to dependence on the continued symbolic appeal of the species: Charles (scientific director, affiliated with an international snow leopard conservation NGO) emphasizes that snow leopard conservation converges with 13 UN Sustainable Development Goals, generating “collateral benefits” that go far beyond the species itself.

However, this broadly positive perception is neither uniform nor stable. Some actors, particularly rangers and herders, express concerns regarding the potential consequences of increasing snow leopard populations, including reduced prey availability and increased livestock depredation. As a large predator, the snow leopard remains part of human–wildlife conflict dynamics, and its symbolic image may shift if conservation success leads to greater economic costs for local communities: “You need to think of the potential consequences of increasing snow leopard populations before favouring snow leopard expansion” (Urs, livestock herder, resident of a village adjacent to a protected area). This highlights the conditional nature of social acceptance and the need for adaptive management and continuous dialogue with local communities with informational work.

Taken together, these elements show that the snow leopard functions as a symbolic keystone, not only structuring ecological processes but also organizing social perceptions, political strategies, and economic flows. Its effectiveness lies in its ability to

⁹ The Bishkek Declaration is a political commitment adopted in 2013 by the 12 snow leopard range countries to strengthen international cooperation for snow leopard conservation and launch the Global Snow Leopard and Ecosystem Protection Programme (GSLEP). The declaration also established 23 October as International Snow Leopard Day to promote awareness and support for the conservation of snow leopards and their mountain ecosystems: <https://globalsnowleopard.org/bishkek-declaration/> (accessed on 20 March 2026)

connect heterogeneous actors and rationalities, acting as a boundary object within the socio-ecological system. Conservation effectiveness in Sarychat–Eertash therefore emerges from the convergence of symbolic, scientific, political, and economic dimensions, rather than from ecological performance alone.

This centrality also explains the crucial role of NGOs within the system. The symbolic and strategic value of the snow leopard generates the resources, attention, and legitimacy upon which NGO action depends. NGOs do not operate independently of this symbolic framework; rather, they translate and operationalize it into concrete conservation practices. The following section therefore examines how NGOs, building on this symbolic foundation, become key actors in structuring governance and sustaining conservation effectiveness.

2.3.3 The central role of NGOs: drivers of conservation governance and fragility

This section examines how environmental governance in Kyrgyzstan, and more specifically snow leopard conservation, for the reasons outlined in the previous section, relies extensively on non-state actors, with NGOs emerging as central drivers of governance, implementation, and coordination. Across nearly all domains: scientific monitoring, ranger training, community engagement, livelihood diversification, ecotourism development, and even policy influence, NGOs effectively fill structural gaps left by limited state capacity. This dependence is widely acknowledged by both conservation practitioners and governmental representatives, who recognize that the operational functioning of protected areas depends largely on external financial and technical support.

NGOs play a particularly decisive role in knowledge production and enforcement support, often reversing expected institutional roles. Empirical data are largely collected through NGO-led programs and later processed by national scientific institutions, while training and capacity-building efforts compensate for weak enforcement capacity at the state level: “Our institute processes and analyses the data that are collected on the field by NGOs to inform conservation policy” (Antoine, researcher affiliated with a national academy of sciences, specializing in vertebrate zoology), highlighting a reversal of expected roles in which non-governmental actors generate much of the empirical knowledge used by state institutions. More broadly, NGOs act simultaneously as implementers, experts, and informal policy advisors, contributing to conservation strategies while maintaining close relationships with government authorities: “[...] core implementation relies on NGO and international partner support for finance and technical expertise.” (Vladimir, senior administrative officer, involved in biodiversity conservation and protected area governance at the national level).

Beyond implementation, NGOs function as key intermediaries within the conservation network, translating information across scales. They channel field-based observations to centralized authorities while adapting conservation measures to local realities. This role is particularly visible in crisis situations, where local ecological concerns, such as extreme climatic events or pressure on wildlife, are communicated through NGO networks, even when they conflict with state economic priorities: “I warned them several time through NGO about the need to suspend hunt after the Jut [extreme snow fall in Kyrgyz], but economic priority are too important for the government...” (Adri, ranger, working in protected area management). In this sense, NGOs act as both mediators and translators, in line with the sociology of translation (Callon, 1986; that principle will be further analysed in section 3.1.1.3). This intermediary role allows NGOs to represent local ecological concerns that would otherwise remain unheard within centralized decision-making processes.

Their influence extends strongly into community-based conservation programs, which combine economic incentives with social and symbolic dimensions. Initiatives such as handicraft programs, anti-poaching bonuses, and awareness campaigns contribute to both livelihood diversification and conservation compliance. These programs have demonstrated that poaching is often rooted in economic necessity, and that alternative income opportunities can effectively shift practices when combined with strong local engagement. By aligning economic incentives with conservation objectives, NGOs build alliances that enhance the effectiveness and social legitimacy of protection measures.

At the same time, NGOs play a key role in mitigating human–wildlife conflict, through a combination of economic incentives, awareness-raising, and continuous interaction with local populations. Their work contributes to maintaining currently high levels of social acceptance for snow leopard conservation, despite emerging concerns related to predation on livestock.

The influence of NGOs extends well beyond SENSr itself and can be observed across other conservation initiatives in Kyrgyzstan. A particularly illustrative example is provided by community-based management initiatives developed within *zakazniks* (wildlife sanctuaries), a category of protected area characterized by lower levels of state investment and enforcement than strict nature reserves. In theory, these sanctuaries contribute to biodiversity conservation; in practice, however, their effectiveness is often constrained by limited resources: “zakaznik are for the moment not really valorised and effective for their purpose” (Morgane, director and educator involved in a citizen science programme on snow leopard conservation). Large and remote territories may be monitored by only one ranger, making surveillance and law enforcement particularly challenging. In response to these limitations, one interviewee described how residents created an association dedicated to biodiversity conservation and ecotourism development, with substantial support from NGOs. According to him, reductions in

overgrazing, improved protection of wildlife, and the recovery of ungulate populations have been accompanied by the return of snow leopards and other large predators. As he explained: “Economic alternatives for communities, through sustainable tourism, can reduce poaching and encourage wildlife conservation” (Thibault, farmer and herder actively involved in local protected-area management). Members of the association devote a substantial part of their free time, alongside their pastoral and agricultural activities, to patrolling, biodiversity monitoring, and awareness-raising efforts. Although they possess no formal law-enforcement authority and must rely on collaboration with the Eco-Police in cases of poaching, NGO support has significantly increased their capacity to act. This support includes training programmes, assistance in securing financial resources, provision of field equipment, and the development of educational infrastructure such as information panels, visitor itineraries, and awareness campaigns. Consequently, this example illustrates how NGOs frequently act as intermediaries between local communities, conservation practitioners, and state institutions, while simultaneously strengthening local stewardship and compensating for limited governmental capacity

Despite their strengths, NGO-led conservation also presents significant limitations and tensions. First, NGOs operate within a political context characterized by increasing centralization of power (as described in section 2.3.1). Their legal status depends on state approval, which limits their ability to openly challenge governmental decisions, particularly regarding extractive industries. As a result, NGOs may tend to depoliticize environmental conflicts to remain operational. This highlights a key insight from political ecology: conservation is never politically neutral, and NGOs, even when operating primarily through technical and scientific activities, remain embedded in broader power relations and governance processes. Nevertheless, most interviewees described generally positive relationships between NGOs and governmental authorities. As one conservation practitioner explained: “We maintain a close relationship with the government: we are officially approved, involve them in trainings, share all data, and they listen to our advice. The Ministry respects our recommendations due to demonstrated results in the field and sustained collaboration.” (Michel, programme coordinator, affiliated with a national snow leopard conservation NGO). However, this perception should be balanced with findings from the scientific literature. While NGOs often occupy a central role in conservation implementation, their institutional position remains relatively fragile (Michel et al., 2024 in Mallon & McCarthy, 2024). This suggests that cooperative relationships with state authorities do not necessarily translate into strong institutional influence or long-term security. The situation therefore reveals a paradox. NGOs frequently increase conservation effectiveness by filling operational, financial, and technical gaps left by public institutions.

Second, the strong reliance on NGOs raises fundamental issues of sustainability and governance coherence. Many conservation activities: including scientific monitoring,

training, and community programs, depend on external funding and donor priorities. This creates vulnerability to sudden disruptions, as illustrated by the suspension of programs due to regulatory constraints or funding changes. It also generates spatial inequalities, as NGO presence varies across regions, leading to uneven conservation outcomes in the absence of a strong national framework. Third, questions of accountability and representation remain unresolved. NGOs operate between donors, governments, and local communities, but their decision-making processes are not always transparent. This can lead to discrepancies between local priorities and externally driven agendas, as well as tensions around benefit distribution: “They [citing some NGO] work not for the well of KG but only for the interest of the company” (Arthur, biodiversity management specialist, affiliated with an international conservation NGO active in Central Asia). Controversial initiatives such as citizen science programs sometimes blur the boundary between conservation and tourism, raising ethical concerns about access to protected areas and the distribution of benefits (developed further in section 3.2.2).

At times, NGOs may also overextend their mandate, for example by promising livestock compensation mechanisms that cannot be sustained institutionally: “NGO promise compensation to shepherd if livestock occur but then ask for photo proof and finally retract to said that shepherd need insurance for livestock, even if no one does that in Kyrgyzstan” (Julien, ranger, working in protected area management).

Ultimately, while NGOs significantly enhance conservation effectiveness in the short and medium term, they also reveal underlying institutional weaknesses. The Kyrgyz conservation system appears highly functional but structurally fragile, as it depends on external actors rather than robust state-led governance: “If the government paid more for protected areas and science, NGOs would not be needed.” (Aurore, researcher specializing in ornithology, affiliated with an international research institute).

The centrality of NGOs is therefore inseparable from the symbolic power of the snow leopard itself. The species’ charismatic and political value attracts funding, international attention, and institutional support, which in turn enable NGO action. NGOs do not operate independently from this context; rather, they translate the symbolic capital of the snow leopard into concrete conservation practices. This interdependence highlights how conservation effectiveness in SENSr emerges from the interaction between symbolic drivers and governance structures, a relationship that forms the basis of the effectiveness framework developed in the following chapter.

Chapter 3: Interdisciplinarity to assess the effectiveness of Sarychat-Eertash Nature State Reserve

3.1. Assessing and discussing the socio-ecological system

Building upon the ecological assessment of the Sarychat–Eertash Nature State Reserve (SENSR) and the socio-anthropological analysis of stakeholder perceptions, this chapter adopts an interdisciplinary perspective to evaluate the effectiveness of the SENSR. The previous sections highlighted that conservation outcomes cannot be understood solely through ecological indicators, but also depend on social, institutional, and political dynamics shaping human–environment interactions.

The socio-anthropological analysis identified two major drivers structuring snow leopard conservation in SENSR region: the symbolic power of the snow leopard and the central role of conservation NGOs. Together, these dimensions influence funding opportunities, public support, governance arrangements, and the implementation of conservation actions. However, their significance can only be fully understood when situated within the broader network of actors and institutions involved in conservation.

The first step of this analysis therefore consists of examining the actor network surrounding SENSR, with particular attention to relationships, dependencies, forms of cooperation, and sources of tension among stakeholders. Building on this network perspective, the chapter subsequently analyses SENSR as a socio-ecological system through the lens of Ostrom’s framework (2009), allowing ecological processes, governance structures, stakeholders, and external pressures to be considered within a common analytical structure.

By combining ecological and socio-anthropological findings, this chapter seeks to move beyond isolated indicators and assess conservation effectiveness as the outcome of a dynamic socio-ecological system. Particular attention is paid to identifying key synergies, tensions, vulnerabilities, and governance mechanisms that shape conservation outcomes.

3.1.1 Actor network assessment and discussion

As a first step in analysing the Sarychat–Eertash socio-ecological system, it is necessary to examine the network of actors involved in snow leopard conservation. Following the

perspective of Actor-Network Theory (Callon, 1986), conservation is understood as the product of interactions, negotiations, alliances, and tensions among a diversity of actors operating at different scales.

This section identifies the principal actors involved in the conservation system, including institutions, NGOs, local communities, reserve staff, and external stakeholders. It then examines the relationships that connect them through mechanisms such as collaboration, enrolment, representation, and resource sharing, while highlighting areas of cooperation, power asymmetries, conflicts, and "shadow zones" within the network.

Figure 13 provides a synthesis of this actor network and illustrates how conservation effectiveness emerges from the interactions among stakeholders rather than from the actions of any single actor. Particular attention is given to the role of NGOs, local communities, and reserve staff, as well as to the tensions and dependencies that shape snow leopard conservation in and around SENSUR.

3.1.1.1 Divergent perceptions and shared constraints

Conservation is shaped by diverging perceptions of threats and priorities. Locally embedded actors tend to emphasize immediate ecological constraints and livelihood needs, such as prey availability or pastoral pressures, whereas conservation-centred actors focus more on long-term dynamics, including habitat degradation, mining expansion, and ecosystem change. Perceptions of poaching also reveal important differences in knowledge and scale. Among locally embedded actors, poaching is often considered largely eradicated: “Poaching is almost gone thanks to penalties.” (Mael, vice-director, working in protected area management). This view is echoed by Edward (head of rangers, working in protected area management), who emphasized the combined effects of enforcement, awareness-raising, and alternative livelihoods: “There is no poaching in Kyrgyzstan; it is impossible in the mind of Kyrgyz people to poach them.” In contrast, conservation-centred actors, particularly NGOs, highlight the persistence of illegal hunting, both for snow leopards and their prey, based on broader monitoring frameworks and trade-flow analyses (Nowell, 2016). As Arthur (biodiversity management specialist, affiliated with an international conservation NGO active in Central Asia) noted, “I am sure that poaching is still happening even with penalty, also with ungulate.” This contrast reflects differences between localized, experience-based perceptions and larger-scale, evidence-based assessments, illustrating how the framing of threats is itself shaped by actor positioning.

A similar divergence emerged regarding the development of ecotourism. While most interviewees viewed tourism as a desirable alternative to extractive industries, important differences appeared between locally embedded actors and conservation-centred actors. Local stakeholders generally emphasized its potential to generate income, employment opportunities, and regional development. As Julien (ranger, working in protected area management) noted, “It would be better than mining. The country could attract more tourists and make more money. We have beautiful nature.” Likewise, Amélie (cook and social support worker, working in a village boarding school) highlighted that the region's landscapes and protected areas already attract visitors who contribute economically while potentially encouraging nature conservation.

Conservation-centred actors expressed a more nuanced position. Although they generally supported ecotourism as one of the least harmful development pathways available, they also emphasized the need to carefully regulate its growth. Concerns were raised regarding waste management, water use, wildlife disturbance, infrastructure development, and the increasing use of technologies such as drones. As Benjamin (educator involved in a citizen science conservation programme and livestock herder) explained: “In any case there are threats to these environments, and ecotourism is, in the end, the least harmful.” This illustrates a recurring tension between economic development and ecological limits. Whereas local actors often focus on economic opportunities and livelihood diversification, conservation practitioners tend to frame

tourism within broader concerns regarding carrying capacity, ecosystem integrity, and long-term sustainability.

At the same time, several interviewees emphasized that, under current political and economic conditions, conservation rarely competes successfully with mining or infrastructure development without demonstrating tangible economic value. In this sense, ecotourism becomes more than a development strategy; it functions as a mechanism for assigning economic value to living ecosystems and strengthening the political legitimacy of conservation. Several NGOs, including Ibirs, Camp Alattoo, and the Snow Leopard Foundation Kyrgyzstan (SLFK), are therefore actively involved in designing tourism initiatives that integrate conservation safeguards, visitor regulations, and mechanisms for equitable benefit-sharing. As one respondent noted, governmental protection measures are often more likely to be supported when accompanied by economic incentives.

Interestingly, tourism was also perceived as a governance tool rather than solely an economic activity. According to Morgane (director and educator involved in a citizen science programme on snow leopard conservation), tourism projects and NGO involvement can contribute to revitalising protected areas by increasing ranger presence, improving monitoring capacity, and indirectly strengthening anti-poaching efforts. However, actors involved in snow leopard tourism programmes remained aware of the risks associated with poorly regulated development. As Jules (Jules, director, affiliated with a national snow leopard conservation NGO) explained in relation to snow leopard tourism initiatives, “[...] if we are not putting the right framework in place, these programmes can harm nature,” highlighting the need for clear rules, effective oversight, and fair distribution of benefits. Consequently, ecotourism emerged not as a consensual solution but as a negotiated compromise, reflecting broader debates within the conservation system about how economic development and biodiversity protection should be balanced (see section 3.2.3).

These differences do not constitute contradictions but rather reflect distinct knowledge systems rooted in positionality. They illustrate how conservation operates across multiple temporal and spatial scales, combining experiential knowledge with scientific and institutional perspectives.

Interestingly, when asked to identify key conservation actors, several locally embedded respondents did not spontaneously mention NGOs, including some rangers who regularly collaborate with them. This omission suggests a normalization of NGO presence, a limited visibility of their role, or a certain ambivalence toward external support. It highlights how actor centrality within the network is not perceived uniformly, despite being structurally decisive.

3.1.1.2 Coordination, livelihoods, and social integration

Actor coordination in SENSr plays a central role in balancing conservation objectives with local socio-economic realities. Livelihood diversification strategies: including handicrafts, tourism, and, more controversially, employment in the mining sector, form part of this balance. While tourism and handicrafts are closely linked to the ecological attractiveness of the reserve, mining introduces significant economic opportunities alongside ecological risks.

As developed in section 2.3.3, NGOs are central to this coordination process, particularly through community-based conservation programs that integrate economic incentives with social and cultural dimensions. These initiatives contribute not only to income diversification but also to community cohesion, transmission of traditional knowledge, and alignment with local values, thereby reinforcing the legitimacy of conservation measures.

An often overlooked but important aspect of the conservation network concerns the integration of women into conservation initiatives (Alexander et al., 2022). This constitutes a notable achievement, as community-based conservation programmes worldwide have frequently struggled to ensure the effective participation of marginalized groups, particularly women (Agrawal & Gibson, 1999; Keane et al., 2016; McShane et al., 2011). In the case of SENSr, the snow leopard handicraft programme developed through local NGOs provided employment opportunities for unemployed women in the villages of Ak-Shyirak and Engilchek. Participants produced and sold felt handicrafts, generating income that directly benefited their households while creating a tangible link between local livelihoods and snow leopard conservation. The programme was further reinforced through a conservation incentive mechanism: communities received an additional bonus when no poaching incidents or other negative impacts on wildlife were reported (SER, 2007). Beyond its economic contribution, interviewees emphasized that the initiative indirectly supported wildlife protection by strengthening community support for conservation and reducing incentives for poaching. The programme also coincided with the recruitment of former hunters and shepherds as reserve rangers, creating alternative sources of income linked to conservation rather than resource extraction (SER, 2007).

Although the programme was officially suspended in 2021 due to administrative and fiscal constraints related to taxation and export regulations, several women continue handicraft activities independently. According to Jules (director, affiliated with a national snow leopard conservation NGO), the initiative was paused rather than abandoned, demonstrating a degree of local ownership that extends beyond direct NGO support. This suggests that the programme generated capacities and economic practices capable of persisting after external funding declined, a key indicator of long-term sustainability. More broadly, interviews revealed that these initiatives contributed to the revitalization of traditional knowledge and local skills that had gradually declined with economic

modernization. Participants highlighted renewed interest in cultural practices that have been lost through changing lifestyles and economic systems, creating interest in reconnecting conservation with local cultural heritage: “I want to reprocess wool, because currently it is burned. I remember old time when we were crafting carpet that give better isolation with natural fabrics. We could also make meat reprocessing: everybody has livestock and sell it, but we could keep it in cans or half cook to have more stable and sustainable income... I think also about using sheep skin [= leather] as in former time and not let it as trash” (Mathilde, schoolteacher, resident of a village adjacent to a protected area).

This example illustrates a broader lesson repeatedly emphasized by interviewees and the community-based conservation literature: long-term effectiveness depends not only on financial incentives but also on community ownership, trust-based relationships, and the ability of interventions to persist beyond donor funding cycles. As Michel (programme coordinator, affiliated with a national snow leopard conservation NGO) stated, “community ownership is critical to sustain interventions beyond donor timelines.” The handicraft programme therefore provides a concrete example of how conservation can simultaneously support biodiversity protection, social inclusion, cultural revitalization, and local economic development, thereby strengthening the legitimacy and resilience of the broader socio-ecological system.

Beyond economic aspects, coordination is also embedded in broader socio-ecological conditions. Access to services such as education, water, and infrastructure, partly strengthened by the presence of the reserve, contributes indirectly to community resilience and shapes the conditions under which conservation can be accepted and sustained.

Ultimately, coordination effectiveness depends on the durability, inclusiveness, and balance of actor relationships.

3.1.1.3 NGOs and rangers: profit-sharing scheme, spokesperson ship and enrolment

Within these conservation arrangements between NGOs and local communities, clear parallels can be identified with the processes of problematization, enrolment, and the establishment of profit-sharing mechanisms described by Callon (1986; direct translation of French step name). By aligning economic incentives with conservation objectives, NGOs create alliances that strengthen both the effectiveness and the social legitimacy of conservation measures. Organizations such as Ilbirs, Camp Alattoo, and the Snow Leopard Foundation Kyrgyzstan (SLFK) also play a central role in structuring ecotourism initiatives, ensuring that tourism development remains compatible with conservation goals while incorporating mechanisms for equitable distribution of benefits: “The main issue is to have a better land management. [...] We are simply telling

community that they will receive more money thanks to eco-tourism if they keep pristine environment” (Michel, programme coordinator, affiliated with a national snow leopard conservation NGO). These findings are consistent with broader community-based conservation literature (see section 3.1.1.2).

From an Actor-Network Theory perspective, NGOs contribute to conservation not only through financial and technical support but also by organizing and stabilizing relationships among actors. Through processes of enrolment and spokespersonship (Callon, 1986), they connect local realities to national and international conservation agendas. Contractual partnerships with rangers illustrate this dynamic particularly well. By providing funding, training, equipment, and professional recognition, NGOs strengthen the capacity of rangers while simultaneously integrating them into wider conservation networks. Rangers, in turn, become local spokespersons capable of translating conservation objectives into everyday management practices and maintaining links with surrounding communities. Their hybrid position (see section 3.1.1.4), embedded in local social realities while connected to transnational conservation networks, further reinforces the coordinating role of NGOs.

The relationship between NGOs and rangers therefore represents one of the main structuring dynamics of the conservation network. As one ranger explained, “We have a one-year contract, renewable, with an NGO for support” (Diego, ranger involved in protected-area management). This arrangement reflects a process of enrolment through which rangers become integrated into a broader conservation system. NGOs act as coordinators and translators by defining conservation priorities, mobilizing resources, and connecting local practices to national and international conservation frameworks. Rangers are simultaneously enrolled as key operational actors responsible for implementing conservation measures and facilitating interactions between conservation organizations and local communities. Similarly, head rangers function as internal spokespersons within the reserve by relaying management decisions and conservation priorities from the SENSR administration to field staff and, ultimately, to local communities.

NGOs are also connected to numerous other actors through similar processes of enrolment. They play a crucial intermediary role between scientific research and field implementation. Through their collaboration with rangers and support for citizen science initiatives, NGOs facilitate the production, circulation, and accessibility of ecological data, which are subsequently mobilized in scientific studies and policy-making processes. At the same time, they maintain close relationships with governmental institutions, whose approval often remains necessary for research activities and information dissemination. These interactions illustrate the political constraints within which conservation organizations operate.

NGOs occupy a central position in relation to financial actors, frequently described by interviewees as “the backbone of conservation” (“le nerf de la guerre” for original French statement). Many conservation activities depend heavily on funding provided by international donors and organizations such as UNDP, WWF, zoological institutions, and private foundations. In return, these actors place trust in NGOs based on their demonstrated field expertise, operational capacity, and long-term presence in conservation landscapes. This combination of technical expertise, financial mediation, and network coordination further consolidates the pivotal role of NGOs within the snow leopard conservation system.

Finally, my own position as a researcher is embedded within this actor network and cannot be considered neutral. My work is partially structured through an enrolment relationship with NGOs, as I rely on their data, long-term monitoring efforts, and field-based knowledge. I also first spend 12 days in the reserve with the NGO that give already an opinion about the reserve and the staff. In return to the relationship with the NGO, I contribute to the valorisation of these data through academic writing, dissemination, and their integration into broader scientific and policy discussions. My affiliation with a Swiss university and collaboration with a specific NGO providing long-term camera trap data further shape my access to information, framing of research questions, and interpretation of results. The supervision and network provided by this NGO also influence the construction of my fieldwork and the perspectives I am exposed to. This reflexive positioning highlights that research itself is part of the actor network, shaped by processes of enrolment, access to resources, and relationships of trust and collaboration. This research is not external to the actor network it analyses, but is itself embedded within it, shaped by relations of access, collaboration, and knowledge production.

These processes allow conservation discourses, knowledge, and practices to circulate across scales, from global biodiversity frameworks to local land-use decisions. At the same time, they reinforce asymmetries within the network, as some actors, particularly NGOs, occupy more central positions in controlling information flow and resource distribution.

3.1.1.4 Rangers as hybrid actors

As highlighted in the previous section on the relationships between rangers and NGOs, rangers occupy a pivotal hybrid position within the conservation system. They combine strong local embeddedness with integration into national and international conservation networks. Their effectiveness largely derives from this dual identity: as members of local communities, they possess detailed contextual knowledge, practical field experience, and social legitimacy, while their collaboration with NGOs provides access to training, equipment, technical expertise, and broader conservation frameworks.

This hybridity is not only institutional but also socio-economic. Ranger salaries remain relatively low, and although state employees are not officially permitted to hold a second occupation, many rangers engage in additional economic activities to support their households. These activities sometimes place them in positions that may appear contradictory to conservation objectives. Some are involved in mining activities, others maintain livestock, and some are assigned to supervise trophy-hunting operations as part of official wildlife management procedures. As one ranger explained: “We are not allowed to participate in hunting company, but it would also be very damaging for a ranger’s reputation to help hunters. However, there is a department in the Ministry that supervises foreign hunting tourism, and rangers are assigned to ensure that hunting activities follow the established regulations” (Diego, ranger involved in protected-area management). This observation highlights a broader analytical theme concerning the concept of occupation and livelihood strategies. In the local Kyrgyz context, activities such as livestock herding are not always perceived as a distinct profession requiring formal training, but rather as a normal component of rural life. Many individuals combine multiple sources of income and social roles simultaneously. Consequently, the distinction between profession, occupation, and livelihood is often less rigid than in Western contexts. Recognizing these differences is important for understanding the social realities of conservation actors and avoiding ethnocentric interpretations of their roles and responsibilities.

Because of their multiple positions within the conservation system, rangers function as interfaces between scales and knowledge systems. They translate abstract conservation objectives into locally meaningful practices while simultaneously communicating local realities to external conservation actors. Their position enables adaptive responses to field conditions and facilitates communication between local communities, reserve administrations, NGOs, and scientific organizations. However, this intermediary role is not without challenges. Rangers often occupy a relatively weak position within decision-making processes despite their extensive field experience and practical knowledge. Several interviewees expressed frustration regarding the limited consideration given to their expertise. As one ranger stated: “The government allowed hunting during the breeding season [early winter], even if we said it was not good, as our fathers taught us, but nobody listened to us” (Adri, ranger involved in protected-area management). This example illustrates broader issues related to the circulation of information and the recognition of local and traditional ecological knowledge. It also suggests that conservation governance may not always adequately integrate the experience of frontline actors. Interestingly, several interviewees described NGOs as their primary channel for communicating concerns and observations to higher administrative levels. While this arrangement strengthens the intermediary role of NGOs, it may also contribute to perceptions that local voices are filtered and that feedback from higher decision-making levels remains limited.

3.1.1.5 Asymmetries, conflicts and network fragilities

Despite its strengths, the conservation network displays significant asymmetries and coordination challenges. Participation in conservation initiatives remains uneven across the region, with NGO activities and ranger presence largely concentrated in one community located close to SENSR. This spatial concentration generates disparities in access to information, awareness campaigns, training opportunities, and conservation-related benefits, which in turn shape contrasting perceptions of conservation costs and outcomes.

It is important to acknowledge that many of the interviews were conducted in villages located near the reserve, where interactions with NGOs and conservation actors are most frequent. This proximity may contribute to more favourable perceptions of conservation. As one ranger explained: “This is logical that there is a difference between people from our village and people outside because we do not have the same living conditions; the mentality might be different” (Julien, ranger involved in protected-area management). Such observations highlight the uneven geographical distribution of conservation influence and suggest that social support for conservation may vary considerably across the broader landscape.

Additional asymmetries emerge from the relationship between NGOs and rangers. As discussed in section 3.1.1.3, rangers often receive financial compensation when participating in NGO-led activities, research projects, or monitoring missions. Because external researchers and conservation practitioners require the accompaniment of reserve staff when operating within SENSR, these collaborations represent an important supplementary source of income. While this arrangement strengthens cooperation, it may also create subtle biases in interactions between rangers and external actors. Rangers may be incentivized to emphasize positive aspects of reserve management or conservation outcomes to maintain productive relationships with conservation organizations and researchers. Although this does not imply intentional misrepresentation, it highlights the importance of considering how financial dependencies can influence knowledge production and information exchange within the network.

Interestingly, interviewees rarely described strong competition among conservation NGOs. As one respondent noted: “There is much more work to do than all the NGOs can provide. [...] There is not really competition between them, maybe a little for grants, but they are complementary” (Charles, scientific director affiliated with an international snow leopard conservation NGO). Nevertheless, important differences exist between internationally connected NGOs and nationally embedded organizations. International NGOs generally benefit from greater financial resources, technical expertise, and global visibility, but may also face stronger political sensitivities and restrictions. Conversely, national organizations are often more deeply embedded in local contexts and governance

structures but typically operate with fewer financial resources. These asymmetries create unequal capacities to shape conservation priorities and influence decision-making processes. From a PARTNERS perspective (Mishra et al., 2017), such disparities raise important questions regarding representation, equity, transparency, and responsiveness within the conservation network.

A more structural source of tension emerges from what may be described as governance “shadow zones”, where conservation objectives coexist with competing economic and political interests. While the state promotes the snow leopard as a flagship species and national conservation symbol, it simultaneously supports economic sectors such as mining, infrastructure development, and, to a lesser extent, trophy hunting. These overlapping priorities can generate contradictions between conservation discourse and land-use decisions, particularly when economic development is perceived as a national priority.

These tensions are especially visible in the relationships between conservation actors and extractive industries. Mining activities compete directly with conservation goals through habitat transformation, infrastructure development, and increasing human presence in remote mountain ecosystems. Several interviewees perceived governmental support for extractive projects as stronger than support for conservation initiatives. As one hunting concession manager stated: “The government does not recognize our role in protecting against poaching, and mining companies are even allowed to poach” (Yann, director of a hunting concession located near a protected area). Although this statement reflects a particular stakeholder perspective, it illustrates broader concerns regarding unequal political influence among actors involved in land-use decisions.

From a political ecology perspective, these dynamics demonstrate that conservation is not a neutral technical activity but rather a contested process embedded within broader struggles over resources, territory, and development trajectories. Conservation outcomes are therefore shaped not only by ecological goals, but also by institutional power relations and competing visions of land use. The coexistence of strong symbolic commitments to biodiversity conservation and ongoing support for environmentally transformative activities may even create conditions for forms of symbolic conservation or environmental greenwashing (see Section 2.3.2; Tälle et al., 2023; Horsley et al., 2020).

Overall, these findings suggest that conservation effectiveness depends not only on the strength of partnerships and collaboration mechanisms, but also on the capacity of the network to manage asymmetries, negotiate conflicts, and adapt to competing economic and political pressures. Understanding these tensions is therefore essential for interpreting both the achievements and the limitations of conservation governance within SENSR.

3.1.1.6 Peripheral but revealing actors: hunting companies

Hunting concessions occupy a peripheral yet analytically important position within the snow leopard conservation network. Their role emerged relatively late during fieldwork and was only addressed through a limited number of interviews. Consequently, the analysis presented here should be considered exploratory. Nevertheless, these actors reveal important tensions at the intersection of conservation, rural development, wildlife management, and resource governance.

The place of trophy hunting within conservation remains highly debated and difficult to categorize, a challenge also highlighted by Frietsch et al. (2023). Trophy hunting simultaneously relates to resource use, biodiversity conservation, local livelihoods, and market-based approaches to environmental management. As a result, its contribution cannot be evaluated through a purely ecological or purely ethical lens.

Within interviews, hunting concession managers frequently described themselves as conservation actors rather than exploiters of wildlife: “Hunting companies are, of course, a good way of preserving snow leopards” (Benoit, director of a hunting concession operating near a protected area). This perspective is strongly contested by some conservation practitioners, who question both the ethical legitimacy and ecological sustainability of trophy hunting: “I don't trust this philosophy because humans will always take all they can. Human beings are animals that cannot stop their needs” (Arthur, biodiversity management specialist affiliated with an international conservation NGO active in Central Asia). Alternative proposals include transforming hunting concessions into protected areas, reflecting divergent visions of conservation strategies: “One goal of SLFK is to convert hunting concession to protected area. When you have the agreement of government it is available for ten years, then in many case we start seeing back snow leopards in those territories” (Jules, director, affiliated with a national snow leopard conservation NGO). These contrasting viewpoints reflect fundamentally different conservation philosophies, ranging from strict preservation approaches to models based on sustainable use of natural resources.

From a policy perspective, trophy hunting remains an important component of wildlife management in Kyrgyzstan. Hunting permits for argali and Siberian ibex are allocated through a quota-based system regulated by state authorities and CITES regulations. Revenue generated by these permits is intended to contribute to wildlife management, local development, and anti-poaching activities and to support local communities, and concession management. According to available sources, trophy hunting of argali alone can generate half a million US dollars annually ¹⁰, with portions theoretically redistributed

¹⁰ For tourist trophy hunter it is \$7 000 for an argali permit plus package fees totalling \$11 000 to \$35 000+. <https://blog.bookyourhunt.com/hunting-in-kyrgyzstan-what-you-need-to-know/> (accessed on 10 July 2026)

among state agencies, local communities, and hunting concessions. The law stipulates that 35 percent be earmarked for the salaries of some 60 employees, whose work includes policing and anti-poaching activities. An additional 25 percent is to go to local communities where hunting takes place, and 40 percent to the hunting concessions themselves, to help finance conservation activities ¹¹. However, interviewees frequently questioned the transparency and effectiveness of these redistribution mechanisms. Similar concerns have been raised where conservation costs are often borne by protected areas while financial benefits are captured by a limited number of actors (Zholdosbekov & Hammer, 2025).

As no ecological surveys specifically addressing this issue were conducted during the present study, the following discussion relies primarily on findings from the scientific literature. The ecological effects of trophy hunting appear equally complex. Several studies suggest that well-managed hunting concessions may contribute to conservation by creating economic incentives to protect wild ungulate populations. In Tajikistan, Kachel et al. (2017), with limited data (low detection rates, small sample sizes and a lack of replication), reported higher snow leopard density and a greater proportion of wild prey in hunting concessions compared with neighbouring areas affected by uncontrolled grazing and poaching. Likewise, community-based hunting programmes in Pakistan have been associated with the recovery of ungulate populations and increased local support for wildlife conservation (Nawaz et al., 2016 in Mallon & McCarthy, 2024). Camera-trap studies have even documented higher snow leopard detection rates in some trophy-hunting landscapes (Nawaz et al., 2016 in Mallon & McCarthy, 2024). These positive outcomes are generally attributed to a simple ecological mechanism: hunting companies depend economically on maintaining abundant populations of argali and ibex, which are also the principal prey species of snow leopards. Consequently, one of their core interests partially aligns with snow leopard conservation through the maintenance of a healthy prey base.

However, the literature also highlights important limitations. Trophy hunting is not a conservation panacea, but, in societies where hunting bans cannot be realistically enforced, and where protected areas are limited in space and insufficiently guarded, it is an important and effective approach to create substantial incentives for conservation of mountain ungulates by local people (Michel et al. 2021 in Mallon & McCarthy, 2024). Its effectiveness depends heavily on governance quality, quota setting, transparency, local participation, and long-term monitoring. Weak oversight may result in overharvesting, corruption, unequal benefit sharing, or financial capture by local elites. Several authors therefore stress the importance of transparency, accountability, external monitoring,

¹¹ <https://outofedenwalk.nationalgeographic.org/2017-04-hunting-marco-polo-sheep-kyrgyzstan/> (accessed on 12 January 2026)

community involvement, and adaptive management in hunting-based conservation programmes (Reading & Amgalanbaatar in Mallon & McCarthy, 2024; Michel et al. 2021 in Mallon & McCarthy, 2024; Di Minin et al., 2021; Lindsey et al., 2007; Ochieng et al., 2023).

This governance dimension appears particularly relevant in the Kyrgyz context. Historically, weak regulation contributed to quota exceedance, unauthorized hunting, and poaching within concessions. Although significant legal reforms since 2014 have improved management standards and facilitated the development of community-based conservancies (Michel et al., 2021 in Mallon & McCarthy, 2024), interviewees continued to express concerns regarding transparency, political influence, and the distribution of revenues generated by trophy hunting.

Interestingly, this controversy already appeared in historical documents related to SENSR. The reserve management plan identified adjacent hunting concessions as one of the principal threats to the reserve, arguing that they benefited from wildlife populations maintained within protected areas without contributing significantly to reserve management (SER, 2007). Yet the same document also acknowledged collaborations between conservation actors and hunting operators, illustrating the ambiguous nature of these relationships (as described with rangers as hybrid actor in section 3.1.1.4).

From a socio-ecological perspective, hunting concessions therefore constitute a revealing example of the complexity of conservation governance. Ecologically, they may contribute to maintaining prey populations and reducing poaching under certain conditions. Economically, they provide an alternative land use that may generate incentives for wildlife conservation in regions where ecotourism remains limited. Socially and politically, however, they raise questions about equity, legitimacy, benefit sharing, and power relations between actors.

Ultimately, the case of trophy hunting demonstrates that conservation effectiveness cannot be assessed solely through ecological outcomes. A management strategy may produce positive effects for snow leopard populations while simultaneously generating ethical, social, or governance concerns. Conversely, rejecting trophy hunting on ethical grounds alone may overlook situations in which it contributes to maintaining habitats and wildlife populations in contexts characterized by limited state capacity and few viable economic alternatives. Rather than asking whether trophy hunting is inherently “good” or “bad” for conservation, the evidence suggests that its effectiveness depends primarily on the quality of governance through which it is implemented.¹²

¹² From my position as a biodiversity conservationist, the analysis of hunting companies proved to be the most challenging part of this research. Indeed, this question itself could constitute a research question for another master thesis. This topic raises profound ethical tensions. From a conservation-oriented perspective, trophy hunting initially appears problematic, as it involves the deliberate killing of wildlife for economic gain. However, adopting a more contextualized perspective grounded in the Kyrgyz socio-economic reality complicates this judgment. From the standpoint of local actors seeking to secure

3.1.2 Assess and discuss socio-ecological system

Building on the actor-network analysis, the SENSIR can be conceptualized as a socio-ecological system (SES) in which conservation effectiveness emerges from the interaction between ecological dynamics, governance arrangements, and social practices rather than from any single actor or institution. The preceding analysis revealed a conservation network structured around two central drivers: the symbolic power of the snow leopard, which mobilizes actors and resources across scales, and the pivotal role of NGOs, which translate this symbolic capital into concrete conservation actions.

Within this network, NGOs act as key intermediaries linking different scope actors and filling the gaps of governance. Rangers occupy a particularly important hybrid position, connecting local knowledge and field realities with broader conservation agendas. At the same time, the network is characterized by important asymmetries in power, resources, and influence, as well as tensions surrounding mining development, hunting concessions, state capacity, and the unequal distribution of conservation benefits. These dynamics demonstrate that conservation outcomes are not solely determined by ecological conditions but also by the quality of governance, stakeholder relationships, and the ability of institutions to coordinate competing interests. The actor-network analysis therefore highlights both the strengths and vulnerabilities of the current conservation system. Strong cooperation between NGOs, reserve staff, and local communities contributes to positive conservation outcomes, while dependence on external funding, uneven participation, and competing economic priorities create structural fragilities that may affect long-term effectiveness.

Moving beyond the question of who interacts with whom, the socio-ecological systems perspective allows examination of how these interactions collectively shape conservation outcomes. Following Ostrom's framework (2009) and the conservation

livelihoods and develop economic activities, hunting concessions are not necessarily perceived as inherently “worse” than other forms of development. When compared to extractive industries such as mining—which exploit non-renewable resources and generate long-lasting, large-scale ecological degradation—trophy hunting may even appear, in the long term, as the lesser of several environmental evils. This ambivalence leads to a broader ethical question: what are the acceptable limits of generating profit from nature, particularly if a portion of that profit is redirected toward conservation? The critical issue here is not only whether such redistribution exists in theory, but whether it is effectively and transparently implemented in practice. From what I understood, such redistribution is nevertheless essential to the sustainability of their business, as hunting companies rely heavily on labour and cooperation from local communities. At the same time, the economic model of trophy hunting is intrinsically dependent on maintaining stable and healthy ungulate populations capable of producing large males sought as trophies, which aligned with snow leopard conservation. As discussed in this section, this conservation market-based instrument is dependent of plenty of factors and will always be debated. And if the objective is not only to preserve the snow leopard, but also to ensure social equity, ethical legitimacy, political coherence, and long-term sustainability, which the case in an ideal world, then trophy hunting raises additional concerns.

effectiveness perspective proposed by Ghoddousi et al. (2022), the next section synthesizes these relationships into a broader system-based analysis to identify the principal synergies, tensions, vulnerabilities, and feedback mechanisms influencing the effectiveness SENS through the lens of snow leopard conservation.

3.1.2.1 Structure of socio-ecological system

Within an Ostrom-inspired framework (2009), the SES can be understood through interacting components:

- Resource system: high-altitude mountain socio-ecosystem, including pasture systems, hydrology, and land-use structures
- Resource units: snow leopards, wild prey (ibex, argali), livestock, vegetation (meadows), glaciers, and watercourses
- Governance systems: protected area regulations, national policies, NGO programs, and informal local norms
- Actors: local communities, rangers, NGOs, state institutions, and economic actors (mining, hunting)

As in much socio-ecological systems, the main tensions revolve around territory and financial flows, both of which directly shape conservation outcomes. In terms of the socio-economic and political settings, it is similar to the arena of actor network theory (ANT). In this project, we focused on scientific and government resource policy settings (Figure 14).

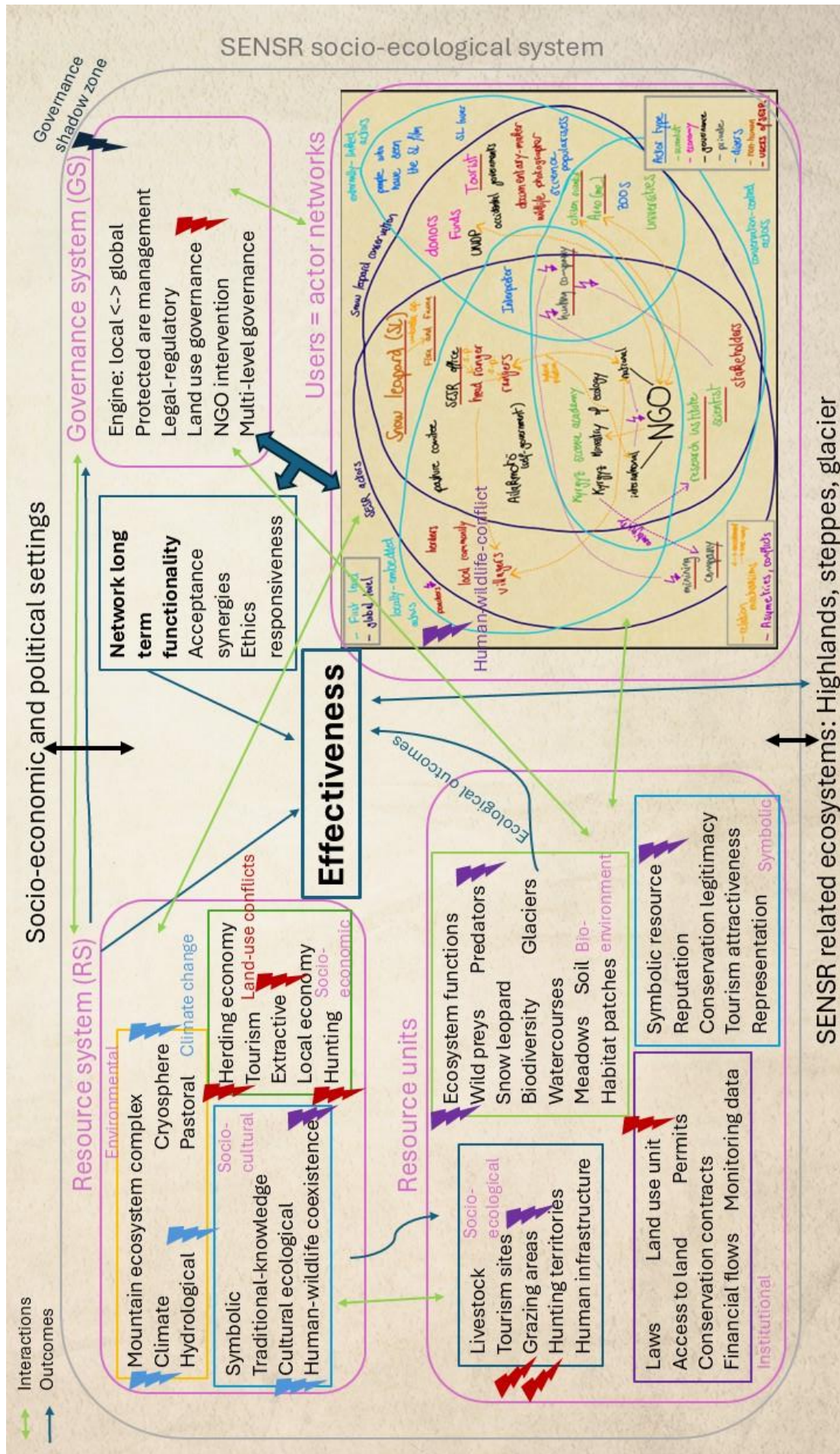


Figure 13: Socio-ecological system of SENSR based on work of Ostrom (2009), conceptualise on Microsoft PowerPoint.

3.1.2.2 Conflicts, threats, and system vulnerability

The socio-ecological system is shaped by a series of interacting threats and conflicts that act as sources of instability and directly influence conservation effectiveness. Rather than operating independently, these pressures are interconnected and mutually reinforcing, contributing to the overall fragility of the system.

Climate change represents an overarching driver that amplifies existing ecological and social challenges. As one interviewee stated, “Climate change is the mother of all other threats; it interacts with them and worsens them” (Jules, director, affiliated with a national snow leopard conservation NGO). This perception is consistent with recent scientific assessments identifying climate change as a major cross-cutting threat to snow leopard conservation. Climate change is expected to affect mountain ecosystems through modifications in snow cover, hydrological regimes, vegetation dynamics, prey distributions, and the frequency of extreme weather events, while simultaneously increasing pressures on local livelihoods and pastoral systems (Kubanychbekov et al., 2026). These environmental changes may reduce tolerance towards wildlife and increase the likelihood of human–wildlife conflict, particularly where pastoral communities face growing economic uncertainty. According to the 2023 Climate Vulnerability Assessment conducted under the Central Asian Mammals and Climate Adaptation project¹³, suitable snow leopard habitat in Kyrgyzstan may increase by approximately 9% under future climate scenarios. However, this apparent expansion is accompanied by declining habitat connectivity caused by upward treeline shifts, contraction of alpine habitats, and increasing fragmentation of high-mountain ecosystems. Such changes may isolate populations and reduce opportunities for dispersal and genetic exchange. Climate-driven modifications are also expected to influence prey distribution and habitat quality, potentially increasing competition between wild ungulates and livestock at higher elevations and bringing snow leopards into closer proximity with human activities (Ghoddousi et al., 2025). Even if this study ecological results don’t show this impact on ungulate population, extreme weather events have already demonstrated their capacity to affect ecosystem functioning through large-scale prey mortality events, such as the ungulate die-off recorded in Issyk-Kul oblast in 2022, with potential cascading effects on snow leopard populations. Furthermore, climate-induced shifts in pathogen distributions may increase disease exposure risks in landscapes where livestock use is expanding (Kubanychbekov et al., 2026).

Beyond climate change, the socio-ecological system is structured by several major tensions that influence both governance and ecological integrity. The expansion of mining activities represents one of the most visible conflicts, as extractive development directly competes with conservation objectives through habitat degradation, infrastructure

¹³ <https://camcaproject.org/> (accessed on 22 October 2026)

expansion, and increasing human presence in remote mountain areas. This tension reflects broader political priorities in which economic development and conservation are often framed as competing objectives rather than complementary ones. This conservation and development dilemma is particularly visible in debates surrounding mining and tourism. Mining projects are frequently presented as opportunities for economic development and employment generation, whereas ecotourism is often promoted by conservation actors as a more sustainable alternative capable of generating long-term benefits while maintaining ecosystem integrity. However, these two pathways may directly conflict with one another. Mining developments can reduce the attractiveness of landscapes for nature-based tourism, while poorly regulated tourism may itself generate environmental impacts and compromise conservation objectives. As one interviewee explained: “We have very good relations with the community and offer opportunities through ecotourism programmes. The goal was to promote ecotourism in the reserve and encourage visitors to spend time in Ush-Koshkon, but with the Chinese mine it is not attractive for tourists because they are currently digging. [...] We also know that if we do not establish the right framework, snow leopard tourism can itself harm nature, so we are working with the government to establish rules and ensure that local communities receive equitable benefits.” (Jules, director, affiliated with a national snow leopard conservation NGO). This quotation illustrates that conservation, tourism, and development should not be viewed as inherently compatible. Rather, their coexistence depends on governance arrangements capable of balancing economic opportunities with ecological and social objectives.

Human-wildlife conflict constitutes another important source of tension within the socio-ecological system. Although the recovery of snow leopard populations is often considered a key indicator of conservation success, it may also increase livestock depredation and exacerbate pressures on pastoral livelihoods. This creates a paradoxical feedback mechanism whereby successful conservation outcomes can generate new social conflicts and weaken local acceptance of conservation measures. Lham et al. (2026) refer to this dynamic as the “perverse effect of conservation success”. This challenge intersects with ongoing transformations in Kyrgyz pastoral systems. Declining support for traditional pastoral practices, changing rural economies, and increasing livestock concentrations in accessible grazing areas have contributed to localized overgrazing in some regions. These processes not only degrade habitat quality for wild ungulates but may also exacerbate competition between livestock and wildlife, thereby reinforcing tensions between conservation objectives and local livelihoods.

Socio-anthropological analysis further suggest that the social legitimacy of conservation initiatives is strongly linked to their perceived capacity to generate tangible benefits for local communities. Acceptance of the reserve and support for conservation measures often depend less on ecological objectives themselves than on the opportunities they create for improving livelihoods. Consequently, the effectiveness of conservation

programmes appears closely linked to mechanisms of economic diversification, benefit sharing, and local participation, many of which are currently facilitated by NGOs. As discussed previously, the success of these initiatives largely depends on the degree of local ownership they generate. This requires early community involvement, trust-based relationships, equitable distribution of benefits, and the ability of projects to persist beyond individual funding cycles.

Taken together, these findings demonstrate that threats to the SENSR socio-ecological system are not solely ecological. They emerge from the interaction of environmental, economic, social, institutional, and political processes. Conservation effectiveness therefore depends not only on protecting biodiversity but also on the capacity of the system to negotiate conflicts, maintain social legitimacy, and adapt to evolving pressures and competing development trajectories.

An additional vulnerability concerns the system's capacity to identify emerging challenges and adapt its management accordingly. Within the PARTNERS framework, this dimension corresponds to the principles of responsiveness and aptness, referring to the ability of conservation actors to recognize threats, learn from experience, and adjust management actions when necessary (Mishra et al., 2017). The present analysis suggests that this adaptive dimension remains only partially developed within SENSR. Interviews revealed recurring concerns regarding the limited integration of scientific research into management decisions and the apparent distance between administrative leadership and field realities: "There is almost no scientific work in the reserve, it need scientific research... but scientific employee is always sitting in office. People of academia of science just did very little." (Julien, ranger, working in protected area management). Several respondents emphasized that ecological knowledge and practical expertise were concentrated among rangers and local actors, while strategic decision-making remained weakly connected to on-the-ground observations. This ecological knowledge and data collected are poorly used in SENSR management: "I warned several times the reserve office about camera-trap evidence, scientific concerns, and risks of flooding caused by a landslide. I never received any reaction, and I am not even sure they read the reports before transmitting them to higher authorities" (Morgane, director and educator involved in a citizen science programme). This concern is reinforced by the fact that the reserve's management plan has not been substantially updated since 2007. Interestingly, many priorities identified nearly two decades ago remain highly relevant today, including strengthening scientific research, expanding ecological corridors toward Jangart, improving collaboration with academic institutions, and increasing engagement with local communities (SER, 2007). The persistence of these recommendations, despite their continued recognition by conservation actors, suggests a limited capacity of the system to translate identified challenges into long-term institutional change. From a socio-ecological perspective, this represents a potential weakness for reserve effectiveness, as

the ability to respond and adapt to evolving environmental, social, and political pressures is a key condition for long-term conservation success.

Finally, a second and often overlooked source of vulnerability concerns the symbolic power of the snow leopard itself. Throughout this study, the snow leopard emerged as a powerful flagship species capable of mobilizing funding, political attention, public support, and conservation action across scales. However, this symbolic capital cannot be taken for granted. As Charles (scientific director, affiliated with an international snow leopard conservation NGO) emphasized, the effectiveness of the snow leopard as a conservation flagship depends on its ability to remain connected to broader societal benefits, including local livelihoods, economic opportunities, and human well-being. As he noted, without these connections, “the snow leopard risks becoming just another species.” In other words, the species retains its mobilizing power only as long as conservation actors succeed in demonstrating its relevance beyond biodiversity conservation alone. The loss of this symbolic and strategic value could weaken political commitment, reduce funding opportunities, and ultimately diminish public support for conservation initiatives. This highlights that, much like NGO support, the flagship status of the snow leopard constitutes both a strength and a potential source of fragility within the socio-ecological system. A further challenge with flagship status, that it may also encourage forms of selective conservation by directing attention toward a single charismatic species at the expense of broader ecosystem processes. Such an approach risks overlooking less visible but equally important components of ecosystem functioning, including glacier dynamics, vegetation change, water resources, and climate-induced ecological transformations.

3.1.2.3 Snow leopard central at socio-ecological system scale

The snow leopard thus occupies a central position within the socio-ecological system: its symbolic power enables mobilization within the actor network, while its ecological role as a key resource unit and umbrella species supports both ecosystem functioning and local economic systems such as tourism. It plays a central integrative role, linking ecological dynamics, local livelihoods, political narratives, and international conservation agendas. This dual function generates a relational dynamic that links ecological processes, governance mechanisms, and social legitimacy, making the snow leopard a biological as well as socio-political cornerstone of the system.

In practice, the snow leopard also functions as a visible indicator of conservation success, as its increased presence is often interpreted by actors as a direct sign of reserve effectiveness.

Furthermore, from an effectiveness perspective, the snow leopard fulfils many of the conditions required for successful conservation promotion. Its aesthetic qualities, rarity, restricted geographic range, and association with high mountain landscapes confer a strong sense of uniqueness and mystique. Even among locally embedded actors who

emphasize that all species are equally important, the snow leopard clearly evokes a particular emotional response that “does not leave people indifferent.” Rather than rejecting this symbolic concentration, many actors view it pragmatically and argue that it should be mobilized positively.

Ecologically, this symbolic legitimacy is reinforced by scientific justification. As both a keystone and an umbrella species, snow leopard conservation supports broader ecosystem integrity. Protecting its habitat indirectly benefits a wide range of high-altitude species and ecological processes. This dual symbolic–ecological status substantially facilitates fundraising, awareness-raising, and international cooperation. Compared to less charismatic species, conservation initiatives centred on the snow leopard more easily attract donor support, including international recognition and funding mechanisms such as UNDP programs.

The species also faces multiple, well-documented threats that help justify sustained investment: high sensitivity of mountain ecosystems to climate change, very low genetic diversity (Solari et al., 2025), and its position as a top predator responsible for regulating trophic dynamics. These factors further consolidate its central role in conservation discourse. In addition, snow leopard conservation aligns with national strategies aimed at strengthening tourism development and enhancing Kyrgyzstan’s international visibility: particularly important for a post-Soviet country often homogenized within the broader “-stan” region. Notably, snow leopard conservation contributes to as many as 13 Sustainable Development Goals, reinforcing its political and financial attractiveness.

Crucially, this conservation system benefits from the presence of a dense and motivated NGO network, whose technical capacity, long-term engagement, and relative trust from political authorities contribute significantly to the durability of snow leopard conservation efforts. This shows that it links local case to global governance reinforcing symbolic power, funding logic and political ecology.

3.1.2.4 Governance constraints and shadow zones

A central characteristic of the SENSR socio-ecological system is the coexistence of ambitious conservation objectives with limited implementation capacity. While Kyrgyzstan occupies a visible position within the international snow leopard conservation community, conservation governance on the ground remains constrained by shortages of financial resources, technical capacity, and long-term strategic planning.

Several interviewees emphasized the symbolic importance of Kyrgyzstan, and particularly Bishkek, within global snow leopard conservation. This perception is partly linked to the historical role of Kyrgyzstan in launching the Global Snow Leopard and Ecosystem Protection Programme (GSLEP) and to the continued presence of major conservation organizations and international meetings in Bishkek. Such visibility brings funding opportunities, expertise, and international recognition. However, it also raises

questions about the extent to which international conservation commitments are translated into effective implementation on the ground.

The governance structure of the system can therefore be characterized as highly collaborative but institutionally fragile. Numerous conservation activities depend on external actors and project-based funding, while state institutions often face difficulties in ensuring long-term continuity, coordination, and monitoring. As noted by Koustubh Sharma (scientific director of SLT), government involvement remains essential because only public institutions possess the mandates, resources, and capacity necessary to ensure the long-term scalability and sustainability of conservation programmes.¹⁴

Historical documents reveal both progress and persistent challenges. The 2007 management plan already emphasized community participation, awareness-raising, scientific monitoring, anti-poaching measures, and local incentive programmes (SER, 2007). Interviews suggest that several of these objectives have produced tangible improvements, particularly regarding local awareness and community engagement. Nevertheless, many priorities identified almost two decades ago remain relevant today (as described in section 2.2.3), suggesting that implementation has progressed more slowly than anticipated.

A major source of vulnerability emerges from what may be described as governance "shadow zones", where conservation objectives coexist with competing economic priorities. A key structural constraint lies within the land-use governance system, where the absence of a coordinated pastoral management framework limits the effective distribution of grazing pressure. In practice, this results in uneven patterns of use, with some areas experiencing overgrazing while others remain underutilized. This imbalance reflects both the fragility of centralized governance capacities and the limited development of multi-level coordination mechanisms linking local practices to national regulation. On the one hand, the snow leopard is promoted as a flagship species and national symbol. On the other hand, state development strategies continue to support extractive industries and major infrastructure projects that may directly threaten mountain ecosystems. Recent proposals for iron mining in the Jetim mountain range and the development of transport corridors linking Kyrgyzstan and China through the Bedel Pass illustrate these tensions (Zholdoshbekov & Hammer, 2025). Similar concerns were repeatedly raised during interviews regarding mining projects located near ecological corridors and important snow leopard habitats. These projects reflect broader trade-offs between economic growth and environmental protection, creating uncertainty regarding the long-term coherence of conservation policy.

¹⁴ <https://www.ethicalconservation.org/resources/#https://vimeo.com/908190475?fl=pl&fe=sh>
(accessed on 26 April 2026)

Another governance limitation concerns the relationship between knowledge production and decision-making. Despite the large amount of ecological information produced through research programmes, camera trapping, citizen science initiatives, and ranger observations, several interviewees described difficulties in translating this knowledge into management actions. While traditional threats such as poaching appear relatively well understood, more complex issues such as mining expansion, climate change, habitat connectivity, and infrastructure development remain insufficiently addressed through adaptive governance mechanisms.

As Charles (Charles, scientific director, affiliated with an international snow leopard conservation NGO) succinctly stated: “Snow leopard conservation does not need more laws, but better enforcement.”

Ultimately, the principal governance challenge facing the SENSr socio-ecological system appears not to be the absence of conservation policies, but rather the difficulty of translating existing knowledge, regulations, and conservation commitments into coordinated and adaptive action. The effectiveness of the reserve therefore depends not only on its ecological performance, but also on its capacity to navigate these institutional weaknesses and reconcile conservation objectives with competing development priorities.

3.1.2.5 Rangers and the institutionalization of conservation

As highlighted in the previous section, rangers occupy a key position within the conservation system. In the broader socio-ecological perspective, their role is best understood not only through their intermediary position within the actor network, but also through their capacity to anchor conservation practices within local territorial realities.

While their strong local embeddedness can entail certain risks, such as informal practices or selective enforcement, interviewees generally emphasized that the advantages outweigh these limitations. As Charles (scientific director, affiliated with an international snow leopard conservation NGO) noted, “for rangers coming exclusively from local communities, the pros outweigh the cons.” Rangers are typically recruited from nearby villages and are often former shepherds, hunters, or individuals with extensive experience in mountain environments, some former poachers had even been recruited as rangers as part of earlier conservation initiatives (Morgane, director and educator involved in a citizen science programme on snow leopard conservation). Their detailed knowledge of the territory, wildlife movements, and local social dynamics enables them to manage conflicts pragmatically and maintain a degree of compliance that formal institutions alone could not achieve.

However, this local expertise is rarely accompanied by formal professional training. Most rangers receive no specialized conservation or ecological education from the state institutions that employ them. Training opportunities are generally provided by NGOs and

external conservation organizations rather than by governmental agencies (Morgane, director and educator involved in a citizen science programme on snow leopard conservation). As a result, conservation management continues to rely heavily on experiential knowledge and individual initiative rather than on institutionalized professional qualifications.

This effectiveness therefore remains contingent. Current reliance on NGO support, combined with limited institutional integration, reveals a structural weakness within the system. A major constraint lies in the insufficient professionalization of the ranger profession, which limits both management capacity and the long-term resilience of conservation efforts. As noted throughout the analysis, strengthening conservation ultimately requires strengthening the people responsible for implementing it on the ground.

Several rangers expressed a clear aspiration to move beyond a purely operational role and develop stronger scientific competencies. As Diego (ranger, working in protected area management) explained: “I wish to have higher education in ecology in order to have deeper understanding... now I feel I miss knowledge and cannot impact decision-making.” He further emphasized the importance of this transition for future generations: “If my children want to be ranger, I will do my maximum to offer them an ecological education to bring more scientific work into this profession.”

In this perspective, professionalization appears as a key lever for the institutionalization of conservation within the socio-ecological system. Strengthening training opportunities, improving working conditions, and increasing integration within scientific and administrative structures would not only improve ecological monitoring and enforcement capacity but also reduce the current dependence on external actors. Interestingly, this challenge is not new. The 2007 management plan already identified professionalization as a priority and recommended increasing ranger salaries, improving technical infrastructure, providing continuous training, and attracting highly qualified staff to the reserve (SER, 2007). Nearly two decades later, many of these recommendations remain highly relevant, suggesting that while conservation activities have evolved, the structural challenges surrounding ranger capacity and professional development have changed only gradually: “Rangers working in remote mountain areas face severe logistical challenges, including difficult terrain, limited transport, inadequate communication infrastructure, and harsh climatic conditions. These factors restrict patrol coverage and limit timely responses to illegal activities.” (Kubanychbekov et al., 2026). This continuity further illustrates the difficulty of translating recognized management needs into long-term institutional reforms.

3.1.2.6 Socio-ecological effectiveness as a relational outcome

The assessment of the SENSR socio-ecological system demonstrates that conservation effectiveness cannot be understood as a single outcome or measured uniformly across

the system. Different components of the SES generate distinct outcomes, which interact with and influence one another. This perspective allows a broader understanding of conservation effectiveness by identifying not only successes but also the principal vulnerabilities and priorities for future action.

At the ecological level, the reserve appears to remain functional. The ecological assessment provided no indication of major ecosystem degradation at the resource unit's level. Wild ungulates and large carnivores continue to occur throughout the reserve, reproduction was documented across several taxa, and SCR analyses suggested a relatively stable snow leopard population over the monitoring period. Many interviewees further described SENSr as a core refuge or "nursery" for snow leopards within the Central Tien Shan, characterized by reduced disturbance, active anti-poaching efforts, and relatively abundant prey populations. These findings support the conclusion that the reserve currently fulfils its primary ecological role of maintaining suitable conditions for snow leopard persistence.

However, ecological effectiveness represents only one dimension of system performance. The socio-anthropological analysis revealed that conservation outcomes emerge from a complex combination of governance arrangements, social acceptance, economic incentives, and symbolic values. Conservation success appears to result from the co-production of material incentives and social norms rather than from either dimension alone. Alternative livelihood programmes, conservation-linked benefit-sharing mechanisms, and the symbolic value of the snow leopard have contributed to embedding conservation within local social relations. Importantly, some conservation practices persisted even after specific NGO programmes were discontinued, suggesting a degree of local ownership and partial internalization of conservation values.

The actor network analysis further revealed both strengths and vulnerabilities. Strong cooperation among NGOs, rangers, local communities, researchers, and conservation agencies has generated significant conservation outcomes despite limited governmental capacity. Yet this same configuration exposes important structural fragilities. Conservation implementation remains heavily dependent on NGO involvement, external funding, and a limited number of highly committed individuals. Consequently, many conservation functions currently rely on actors operating outside formal state structures. The network therefore appears functional but only partially institutionalized, raising questions about its long-term sustainability.

The analysis also highlighted several persistent tensions within the system. Land-use conflicts emerged repeatedly as one of the central challenges affecting conservation effectiveness. Mining development, infrastructure expansion, tourism ambitions, pastoral activities, and wildlife conservation all compete for access to the same landscapes and resources. Human-wildlife conflicts similarly reflect tensions between resource users and conservation objectives, particularly regarding livestock predation

and competition between domestic and wild ungulates for grazing resources. These conflicts do not necessarily undermine conservation directly, but they continuously shape the conditions under which conservation actors must operate.

From a governance perspective, the system demonstrates a capacity to function despite substantial limitations but shows weaker performance regarding long-term adaptability and responsiveness. Many challenges identified in the 2007 management plan remain relevant nearly two decades later, including ranger professionalization, scientific integration, community engagement, and coordination among actors. This continuity suggests that while conservation actions have continued, institutional learning and structural reform have progressed more slowly. Effectiveness therefore appears stronger in terms of implementation than in terms of adaptive governance.

The assessment also revealed that the two pillars identified throughout this study: the central role of NGOs and the symbolic power of the snow leopard, are simultaneously strengths and sources of fragility. The current functioning of the system depends heavily on both. Should NGO funding decline or political priorities shift, conservation capacity could be significantly affected. Likewise, the snow leopard currently functions as a powerful flagship species capable of mobilizing public attention, funding, and political support. Yet, as some interviewees noted, this symbolic value depends on maintaining visible links between conservation, local livelihoods, and human well-being. Without these connections, the species risks losing part of its ability to mobilize resources and support.

An additional contribution of this study lies in the interdisciplinary approach adopted to assess conservation effectiveness. By confronting ecological monitoring results, socio-anthropological interviews, and findings from the scientific literature, it becomes possible to identify both convergences and discrepancies among different sources of knowledge. Such discrepancies should not necessarily be interpreted as contradictions, but rather as opportunities to generate new research questions and improve our understanding of socio-ecological dynamics. A particularly illustrative example concerns the extreme snow event (*jut*) that affected parts of Kyrgyzstan in 2022 (Kubanychbekov et al., 2026). Both the literature and interviewees described this event as having severe consequences for wild ungulate populations, with potential cascading effects on snow leopard ecology. Rangers consistently reported substantial mortality among prey species and expressed concerns regarding increased predation on livestock following the event. As one ranger explained: “Argali suffered the most. There were around 3,500 individuals before the *jut* and only around 1,500 afterwards. Ibex were less affected because they live at higher elevations [where steep slopes prevent snow accumulation and allow access to food]. For sure there are consequences for snow leopards, and the increase in attacks on livestock is linked to this event” (Diego, ranger, working in protected area management). However, the ecological analyses conducted in this study, particularly those based on

citizen science monitoring data, did not reveal such dramatic population declines. Although these datasets have limitations and cannot be considered definitive evidence, the contrast between local observations, expert perceptions, and ecological monitoring is itself highly informative. It highlights the value of combining multiple sources of knowledge rather than relying on a single analytical approach.

More broadly, this example illustrates how interdisciplinary research can strengthen conservation assessments by revealing uncertainties, identifying knowledge gaps, and generating hypotheses that would remain invisible within a purely ecological or social analysis. In the present case, the apparent discrepancy between local perceptions and monitoring results suggests that the ecological consequences of the 2022 snow extreme events may not yet be fully understood and deserve further investigation. This question is particularly relevant given climate projections indicating an increasing frequency and intensity of extreme climatic events in Central Asian Mountain ecosystems, with potentially significant implications for ungulate populations, predator-prey dynamics, and human-wildlife interactions.

Overall, the SENSR socio-ecological system can therefore be characterized as ecologically functional, socially legitimate in many respects, but institutionally fragile. Conservation effectiveness emerges not from a single actor, policy, or ecological indicator, but from the continuous interaction between ecological processes, governance structures, social relations, and economic realities. The system currently succeeds in maintaining positive conservation outcomes, yet its long-term resilience remains constrained by governance weaknesses, land-use conflicts, and dependence on external actors and funding mechanisms.

Finally, it is important to recognize that the present assessment captures only part of the complexity of the socio-ecological system. The analysis was deliberately centred on snow leopard conservation as a lens through which to evaluate reserve effectiveness. Additional assessments of ecosystem functions, habitat connectivity, biodiversity dynamics, socio-economic transformations, and political processes would further enrich this understanding. In this regard, Ostrom's framework (2009) proved particularly valuable by providing a structure capable of integrating multiple dimensions and scales of analysis. More importantly, it demonstrates that conservation effectiveness should not be understood as a fixed state, but as a dynamic and relational outcome continuously produced through negotiation, adaptation, and the management of competing ecological, social, and economic interests.

3.2. Interdisciplinary discussion of the research question

3.2.1. Are snow leopards a relevant lens for assessing protected-area effectiveness?

A central methodological choice of this thesis was to evaluate the effectiveness of the Sarychat-Eertash Nature State Reserve (SENSR) through the lens of snow leopard conservation. This choice inevitably simplifies the complexity of the socio-ecological system by focusing on a single species. However, the results of both the ecological and socio-anthropological analyses suggest that this simplification is largely justified, provided its limitations are explicitly acknowledged.

First, the scientific literature strongly supports the snow leopard's status as a flagship species, while providing substantial, though somewhat less unequivocal, support for its role as an umbrella species. By contrast, its designation as a keystone species remains more speculative and should be used with caution. Keystone species are characterized by ecological impacts that are disproportionate to their abundance, typically demonstrated through quantitative analyses of trophic interactions and ecosystem functioning. While the snow leopard occupies the position of apex predator in Central Asian Mountain ecosystems, no study has yet formally demonstrated its keystone role through food-web analyses comparable to those conducted for other large carnivores such as tigers (Sun et al., 2024). As Mallon & McCarthy (2024) note, many assertions regarding the snow leopard as a keystone species remain largely inferential and are extrapolated from studies of better-known apex predators rather than directly demonstrated. Consequently, although the species likely exerts important ecological influences across multiple trophic levels, current evidence remains insufficient to firmly classify it as a keystone species.

The situation is considerably clearer regarding the concepts of flagship and umbrella species. Flagship species are primarily social and political tools used to mobilize public support, conservation funding, and institutional commitment (Xu et al., 2022). Throughout this study, the snow leopard repeatedly emerged as a symbol around which conservation actors, funding mechanisms, and public narratives are organized. The socio-anthropological analysis revealed its central role in attracting NGOs, international donors, government attention, and local conservation initiatives. This finding aligns closely with Jepson & Barua (2015) argument that flagship species derive their effectiveness from their ability to connect with pre-existing cultural narratives and social values. In Kyrgyzstan, the snow leopard has clearly transcended its biological identity to become a cultural and political symbol of mountain ecosystems and national natural heritage.

Moreover, the species fulfils many of the criteria generally associated with umbrella species. Its large home ranges, dependence on extensive mountain landscapes, and requirement for abundant populations of wild ungulates mean that maintaining viable snow leopard populations necessitates the protection of large areas and multiple ecological components. Consequently, conserving snow leopards indirectly protects numerous other species and ecosystem functions (Snow Leopard Survival Strategy, 2014; (Mallon & McCarthy, 2024). Nevertheless, the umbrella-species concept itself remains debated. Meta-analyses indicate that umbrella species do not always provide consistent conservation benefits and that their effectiveness must be evaluated within specific ecological contexts rather than assumed a priori (Branton & Richardson, 2011; Yang et al., 2023). Therefore, while the snow leopard appears to function as a meaningful umbrella species in the Central Asian mountain context, this role should not be considered universally applicable.

Taken together, these elements suggest that the snow leopard is best understood as both a flagship species and an umbrella species. Its flagship function explains its exceptional capacity to mobilize conservation action, while its umbrella function justifies the use of its conservation status as an indicator of broader ecosystem integrity. This dual role provides a strong rationale for using snow leopard conservation as an entry point for assessing protected-area effectiveness.

However, this choice should not obscure important limitations. As emphasized by Mallon & McCarthy (2024), mountain ecosystems do not fundamentally depend on snow leopards in the same way that snow leopards depend on functioning mountain ecosystems. The species does not directly maintain water resources, regulate vegetation dynamics, or sustain ecosystem productivity. What it contributes above all is symbolic value. Snow leopards embody cultural, aesthetic, and political meanings that facilitate conservation action. In this sense, the effectiveness of snow leopard conservation cannot automatically be equated with the effectiveness of ecosystem conservation as a whole.

This point became particularly evident through the socio-ecological analysis. The reserve appears successful in maintaining snow leopard populations, wild prey, and relatively intact ecological processes. Yet many of the major governance challenges identified during this research, including mining expansion, pastoral management, local livelihoods, institutional weaknesses, climate change, and tourism development, extend far beyond the conservation of a single species. Assessing effectiveness exclusively through the snow leopard therefore risks overlooking other critical dimensions of ecosystem functioning and environmental governance.

The case of the wolf illustrates this limitation particularly well. Although largely absent from conservation narratives and international funding programmes, wolves occupy an important ecological and social position within the system. Several studies have shown that local attitudes toward snow leopards are strongly influenced by perceptions of

wolves and patterns of livestock depredation (Suryawanshi et al., 2013). In some contexts, efforts that favour snow leopard conservation may also indirectly benefit wolf populations, potentially increasing human-carnivore conflicts and creating social tensions that are not captured by a snow leopard-centred perspective (Augugliaro et al., 2025; Chetri et al., 2020). This demonstrates that even highly effective flagship species can simplify ecological realities and obscure important interactions within the broader socio-ecological system.

Ultimately, the present study suggests that snow leopard conservation provides a highly relevant, but incomplete, lens through which to assess protected-area effectiveness. It offers a powerful entry point because it simultaneously links ecological integrity, social acceptance, political support, international funding, and governance processes. Few species can connect so many dimensions of conservation within a single analytical framework.

3.2.2. Is land sparing necessary for snow leopard conservation?

The present study was not designed to directly test the relative merits of land sparing and land sharing approaches for snow leopard conservation. Addressing this question would require comparative studies across multiple landscapes, conservation regimes, and socio-ecological contexts. Nevertheless, the ecological and socio-anthropological results obtained here provide several insights that contribute to this broader debate.

At first sight, the results from SENSr appear to support the importance of land sparing strategies. Despite the methodological limitations discussed previously, the reserve hosts a reproductively active snow leopard population, relatively abundant wild prey populations, low levels of direct human disturbance, and some of the highest density estimates reported for the species. Whether these density estimates fully reflect ecological reality or are partially influenced by methodological factors, all available evidence points toward SENSr functioning as an important refuge for snow leopards within the Central Tien Shan. This observation is particularly relevant because snow leopards require extensive and relatively undisturbed landscapes. Johansson et al. (2016) showed that many protected areas across the species' range are smaller than the home range of a single adult male and therefore incapable of supporting even a reproducing pair in isolation ($615 \pm 319 \text{ km}^2$ for male adult; $327 \pm 200 \text{ km}^2$ for female adult with minimum convex polygon methods in Johansson et al., 2016). Similarly, the GSLEP framework considers that a healthy snow leopard population should include at least 100 breeding age individuals, adequate prey populations, and connectivity with neighbouring populations¹⁵. These criteria highlight that protected areas alone are rarely sufficient and that connectivity across larger landscapes remains essential.

¹⁵ <https://globalsnowleopard.org/what-is-gslep/gslep-goals/20by2020/> (accessed on 14 March 2026)

From this perspective, SENSR may be viewed as a successful example of land sparing. The reserve provides a relatively secure area where snow leopards, ibex, and argali can reproduce with limited human disturbance. Such refuges may serve as population reservoirs from which individuals disperse into surrounding landscapes. However, the results also indicate that this role depends on the existence of functional ecological corridors capable of maintaining demographic and genetic exchange with neighbouring populations. Without connectivity, even highly protected reserves may eventually become isolated. At the same time, the findings clearly demonstrate the limits of a purely land-sparing approach. Snow leopards frequently move beyond protected-area boundaries, and many of the threats identified in the socio-ecological analysis, including pastoral expansion, mining projects, infrastructure development, tourism, and human-wildlife conflict, occur outside the reserve itself. Consequently, long-term conservation cannot rely exclusively on protected areas. A land-sharing perspective remains necessary because coexistence between humans and wildlife ultimately determines the permeability of the wider landscape.

This conclusion aligns with Johansson et al. (2016), who argued that the large home ranges of snow leopards require a combination of land sparing and land sharing implemented at the scale of entire landscapes. However, such conclusions should not be accepted uncritically. Much of the current argumentation in favour of land sharing is based on relatively limited empirical information regarding snow leopard home-range requirements, population viability, and responses to different land-use regimes. Home-range size varies considerably among regions and individuals according to prey availability, habitat structure, human disturbance, and environmental conditions. Similarly, despite its frequent use in conservation planning, the minimum viable population thresholds proposed under the GSLEP framework remain partly normative and continue to be debated. Further research is therefore required before definitive recommendations can be made regarding the optimal balance between land sparing and land sharing.

Another important lesson emerging from this study is that even within a land-sparing framework, human dimensions remain central. The socio-ecological analysis repeatedly demonstrated that conservation effectiveness depends on local acceptance, economic opportunities, environmental education, and community engagement. Strict protection did not produce conservation outcomes independently of society; rather, these outcomes emerged through continuous interactions among reserve staff, NGOs, local communities, and governmental institutions. In this regard, the findings support the broader literature on community-based conservation, which shows that successful conservation initiatives generally combine biodiversity protection with livelihood improvements, institutional capacity building, and participatory governance (Brooks, 2017).

This conclusion is particularly relevant for large carnivore conservation. Social legitimacy, trust among stakeholders, and communication between institutions and local communities often determine whether conservation measures are accepted or resisted (Salvatori et al., 2020). Moreover, socio-economic shocks such as economic crises, political instability, pandemics, or climate-related disasters may rapidly alter the balance of socio-ecological systems and undermine conservation gains if local communities do not perceive benefits from conservation (Murali et al., 2025). Emerging research further emphasizes that attitudes toward carnivores are shaped not only by material costs but also by psychological and cultural dimensions such as emotions, beliefs, risk perception, and social identity (Monfared et al., 2026). These dimensions were not explicitly assessed in this study and represent promising avenues for future research.

Finally, maintaining some strictly protected areas may also provide a safeguard against emerging pressures associated with tourism development. Although ecotourism is often presented as a desirable alternative to extractive industries and was widely supported by locally embedded actors interviewed during this study, conservation-centred actors expressed greater caution. Recent literature highlights the paradox that tourism, including wildlife tourism centred on snow leopards, may simultaneously support conservation while contributing to habitat disturbance, increased infrastructure development, and additional carbon emissions (Rigzin, 2025). Consequently, maintaining areas where conservation remains the primary objective may become increasingly important as tourism expands across mountain landscapes.

An additional point emerging from this study concerns the notion of strictness itself. Although SENSr is officially designated as a strictly protected area, the socio-ecological analysis suggests that the reality is more nuanced. Conservation activities, scientific monitoring, ranger operations, and increasingly discussions surrounding ecotourism all create forms of human presence within the reserve. From this perspective, strict protection should not be understood as the complete exclusion of human activities, but rather as a negotiated balance between conservation objectives and controlled uses of the landscape. This observation raises an important question: to what extent is the current level of protection necessary to maintain SENSr as a refuge where snow leopards can reproduce and from which individuals may subsequently disperse into the wider landscape? While this remains fundamentally a land-sparing model, interviews revealed growing debates regarding the future use of the reserve, particularly in relation to snow leopard tourism and wildlife photography. As one interviewee explained: “The current law and land-use zoning of the reserve were not designed for tourism development, nor even in the buffer zone. If tourism is to be developed, the zoning system will need to change. We are currently discussing these issues with the SENSr administration” (Jules, director, affiliated with a national snow leopard conservation NGO). Interestingly, similar discussions were already present in the 2007 management plan, which identified both the opportunities and risks associated with increasing tourism pressure around the

reserve. While ecotourism was viewed as a potential source of income for local communities and reserve management, the plan also warned that growing visitor numbers could create tensions between tourism development and environmental protection if not carefully regulated (SER, 2007). These debates therefore appear to be long-standing rather than recent.

The question of strictness also emerged indirectly through discussions surrounding scientific access to the reserve. Some interviewees expressed concerns that research programmes involving external participants, including citizen science initiatives such as OSI-PANTHERA¹⁶, might be perceived as privileged access to areas that remain closed to most visitors. Although such programmes serve clear conservation and scientific objectives, perceptions of unequal access may generate tensions and potentially weaken the legitimacy of restrictions imposed on other users. More broadly, this illustrates how the effectiveness of strict protection depends not only on ecological outcomes but also on the social legitimacy of the rules governing access to protected spaces.

Consequently, the debate is perhaps not whether SENSr should remain strictly protected or become fully integrated into a land-sharing approach. Rather, the challenge lies in determining which activities can be accommodated without compromising the ecological conditions that currently make the reserve an important refuge for snow leopards and other mountain wildlife.

Overall, the results of this study do not support the view that either land sparing or land sharing alone can ensure long-term snow leopard conservation. Instead, they suggest that effective conservation requires a combination of both approaches. Large, well-protected reserves such as SENSr appear essential for maintaining core populations and ecological processes, while multifunctional surrounding landscapes remain necessary to ensure connectivity, coexistence, and long-term social legitimacy. The challenge for future conservation planning is therefore not choosing between land sparing and land sharing but determining how these two approaches can be effectively combined within a coherent socio-ecological framework and bring more advanced research to make evidence-based decision and action.

¹⁶ From my own experience and perspective and as in part developed in section 1.5.5, one of the main weaknesses of OSI-PANTHERA is the limited valorisation of the data they collect. They gather substantial material through camera traps and transect, yet the communication and long-term scientific use of these data seem underdeveloped. In my view, one priority should be to reinvest part of their income into better data dissemination—both toward local stakeholders and within the scientific community. This could involve stronger partnerships with academic institutions, such as universities, in order to build long-term research projects that combine citizen science with more rigorous scientific design. Such collaboration could improve sampling methods, data interpretation, and publication, while also strengthening the legitimacy of their work. It could also help address another concern: the potential impact of bringing foreign participants into the strict zone of the reserve. Even if framed as citizen science, allowing tourism activities in highly protected areas may weaken the original purpose and effectiveness of the reserve. Without clearer scientific protocols and institutional partnerships, this access risks appearing more justified by financial logic than by conservation necessity.

3.2.3. How to reconcile development and conservation within an effective socio-ecological system?

One of the most recurrent themes emerging from this research concerns the apparent opposition between economic development and environmental protection. However, the socio-ecological assessment suggests that this tension cannot be reduced to a simple binary choice between conservation and development. Rather, it reflects a broader governance challenge involving competing interests, unequal power relations, institutional capacities, and societal aspirations. This section should therefore be understood as a reflexive exploration of a much wider debate rather than an attempt to provide definitive answers. This question is particularly relevant in the Kyrgyz context. As a post-Soviet state still undergoing economic, institutional, and political transformations, Kyrgyzstan faces development priorities that differ substantially from those of many wealthier countries. Improving employment opportunities, attracting investments, developing infrastructure, and increasing living standards remain legitimate policy objectives. Consequently, conservation cannot be analysed independently from the broader socio-economic realities within which it is embedded. Exploring this dilemma in depth would constitute a research topic in its own right. Drawing on the results obtained in SENSR, it aims to identify key points of discussion and future research directions regarding how societies negotiate the coexistence of conservation objectives and development ambitions within complex socio-ecological systems.

A major finding of this research is that the effectiveness of conservation cannot be understood solely through ecological indicators. As Evrard and Lascoumes (2024) argue, environmental issues are fundamentally matters of public action, requiring continuous arbitration between competing objectives and actors. The challenge is therefore not only to conserve biodiversity, but also to understand how conservation is negotiated, implemented, financed, and legitimized within a broader socio-ecological system. In this perspective, environmental effectiveness becomes a product of governance rather than the simple outcome of ecological protection.

The case of ecotourism illustrates this complexity particularly well. Recent initiatives developed around snow leopard observation demonstrate the potential economic benefits that conservation can generate. According to the Snow Leopard Foundation Kyrgyzstan, tourism programmes provide employment opportunities for rangers, guides, cooks, and guesthouse owners while contributing directly to conservation funds and reserve management. At the same time, tourism has contributed to increasing the perceived value of wildlife among local communities, transforming species previously regarded as nuisances into potential economic assets. Consequently, the debate is not simply whether tourism should be promoted, but under which conditions and governance structures it can remain compatible with conservation objectives.

In many cases, the challenge is not the absence of environmental regulations but the difficulty of implementing them consistently. This observation mirrors one of the central conclusions of the present study: snow leopard conservation in Kyrgyzstan suffers less from a lack of legal protection than from difficulties related to coordination, enforcement, and governance capacity. Mining projects, ecological corridors, tourism development, climate adaptation, and community engagement all illustrate situations where the issue is not whether conservation is desirable, but how competing priorities are negotiated.

Seen from this perspective, the conflicts observed between conservation and development should not necessarily be understood as failures of governance. As Evrard and Lascoumes (2024) argue, environmental governance is inherently characterized by conflicts among legitimate interests. In the case of SENSr, these conflicts involve conservation organizations, local communities, pastoralists, tourism operators, mining interests, state institutions, and international actors. The objective is therefore not to eliminate conflicts but to create governance systems capable of managing them in transparent, equitable, and adaptive ways.

More broadly, the results suggest that many contemporary conservation strategies rely on assigning economic value to nature. Both ecotourism and, to some extent, trophy hunting seek to create financial incentives that justify conservation relative to competing land uses such as mining, infrastructure development, or intensive resource extraction. Such approaches have often produced positive outcomes for biodiversity and local livelihoods. Yet they also raise important questions. Does conservation need to be economically profitable to be politically viable? To what extent should the protection of biodiversity depend on market mechanisms? What happens when conservation becomes less economically attractive than alternative forms of development?

A particularly interesting perspective for future research is offered by the concept of convivial conservation (Büscher & Fletcher, 2019). This approach challenges conservation models based primarily on market incentives and economic valuation of nature. Rather than seeking to conserve biodiversity through tourism revenues, hunting quotas, carbon markets, or ecosystem-service payments, convivial conservation advocates forms of coexistence in which both humans and non-human species are recognized as integral components of shared socio-ecological systems. It emphasizes democratic participation, social justice, local empowerment, and the intrinsic value of nature beyond its economic utility.

While such a model may appear difficult to implement in contemporary conservation contexts, particularly in countries facing important development challenges, it nevertheless provides a valuable framework for reflection. The socio-ecological analysis presented in this thesis repeatedly demonstrated that local participation, trust, cultural values, and community ownership were central to conservation effectiveness. In this respect, some of the most successful initiatives observed around SENSr already reflect

elements of convivial conservation, particularly through the involvement of local communities, environmental education programmes, community-based conservation funds, and efforts to align wildlife conservation with human well-being.

Ultimately, the results of this study suggest that the question is not whether development should be prioritized over conservation, or vice versa. Rather, the challenge lies in designing socio-ecological systems capable of maintaining biodiversity while simultaneously responding to legitimate social and economic aspirations. Such systems require not only sound ecological knowledge but also effective governance, adaptive institutions, social legitimacy, and the capacity to navigate uncertainty. Conservation effectiveness therefore emerges less as a fixed ecological outcome than as a continuous process of negotiation among competing values, interests, and visions of the future. From this perspective, the long-term success of snow leopard conservation may depend as much on the ability of societies to govern these tensions as on the ecology of the species itself.

3.2.4 Conservation implications and future use of the framework

3.2.4.1. Conservation implications

The present study highlights several implications for snow leopard conservation and protected-area management. At the ecological level, conservation priorities remain aligned with the literature: maintaining viable populations of wild prey, limiting habitat degradation and fragmentation, preserving ecosystem functionality, and ensuring the long-term persistence of snow leopard populations. One of the most important findings concerns the role of landscape connectivity. The persistence of the snow leopard population does not depend solely on protection within SENSr but also on maintaining functional ecological connections with neighbouring mountain systems. This result supports contemporary snow leopard conservation strategies emphasizing ecological corridors, dispersal opportunities, and coexistence across multiple-use landscapes rather than conservation confined exclusively to protected areas. However, the results also demonstrate that conservation effectiveness cannot be reduced to ecological indicators alone.

The socio-ecological assessment further revealed that conservation outcomes are strongly influenced by governance quality. Although the current system remains functional and has generated positive ecological outcomes, it is characterized by several institutional fragilities. Among the most evident priorities is the professionalization of the ranger profession through the creation of formal vocational and higher-education pathways leading to nationally recognized qualifications. Such programmes would build upon the exceptional field knowledge already possessed by local rangers while providing scientific training, technical skills, and professional certification. Combined with stronger

career-development opportunities and greater integration into governmental conservation structures, this would contribute to transforming ranger work from a primarily experience-based occupation into a fully recognized conservation profession. Such measures would not only improve monitoring and management capacity but also reduce the current dependence on NGOs and strengthen the long-term resilience of conservation institutions.

Another key implication concerns social legitimacy and local acceptance. Throughout the analysis, support for conservation emerged as a dynamic and fragile process influenced by economic opportunities, human-wildlife conflict, perceptions of fairness, and trust in institutions. Maintaining this legitimacy therefore requires continuous investment in environmental education, community engagement, conflict mitigation, and benefit-sharing mechanisms. Conservation cannot be viewed as a one-time achievement but rather as an ongoing social process that must be renewed across generations.

The study also highlights the need to update and operationalize the reserve management framework. Although many challenges identified in the 2007 management plan remain relevant today, implementation has often lagged behind strategic objectives. Future planning should therefore move beyond broad recommendations and develop clear operational priorities, measurable objectives, adaptive monitoring procedures, and mechanisms for responding to emerging threats such as mining expansion, climate change, tourism development, and changing pastoral systems.

More broadly, this research suggests that conservation effectiveness depends as much on the governance of socio-ecological interactions as on wildlife management itself. Conservation implications for SENSr, that would notably be beneficial for conservation of snow leopard, requires institutions capable of navigating tensions between biodiversity protection, local livelihoods, tourism, infrastructure development, and extractive activities while maintaining both ecological integrity and social legitimacy.

3.2.4.2 Future use of the framework

Beyond the case of SENSr, this study proposes an exploratory interdisciplinary framework for assessing the effectiveness of protected areas through the lens of an umbrella species. The use of the snow leopard as the focal species proved particularly relevant because it simultaneously connects ecological processes, governance dynamics, conservation funding, social perceptions, and political priorities. Its flagship role further strengthens its analytical value by revealing dimensions of conservation effectiveness that would remain less visible when focusing solely on ecological indicators.

The framework combines ecological monitoring, socio-anthropological analysis, actor-network approaches, and socio-ecological systems thinking. Although additional dimensions could be incorporated in future applications, such as broader political-

economic drivers, psychological determinants of conservation attitudes, or additional species interactions, the framework proved sufficiently flexible to capture the major dynamics shaping conservation outcomes. For example, future studies could more explicitly integrate wolves and other large carnivores into the analysis. Several studies demonstrate that attitudes towards snow leopards are closely linked to perceptions of wolves and livestock depredation, suggesting that a broader carnivore perspective could enrich future effectiveness assessments. More importantly, the framework illustrates how the conservation of a single species can serve as an entry point for understanding the functioning of an entire socio-ecological system. The objective is not to reduce conservation effectiveness to the status of one species but rather to use that species as a window through which broader ecological, social, institutional, and political processes can be examined.

Ultimately, the principal contribution of this study is methodological as much as empirical. It demonstrates that evaluating conservation effectiveness requires moving beyond purely ecological assessments toward genuinely interdisciplinary approaches. Conservation measures are embedded within socio-ecological systems shaped by institutions, stakeholder perceptions, governance arrangements, economic incentives, and human-nature relationships. Understanding effectiveness therefore requires analysing not only whether biodiversity is maintained, but also how conservation is implemented, negotiated, legitimized, and sustained over time.

3.3 Study conclusion

This thesis demonstrates that the Sarychat-Eertash Nature State Reserve (SENSR) is currently functioning effectively as a protected area. The presence of stable populations of wild ungulates, together with evidence of continued reproduction among both prey and predator species, suggests that the reserve is successfully fulfilling its primary ecological role. Although they require cautious interpretation due to limitations in sampling design and data quality, spatial capture-recapture analyses revealed snow leopard density estimates that are particularly high compared to most published values across the species' range (7.29 individuals/100 km²; 95% CI: 3.42–15.75). Taken together, these results demonstrate that the SENSR is likely acting as a source population within the wider Central Tien Shan landscape. The findings also highlight the scientific value of long-term citizen science monitoring, showing that such programmes can generate data sets capable of supporting advanced ecological analyses and informing conservation management.

This research also shows that ecological performance alone cannot explain conservation success. Combining ecological analysis with socio-anthropological approaches, Actor-Network Theory (Callon, 1986) and the Socio-ecological Systems Framework (Ostrom,

2009) reveals that conservation outcomes stem from the interactions between species, people, institutions, governance arrangements and broader political and economic contexts. While ecological indicators reveal whether conservation is succeeding, only interdisciplinary approaches can explain why it succeeds and under which conditions it can be sustained.

Socio-anthropological analyses, based on semi-structured interviews and field observations, identified two major factors that underpin the current effectiveness of SENSR. Firstly, the snow leopard functions as both an apex predator and a flagship and umbrella species, whose symbolic value mobilises scientific interest, political commitment, financial resources, national pride and public support. Secondly, conservation NGOs occupy a pivotal role within the network of actors by connecting international donors, government agencies, researchers, reserve staff and local communities. They also provide many of the technical, financial and educational resources necessary for conservation action, often compensating for limitations in state capacity. Rangers also emerged as strategic hybrid actors, linking local ecological knowledge and field realities with national and international conservation agendas. Their professionalisation represents a significant opportunity to strengthen the effectiveness of protected areas. Together, they create a governance network that enables conservation actions far beyond what ecological protection alone could achieve. The analysis also highlighted the important yet insufficiently understood role of hunting concessions. Due to their extensive presence in landscapes surrounding protected areas, they can contribute positively or negatively to snow leopard conservation, depending on the quality of governance, wildlife management practices and benefit-sharing mechanisms.

However, this finding also reveals an important paradox. While NGO involvement significantly improves conservation outcomes, it also creates structural dependencies on external funding, donor priorities and broader political contexts. Furthermore, the system remains partly dependent on the symbolic power of the snow leopard to mobilise attention, resources and political support. Therefore, conservation success is built, at least in part, upon inherently fragile foundations.

At the socio-ecological system scale, the effectiveness of protected areas is continuously negotiated alongside competing land uses and development objectives, including mining, pastoralism, tourism, and infrastructure expansion. Consequently, although SENSR currently delivers positive conservation outcomes, its long-term resilience is limited by governance weaknesses, land-use conflicts and dependence on external funding. The reserve can therefore be characterised as ecologically effective and socially legitimate in many respects, but institutionally fragile.

Several practical conservation implications emerge from this work. Maintaining viable prey populations, ecological connectivity and overall ecosystem functionality remain key conservation priorities. However, the findings demonstrate that long-term conservation

success also depends on good governance, social legitimacy, environmental education and meaningful stakeholder participation. Large, strictly protected reserves such as SENSR are indispensable for maintaining core snow leopard populations and ecological processes. Nevertheless, protected areas alone are unlikely to ensure the long-term persistence of the species. Effective conservation must extend beyond reserve boundaries, adopting landscape-scale approaches that promote coexistence, connectivity and cooperation across human-used environments.

Future research should continue to expand this interdisciplinary perspective. Incorporating socio-economic, political, psychological (Monfared et al., 2026) and cultural dimensions would help to identify additional factors that influence conservation effectiveness. Multi-temporal assessments would be particularly valuable in understanding how effectiveness evolves over time (Frietsch et al., 2023), while genetic analyses and continued citizen science monitoring could improve our understanding of snow leopard population dynamics further and strengthen future spatial capture-recapture models. Several questions deserve particular attention and could be explored in future research: What role do hunting concessions play in snow leopard conservation? To what extent are land-sparing approaches necessary for the long-term persistence of snow leopards, and under which conditions can coexistence-based strategies succeed? How can biodiversity conservation and economic development be reconciled in post-Soviet contexts such as Kyrgyzstan?

Beyond its empirical findings, this thesis's principal contribution is both methodological and conceptual. Methodologically, it demonstrates the value of a framework that integrates ecological, social and governance perspectives in order to assess the effectiveness of protected areas. Conceptually, it posits that the effectiveness of protected areas should be understood as an emergent property of socio-ecological systems, rather than merely a measure of ecological condition.

More broadly, this research invites a renewed perspective on conservation science. The present findings resonate with emerging approaches such as convivial conservation (Büscher & Fletcher, 2019), which advocate moving away from conservation models centred primarily on technical interventions or market-based mechanisms, towards approaches that recognise coexistence, justice, participation and shared stewardship.

Ultimately, the SENSR case study shows that successful conservation depends on much more than just protecting biodiversity. It also hinges on maintaining the institutions, partnerships, governance arrangements and social legitimacy that enable ecological systems to persist. In this sense, interdisciplinarity is not just a methodological choice, but a prerequisite for understanding, evaluating and improving conservation effectiveness through evidence-based approaches. The long-term future of snow leopard conservation may depend less on the ecological performance of protected areas than on

societies' capacity to sustain the governance systems, institutions and social legitimacy that enable conservation over time.

Data availability statement

The data and code supporting the findings of this study are archived on GitHub. To protect the conservation of snow leopards and comply with data-sharing agreements, precise geolocation data associated with snow leopard detections are not publicly available. These sensitive data remain the property of the OSI-PANTHERA programme and are withheld to prevent potential risks to the species and its habitats. (https://github.com/Gatto49/Gattolliat_Arno_MSc_thesis_2026.git)

Declaration on generative Artificial Intelligence

During the preparation of this thesis, I used Microsoft Copilot to improve the fluency of the text and assist with grammar correction. I also used this tool to support certain aspects of the coding process, particularly when addressing technical challenges and troubleshooting specific programming issues. As indicated in the main text, one figure was generated with the assistance of Microsoft Copilot to visualize a word cloud based on responses provided by interview participants to a specific question.

All content generated with the assistance of this tool was carefully reviewed, verified, and revised where necessary. I take full responsibility for the final content, analyses, interpretations, and conclusions presented in this thesis.

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Appendices

Appendix 1: Ecological analysis and raw data

1. Carnivores transect data

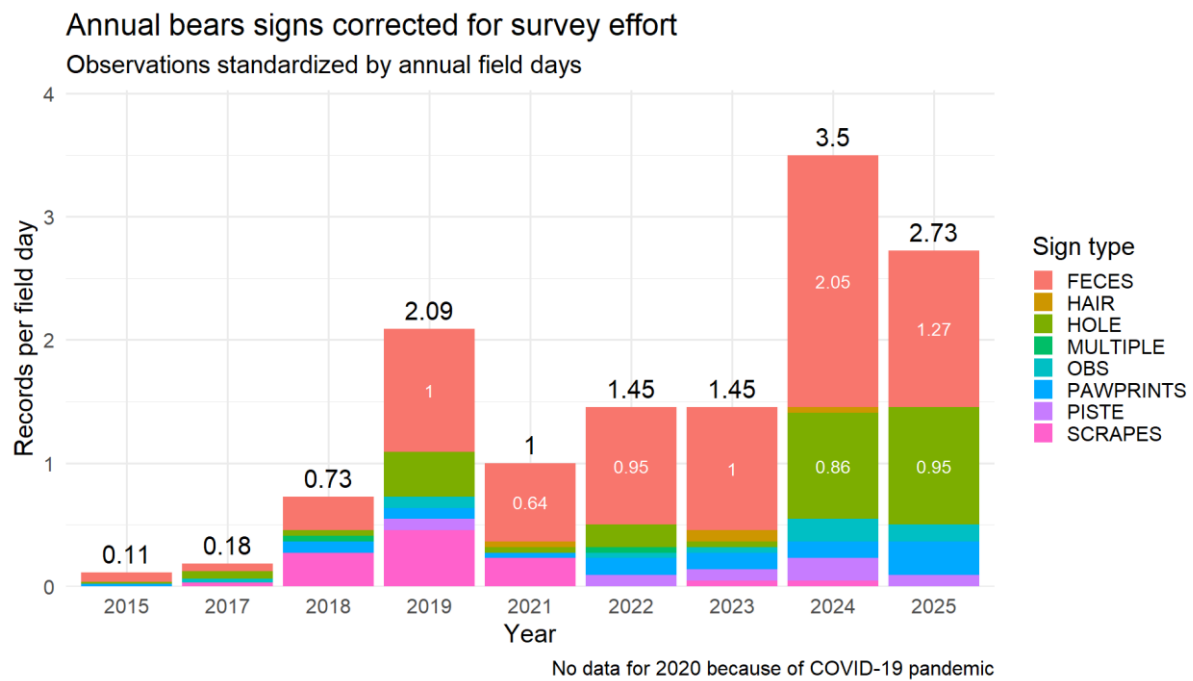


Figure 14: Annual relative abundance index of brown bear (*Ursus arctos isabellinus*) recorded during transect surveys in the Sarychat-Eertash State Nature Reserve between 2015 and 2025. Values were standardized by annual survey effort and calculated as the number of signs recorded per field day. Stacked bars represent the sign type. Values above bars indicate annual totals. No surveys were conducted in 2020 due to restrictions associated with the COVID-19 pandemic.

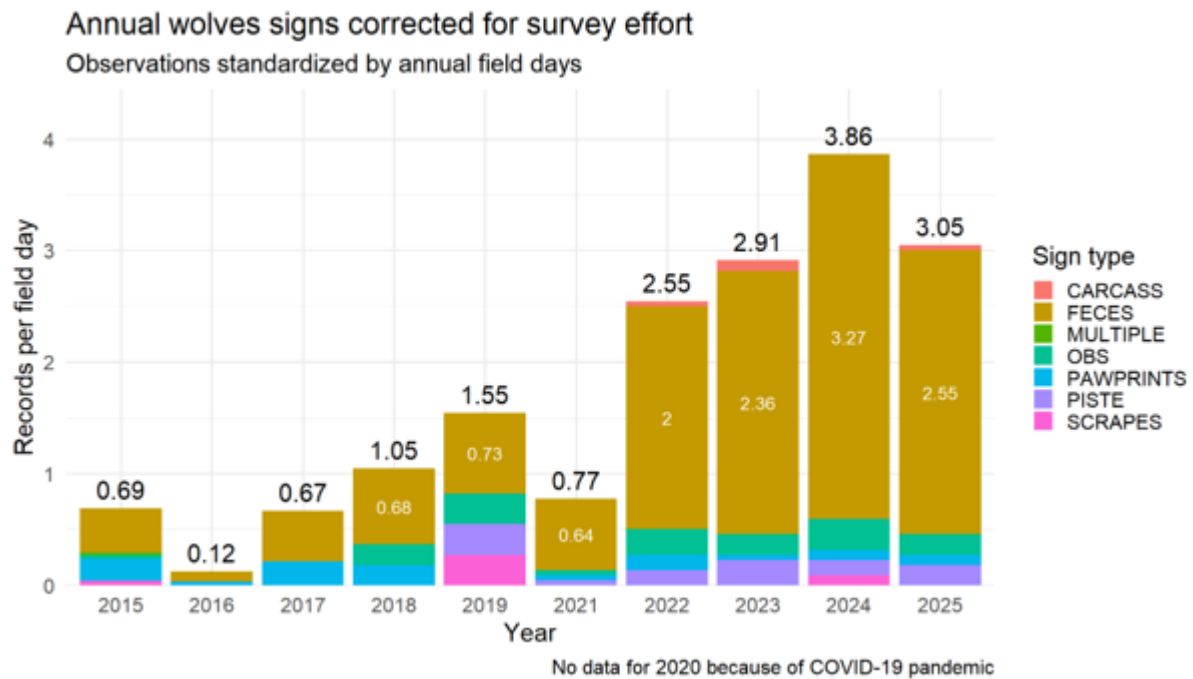


Figure 15: Annual relative abundance index of wolves (*Canis lupus*) recorded during transect surveys in the Sarychat-Eertash State Nature Reserve between 2015 and 2025. Values were standardized by annual survey effort and calculated as the number of signs recorded per field day. Stacked bars represent the sign type. Values above bars indicate annual totals. No surveys were conducted in 2020 due to restrictions associated with the COVID-19 pandemic.

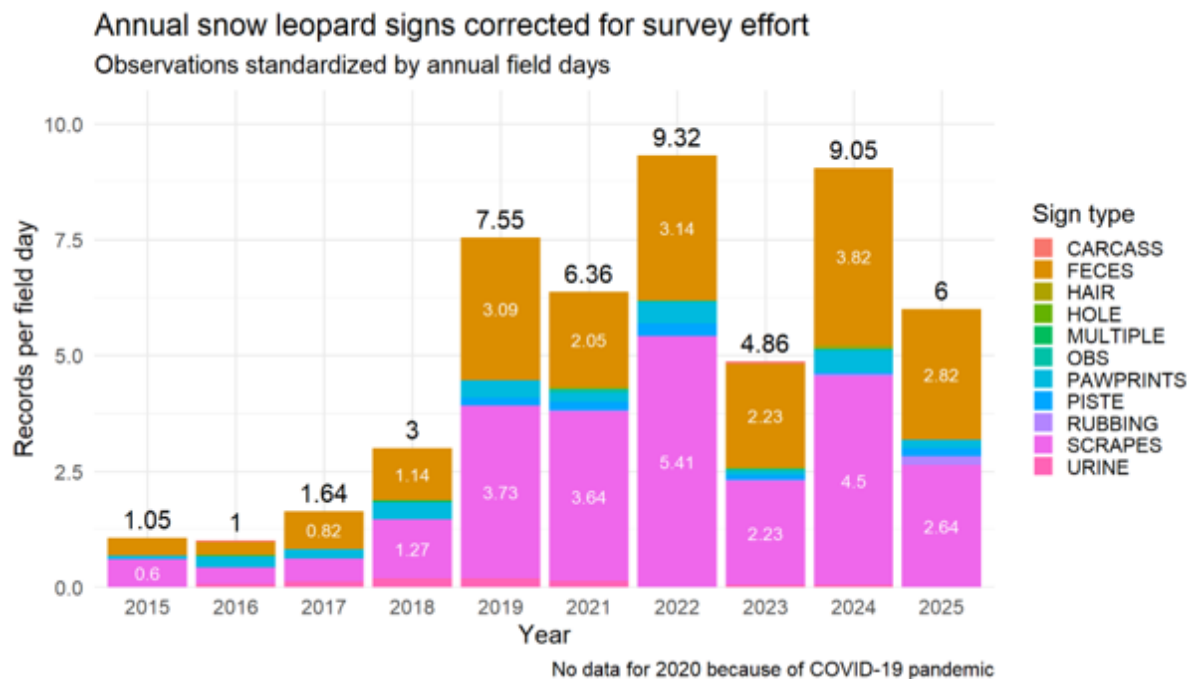


Figure 16: Annual relative abundance index of snow leopard (*Panthera uncia*) recorded during transect surveys in the Sarychat-Eertash State Nature Reserve between 2015 and 2025. Values were standardized by annual survey effort and calculated as the number of signs recorded per field day. Stacked bars represent the sign type. Values above bars indicate annual totals. No surveys were conducted in 2020 due to restrictions associated with the COVID-19 pandemic.

2. Camera trap deployment and data captured

Tableau 1: list of all camera traps used over the decade of photographic capture in Sarychat-Eertash Nature State Reserve, with number of years of function, number of raw capture and capture used for secr modelling

	Camera-trap site with year of deployment	Raw records	photographic detections used in SECR
1	Kitchi Uch Baital (2021–2024)	2228	86
2	Orthobordou (2014–2024)	1873	82
3	Face À Oroï Suu (2018–2024)	1853	50
4	Kizil Kérégué (2016–2024)	1615	135
5	Sirdibai3 (2022–2024)	858	28
6	Bir Baital (2021–2024)	854	80
7	Chong Sary Etchki (2019–2024)	842	100
8	Kitchi Kashkater (2015–2023)	591	34
9	Kitchi Sary Etchki (1019–2023)	587	44
10	Ortho Bordou (2022–2023)	549	26
11	Chomoï (2020–2024)	508	28
12	Jaman Suu (2019–2023)	499	34
13	Sirdibai 1 (2021–2022)	434	14
14	Sirdibai1 (2017–2023)	428	25
15	Boroko (2017–2023)	419	13
16	Kitchi Bordou (2021–2023)	380	6
17	Solomo Vallon (2021–2024)	307	20
18	Chateau Koilou (2017–2024)	285	23
19	Uch Baital (2022–2024)	265	6
20	Atcha (2018–2024)	260	18
21	Solomo (2011–2020)	254	28
22	Chon Koilou (2019–2023)	229	17
23	Tchong Bordou (2019–2024)	202	9
24	Kizil Djar (2019–2024)	175	7
25	Oroï Suu (2021–2023)	129	10
26	Jili Boulak (2014–2016)	76	9
27	Ortho Bordou (2013–2014)	64	0
28	Solomo Piste (2021–2023)	50	1
29	Bich Jilga (2021–2022)	40	2
30	Kitchi Uch Baital (2021–2021)	33	3
31	Eki Baital (2014–2014)	24	0
32	Vallée Grand Koilou (2017–2018)	23	13
33	Oroi Suu (2020–2020)	20	4

34	Piste Solomo (2022–2022)	20	1
35	Boroko (2019–2019)	14	3
36	Kitchi Koilou (2010–2014)	11	2
37	Bir Baital (2018–2018)	9	2
38	Bir Baital (2020–2020)	8	1
39	Uch Baital (2016–2016)	6	4
40	Tchong Sary Etchki 2019 (2018–2018)	3	1
41	Uch Baital (2010–2010)	3	0
42	Jaman Suu (2013–2013)	2	0
43	Sary Etchki (2011–2011)	2	0
44	Sirdibai 2 (2015–2015)	2	0
45	Petit Gueulu (2012–2012)	1	0
46	Solomo Moraine (2015–2015)	1	1
47	Uch Baital (2008–2008)	1	0

2.1 Snow leopard individual summary

Table 5: summary of all information about individual, based on camera trap information, collared individual and species knowledge. Table is sort in descending order for number of detections

Individual	Sex	Age	Detectio ns	site_visit ed	Years_se en	First_se en	Last_se en
Elmijas	Fema le	Adult	1647	13	8	2016-10- 05	2024-07- 24
Agim	Male	Adult	1396	10	5	2020-07- 06	2024-08- 09
Italiya	Male	Adult	981	10	5	2020-06- 07	2024-05- 13
Ulus	Male	Adult	738	10	4	2021-11- 15	2024-07- 18
Kelemis	Male	Adult	707	6	5	2020-03- 29	2024-02- 24
Aiperi	Male	Adult	638	10	9	2014-06- 20	2022-01- 28
Jasjigit	Male	Adult	574	4	3	2021-09- 13	2023-01- 07
Sub'elmi	NA	Subad ult	571	5	2	2022-08- 05	2023-06- 05
Jurok	Male	Adult	473	4	4	2021-08- 17	2024-07- 17
Ilep	Fema le	Adult	457	4	5	2019-09- 11	2023-10- 23
Sogusker	Male	Adult	406	5	5	2018-09- 23	2023-11- 27
Elmikau	Fema le	Adult	370	5	7	2016-10- 12	2022-07- 31
Tuman	Fema le	Adult	275	3	2	2022-08- 31	2024-06- 08
Cub1'Dinara	NA	Cub	245	2	2	2022-10- 29	2023-05- 30
Kumir	Male	Adult	235	3	2	2023-01- 18	2024-07- 02
Illep's Cub	NA	Cub	234	1	2	2021-12- 22	2022-02- 06

Chagilgan	Male	Adult	219	2	4	2017-06-27	2020-04-04
Cub2'Dinara	NA	Cub	203	2	2	2022-10-29	2023-05-30
Niabaz	Female	Adult	195	1	6	2019-11-09	2024-02-08
Cub Of Elmijas	Female	Cub	172	3	4	2021-09-14	2024-03-31
Muktderlik	Male	Adult	159	4	4	2019-11-09	2022-04-29
Primula	NA	Adult	159	3	3	2022-07-31	2024-03-05
Dinara	Female	Adult	146	3	1	2023-03-02	2023-08-21
Cub3'Dinara	NA	Cub	130	2	2	2022-10-29	2023-03-20
Jugazin	NA	Adult	113	4	3	2021-09-14	2023-12-10
Subd1	NA	Subadult	99	2	2	2023-08-05	2024-03-22
Sana	Male	Adult	88	2	2	2022-07-27	2023-08-06
Niazov	Male	Adult	85	4	3	2018-05-30	2020-11-02
Altitrio	NA	Adult	78	3	2	2021-09-24	2022-04-13
Bulut	NA	Adult	67	1	1	2022-05-17	2022-11-30
Birkozdu	Male	Adult	65	3	2	2021-09-24	2022-04-13
Subsl5	NA	Subadult	65	2	1	2023-08-12	2023-09-19
Tortupay	Female	Adult	65	4	5	2019-12-01	2023-11-21
Subd2	NA	Subadult	62	2	2	2023-08-05	2024-03-22
Cub 1 (Tuman, 2024)	NA	Cub	53	1	1	2024-03-12	2024-06-06

Kitchigul	NA	Adult	51	3	1	2022-01-15	2022-07-10
Subsl6	NA	Subadult	47	1	1	2023-09-19	2023-09-19
Sub'ilep Cubdé2	NA	Cub	43	1	1	2022-09-30	2022-12-31
Edel	NA	Adult	42	1	1	2023-06-11	2023-06-24
Altynai	Female	Adult	41	3	4	2017-09-03	2020-10-05
Finaltinay	Male	Adult	41	1	1	2020-07-18	2020-07-18
Tokulgan	NA	Adult	41	2	1	2022-01-19	2022-01-29
Birok	NA	Adult	36	1	1	2022-08-07	2022-08-07
Balasi	NA	Subadult	34	3	2	2021-11-16	2022-04-01
Ilep's Cub 2	NA	Cub	34	1	2	2021-11-21	2022-05-27
Niaginbaz	NA	Subadult	34	1	2	2021-08-12	2022-05-15
Macha	Female	Adult	27	1	2	2018-07-15	2020-03-11
Niapayi	NA	Subadult	27	1	2	2021-08-12	2022-01-16
Ilep's Cub 3	NA	Cub	26	1	2	2021-11-21	2022-05-27
Ilep's Cub 1	NA	Cub	25	1	2	2021-11-21	2022-05-27
Kiz	NA	Cub	25	1	1	2022-06-04	2022-07-12
Zhyldyz	Male	Adult	25	1	3	2015-08-09	2017-09-01
Kalempir	NA	Adult	21	1	1	2011-10-03	2011-10-03
Rosalie	Female	Adult	21	1	1	2016-08-23	2016-10-01

Sulu	NA	Adult	21	1	1	2022-08-07	2022-08-07
F2	Female	Adult	18	1	1	2017-05-15	2017-06-19
Sutamsisi	NA	Adult	18	2	2	2019-04-10	2022-05-25
Arpa	NA	Adult	17	1	1	2022-08-07	2022-08-07
Sub'ilep Cubdé3	NA	Cub	17	1	1	2022-09-30	2022-12-29
Muktar	NA	Adult	16	2	4	2018-10-27	2021-04-28
Kauhar	Female	Adult	14	1	1	2018-01-10	2018-01-10
Aitilek	NA	Adult	12	1	1	2016-07-21	2016-07-21
Belgisiz	NA	Adult	11	1	1	2020-06-10	2020-06-10
Sub1'Tortupay	NA	Subadult	11	1	1	2022-08-29	2022-08-29
Tsikoriy	NA	Adult	9	1	1	2014-07-06	2014-08-16
Sub2'Tortupay	NA	Subadult	8	1	1	2022-08-29	2022-08-29
Ainazik	Male	Adult	7	1	1	2016-08-23	2016-10-12
Cub'dinara	NA	Cub	6	1	1	2023-04-07	2023-04-07
Jalgiz	Male	Adult	6	1	1	2019-09-18	2019-09-18
Korolkova	NA	Adult	6	1	2	2014-09-13	2015-03-12
Nurlan	Male	Adult	6	1	1	2016-08-23	2016-10-01
Rarat	NA	Adult	6	1	2	2017-11-16	2018-02-20
Gibiskus	NA	Adult	5	1	1	2011-08-14	2011-08-14

Kalem	NA	Adult	5	1	1	2019-11-08	2019-11-08
Saikal	NA	Adult	5	2	1	2016-09-28	2016-11-03
Jyrgal	NA	Adult	4	1	1	2016-05-06	2016-05-06
Kuban	NA	Adult	4	1	1	2016-09-20	2016-09-20
Omourbek	NA	Adult	3	1	1	2018-09-09	2018-09-09
Pereyti	NA	Adult	3	1	1	2016-11-20	2016-11-25
Sub'ilep	NA	Subadult	3	1	1	2022-08-17	2022-08-17
Taalay	NA	Adult	3	1	1	2018-02-10	2018-02-10
Akbede	NA	Adult	2	1	1	2011-08-20	2011-08-20
Cub A Niabaz	NA	Cub	2	1	1	2021-11-01	2021-11-01
Cub B Niabaz	NA	Cub	1	1	1	2021-11-01	2021-11-01
Jas	Female	Adult	1	1	1	2017-01-13	2017-01-13
Nastia	NA	Adult	1	1	1	2015-07-12	2015-07-12

3. Temporal evolution and activity of snow leopard detection through camera trap

Temporal evolution of snow leopard detections and new identified individuals

All snow leopard capture record whitout passage data process

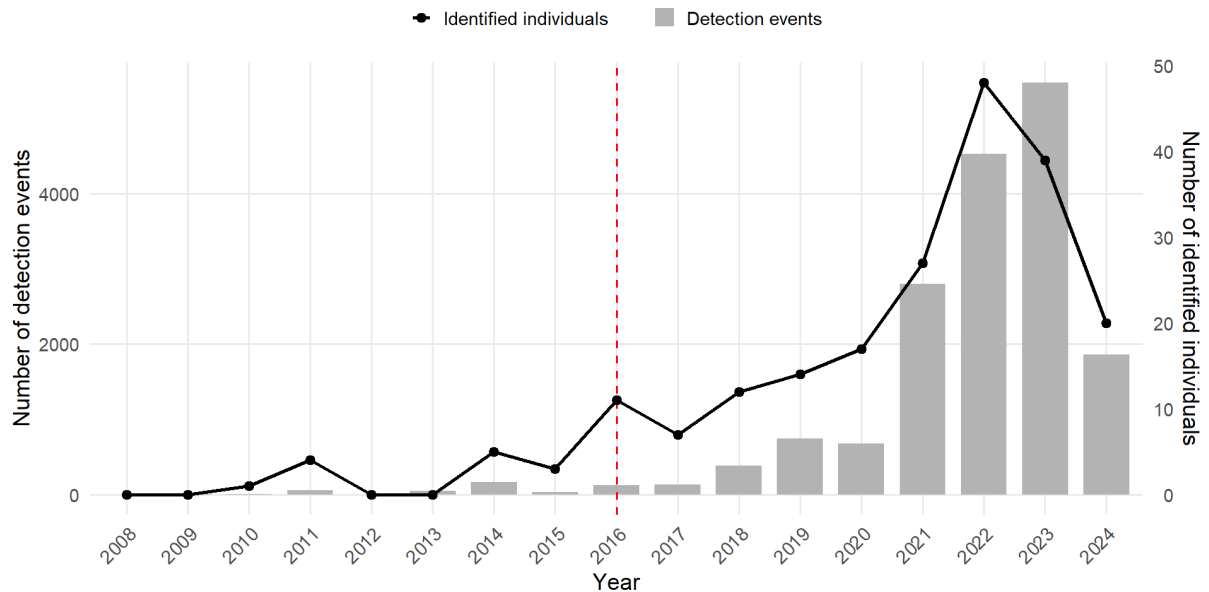


Table 6: Temporal evolution of snow leopard capture events and identified individuals recorded by the OSI-PANTHERA camera-trap programme. Grey bars represent the annual number of processed detection events, whereas the black line indicates the number of unique identified snow leopards detected each year. This figure illustrates the increase in monitoring effort and the resulting growth in available capture–recapture information through time.

3.1 Annual activity per month

When corrected for sampling effort, monthly activity appears even more homogeneous. The standardized detection rates (expressed as passages per km² monitored; Figure 18) show limited variation across months, with overlapping uncertainty estimates. This suggests that apparent differences in raw detections are partly driven by variation in sampling effort rather than true biological changes in activity.

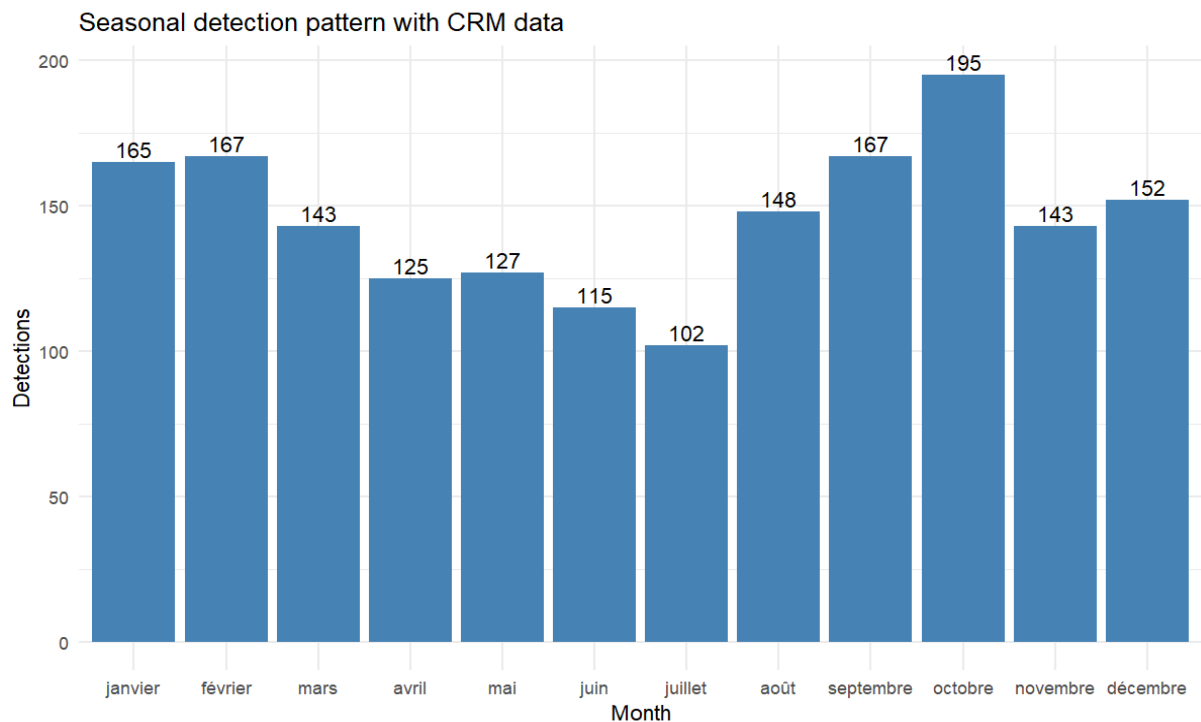


Figure 17: seasonal difference of SL picture considering only adult with passage cleaning

Statistical analyses confirm this interpretation. Seasonal variation in snow leopard detections was tested using a generalized additive model (GAM) with a cyclic smooth on month. Although the effect of month was statistically significant ($p < 2 \times 10^{-16}$), the model explained only a small proportion of total variance ($\approx 5.6\%$), indicating weak overall seasonality. Similarly, when data were aggregated at the monthly level, non-parametric comparison among months did not detect significant differences (Kruskal–Wallis test, $p = 0.44$), likely due to reduced statistical power.

Taken together, these results indicate that seasonal variation in detection is present but

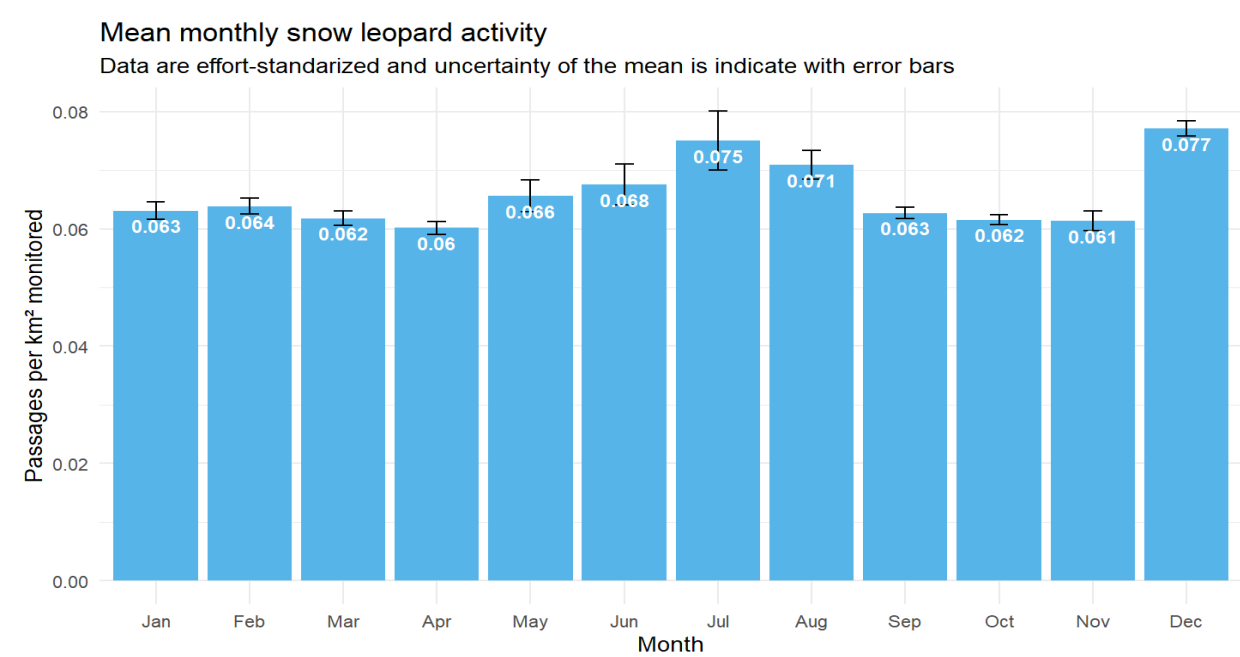


Figure 18: mean monthly passage standardized by km2 monitored

relatively weak and does not strongly structure snow leopard detection patterns at the temporal resolution considered here. Consequently, the definition of sampling sessions for SCR analyses was not based solely on detection patterns, but primarily on biological knowledge of snow leopard ecology, to avoid periods associated with strong behavioural biases (e.g., reproduction or restricted movement).

4. Population structure

The strong male-biased sex ratio deviation from parity was statistically significant (exact binomial test, $p < 0.001$). Among adult individuals of known sex, males were more frequently detected than females (18 versus 11 identified individuals) and generated approximately twice as many camera-trap detections per individual (31.6 ± 35.0 versus 16.1 ± 14.9 detections). The proportion of males detected remained relatively stable throughout the study period, with no significant temporal trend (binomial GLM, $p = 0.76$) and no significant interannual variation ($\chi^2 = 13.36$, $df = 8$, $p = 0.10$). This suggests that sex-related differences in detectability were consistent across years. (Tableau 2).

Tableau 2: description of anow leopard adult with known sex identification and their passages captured on camera trap during the survey (2016-2024)

Sex identification	Mean passage in survey time	Standard deviation of passage	Number of individuals
Female	16.1	14.9	11

Male	31.6	35.0	18
------	------	------	----

Age structure analyses were limited by uncertainty in the identification and long-term tracking of cubs and subadults. Individuals that could not be confidently associated with a known snow leopard were excluded from this analysis. Consequently, only identified individuals with an assigned age class were considered for younger age classes.

5. Summary of camera trap data during decade of survey

year	Spacing within camera trap	Surface monitored (km2)	Camera stations functioning	Stations used in secr modelling	Raw captures records	Detections in secr	SL individual in secr	Spatial recapture
2016	3700.367	171.0	7	4	127	39	9	3
2017	6645.147	370.0	15	6	131	38	6	3
2018	5107.700	661.5	15	8	387	162	6	5
2019	4630.148	819.0	20	9	746	135	12	4
2020	5767.077	171.0	23	5	677	103	6	7
2021	3063.165	702.0	18	17	2802	265	24	12
2022	3063.165	577.5	29	13	4522	433	17	19
2023	3063.165	637.0	30	15	5471	386	14	24
Survey means	4379.991	513.6	19	9	1857	195	11	9

Table 3: summary of the data all along the survey that will be used in secr modelling

Appendix 2: spatial capture-recapture modelling

1. Environmental covariates explaining density

<i>model</i>	detect fn	np ar	logLik	AIC	AICc	dAI C	AIC wt
<i>D~raster.TPI + raster.TRI g0~h2 sigma~1 pmix~h2</i>	halfnormal	7	-309.3736	632.747	634.050	0.000	0.5470
<i>D~raster.NDVI g0~h2 sigma~1 pmix~h2</i>	halfnormal	6	-311.0773	634.155	635.120	1.408	0.2706
<i>D~raster.TRI g0~h2 sigma~1 pmix~h2</i>	halfnormal	6	-312.2447	636.489	637.455	3.742	0.0842
<i>D~session g0~h2 sigma~1 pmix~h2</i>	halfnormal	12	-307.3437	638.687	642.539	5.940	0.0281
<i>D~session + raster.NDVI g0~h2 sigma~1 pmix~h2</i>	halfnormal	13	-306.5328	639.066	643.616	6.319	0.0232
<i>D~session + raster.NDVI_growing g0~h2 sigma~1 pmix~h2</i>	halfnormal	13	-306.9470	639.894	644.444	7.147	0.0153
<i>D~session + raster.TPI g0~h2 sigma~1 pmix~h2</i>	halfnormal	13	-307.2674	640.535	645.085	7.788	0.0111
<i>D~session + raster.altitude g0~h2 sigma~1 pmix~h2</i>	halfnormal	13	-307.3339	640.668	645.218	7.921	0.0104
<i>D~session + raster.TRI g0~h2 sigma~1 pmix~h2</i>	halfnormal	13	-307.3795	640.759	645.309	8.012	0.0100

2. Other occasion structure result of best model estimation

2.1 Four occasions best model estimation results

Year	Sex	Density_km2	Density_LCL_km2	Density_UCL_km2	g0	g0_LCL	g0_UCL	sigma_m	N_detected	Population_est	Population_RN	Population_LCL	Population_UCL
2020	Female	0.319	0.146	0.697	0.364	0.269	0.471	6532.702	26	23.899	23.899	14.134	49.207
2020	Male	0.319	0.146	0.697	0.104	0.063	0.168	6532.702	8	23.899	23.899	14.134	49.207
2021	Female	0.092	0.06	0.141	0.364	0.269	0.471	6532.702	14	46.747	46.747	36.469	67.116
2021	Male	0.092	0.06	0.141	0.104	0.063	0.168	6532.702	17	46.747	46.747	36.469	67.116
2022	Female	0.088	0.052	0.149	0.364	0.269	0.471	6532.702	26	35.237	35.237	25.591	55.717
2022	Male	0.088	0.052	0.149	0.104	0.063	0.168	6532.702	8	35.237	35.237	25.591	55.717
2023	Female	0.057	0.033	0.1	0.364	0.269	0.471	6532.702	14	26.313	26.313	19.358	42.298
2023	Male	0.057	0.033	0.1	0.104	0.063	0.168	6532.702	17	26.313	26.313	19.358	42.298

2.2 two occasion structure estimation of the best model

Year	Density_km2	Density_LCL_km2	Density_UCL_km2	g0	sigma_m	Population_est	Population_RN	Population_LCL	Population_UCL	N_detected
2016	0.13248038	0.049308179	0.35594602	0.28654043	13805.91	22.654144	22.316097	12.448659	60.41664	9
2017	0.02699144	0.010860461	0.06708168	0.52738866	13805.91	9.986834	9.808388	6.850485	23.05359	6
2018	0.02281165	0.007732311	0.06729831	0.23018244	13805.91	15.089907	14.714801	8.066138	42.75833	6
2019	0.05973472	0.019992358	0.17848002	0.08093407	13805.91	48.922734	48.950743	22.490600	142.15056	12

2 0 2 0	0.086 50058	0.03279 2906	0.22816 980	0.26 7927 26	138 05. 91	15.613 355	15.616 362	9.7447 95	41.246 87	8
2 0 2 1	0.057 32715	0.03645 5948	0.09014 720	0.19 4823 00	138 05. 91	40.243 657	39.293 477	31.171 764	60.169 49	26
2 0 2 2	0.042 78066	0.02507 8278	0.07297 888	0.29 0742 64	138 05. 91	24.705 829	24.398 233	19.442 626	39.407 79	17
2 0 2 3	0.027 40632	0.01611 0159	0.04662 315	0.44 3532 42	138 05. 91	17.814 108	17.967 774	15.757 236	26.631 36	15

Appendix 3: Interviews and interdisciplinary data

1. Table of actors interviewed with their analytical group category

Code	Actor category	Standardised anonymised description	Analytical group category
<i>R1</i>	International NGO	Charles, scientific director, affiliated with an international snow leopard conservation NGO.	Conservation-centred actors
<i>R2</i>	National NGO (Kyrgyzstan)	Jules, director, affiliated with a national snow leopard conservation NGO.	Conservation-centred actors
<i>R3</i>	National NGO (Kyrgyzstan)	Michel, programme coordinator, affiliated with a national snow leopard conservation NGO.	Conservation-centred actors
<i>R4</i>	International NGO	Arthur, biodiversity management specialist, affiliated with an international conservation NGO active in Central Asia.	Conservation-centred actors
<i>R5</i>	Research expertise /	Antoine, researcher affiliated with a national academy of sciences, specialising in vertebrate zoology.	Conservation-centred actors
<i>R6</i>	NGO / local civil society	Benjamin, educator involved in a citizen science conservation programme and livestock herder.	Conservation-centred actors
<i>R7</i>	Research institute	Aurore, researcher specialising in ornithology, affiliated with an international research institute.	Conservation-centred actors
<i>R8</i>	Private sector (hunting)	Benoît, director of a hunting company operating close to a protected area.	Conservation-centred actors
<i>R9</i>	Private sector (hunting)	Yann, director of a hunting company operating close to a protected area.	Conservation-centred actors
<i>R10</i>	International NGO	Morgane, director and educator involved in a citizen science programme on snow leopard conservation.	Conservation-centred actors
<i>R11</i>	Local association	Thibault, farmer and livestock herder, member of a local association supporting the management of a protected area.	Locally embedded actors
<i>R12</i>	Protected area management	Tibor, director, working in protected area management.	Locally embedded actors
<i>R13</i>	Protected area management	Mael, vice-director, working in protected area management.	Locally embedded actors
<i>R14</i>	Government actor	Vladimir, senior administrative officer, involved in biodiversity conservation and protected area governance at the national level.	Locally embedded actors
<i>R15</i>	Local community	Charlotte, community programme manager, involved in a community-based conservation initiative in a village adjacent to a protected area.	Locally embedded actors
<i>R16</i>	Local community	Urs, livestock herder, resident of a village adjacent to a protected area.	Locally embedded actors
<i>R17</i>	Protected area management	Marc, ranger, working in protected area management.	Locally embedded actors

R18	Protected area management	Edward, head of rangers, working in protected area management.	Locally embedded actors
R19	Local community	Mathilde, schoolteacher, resident of a village adjacent to a protected area.	Locally embedded actors
R20	Local community	Christine, school staff member, resident of a village adjacent to a protected area.	Locally embedded actors
R21	Local community	Amélie, cook and social support worker, working in a village boarding school.	Locally embedded actors
R22	Local community	Camille, vice-director and teacher, working in a village school adjacent to a protected area.	Locally embedded actors
R23	Local community	Nicolas, art teacher, resident of a village adjacent to a protected area.	Locally embedded actors
R24	Protected area management	Adri, ranger, working in protected area management.	Locally embedded actors
R25	Local community	Narcisse, biology teacher, resident of a village adjacent to a protected area.	Locally embedded actors
R26	Private sector (mining)	Gaspard, mine worker, employed in an extractive industry operating near a protected area.	Locally embedded actors
R27	Protected area management	Diego, ranger, working in protected area management.	Locally embedded actors
R28	Protected area management	Esteban, ranger, working in protected area management.	Locally embedded actors
R29	Protected area management	Julien, ranger, working in protected area management.	Locally embedded actors

Anonymized named were keep with gender of people interviewed to express the distribution of sex around the actors interviewed.

2. Document used during the interview:

2.1 Example of text I have printed with translation in Kyrgyz and Russian and I presented to people I wanted to interview

Short Introduction: Request for Interview

My name is Arno Gattolliat, I am a master's student in Biology at the University of Neuchâtel in Switzerland. I specialize in conservation biology and am currently conducting research for my master's thesis on snow leopard conservation in Kyrgyzstan.

As part of my fieldwork, I am studying how snow leopards are perceived by different actors and how these perceptions influence conservation strategies. I also aim to better understand the network of stakeholders involved in snow leopard protection, from local communities to conservation professionals and institutions.

I will be accompanied by a local interpreter and would be very grateful if you would be willing to have a short conversation with us to share your knowledge, opinions, or experiences on this topic. Your perspective is very valuable for building a more inclusive and realistic view of conservation efforts in Kyrgyzstan.

If you prefer, the interview can remain entirely confidential, and your name or image will not be used.

However, if you agree to let us use your words or image for the interpreter's project or educational purposes, we can provide a simple consent form to sign.

Thank you in advance for your time and consideration.

Arno Gattolliat

Master's student – University of Neuchâtel (Switzerland)

2.2 Example of question for interview:

2.2.1 Conservation-centred actors:

This interview is part of the social science component of my master's thesis, which focuses on snow leopard conservation through interdisciplinary approaches. The aim is to collect qualitative data to better understand the network of actors involved in snow leopard conservation, as well as local perceptions of this species and how these perceptions influence conservation measures. There is no wrong or true answer, what matter for me is your opinion.

All data collected will remain strictly confidential, and if used in any publications, it will be fully anonymized. In practice it will be mostly to have a second listening for analysis and better translation. This interview is part of my academic research and aims to produce results that can contribute to more effective and socially integrated conservation strategies.

Is that ok with you if I record?

General background and personal link

Could you please tell me about your background (education, biography) and how you came to work in your current position?

Snow Leopard:

1. 3 first words that come to your mind when you think about this species?
2. What is the current situation of population dynamics in Kyrgyzstan?
3. Threats against it?
 - a. What about climate change?
 - b. Mining activity?
4. Measure of conservation to mitigate those threats?
 - a. What is your opinion about development of tourism?
 - i. Do you think that it could be independent from activity in Sarychat-Eertash

5. How do you explain the new president's decision to establish the snow leopard as a national symbol, and why was this done only recently?

Actors and networks

From your perspective, who are the main actors involved in snow leopard conservation in Kyrgyzstan, and what are their respective roles? (Prompt if needed: government, scientists, NGOs, local communities, livestock herders)

Ecological concepts

Have you heard of the concept of an "umbrella species" or "flagship species"?

Conclusion

Is there anything else you would like to share that I haven't asked, but that you think is important to understand snow leopard conservation here?

2.2.2 Locally embedded actors:

*This interview is part of the social science component of my master's thesis, which focuses on snow leopard conservation through interdisciplinary approaches. The aim is to collect qualitative data to better understand the network of actors involved in snow leopard conservation, as well as local perceptions of this species and how these perceptions influence conservation measures. There is no wrong or true answer, what matter for me is your opinion. **Indeed, this important from my point of view to consider and involve local community in conservation project.***

All data collected will remain strictly confidential, and if used in any publications, it will be fully anonymized. In practice it will be mostly to have a second listening for analysis and better translation. This interview is part of my academic research and aims to produce results that can contribute to more effective and socially integrated conservation strategies.

Is that ok with you if I record?

General background and personal link

Could you please tell me about your background (education, biography) and how you came to work in your current position? And specially in this place?

Can you describe a normal day at work?

What bother you at work? and make you very happy?

What percentage of your time is spent on your main work activity compared to household tasks and livestock care?

Questions to Rangers:

What would you say if your children wanted to become rangers?

What would you say to a shepherd who is very angry after losing livestock to a snow leopard attack?

Snow Leopard:

1. 3 first words that come to your mind when you think about this species?
2. What is the current situation of population dynamics in Kyrgyzstan?
3. Threats against it?
 - a. What about climate change?
 - b. Mining activity?
4. Measure of conservation to mitigate those threats?
 - a. What is your opinion about development of tourism?
 - i. Do you think that it could be independent from activity in Sarychat-Eertash
5. How do you explain the new president's decision to establish the snow leopard as a national symbol, and why was this done only recently?

Actors and networks

From your perspective, who are the main actors involved in snow leopard conservation in Kyrgyzstan, and what are their respective roles? (Prompt if needed: government, scientists, NGOs, local communities, livestock herders)

Is there difference of opinion and mentality with Engilchek or Ush-Koshkon?

What do you think about Sarychat-Eertash governance and administration?

What about scientific project over there?

Conclusion

Is there anything else you would like to share that I haven't asked, but that you think is important to understand snow leopard conservation here?

3. Detail of answer to the question “what are the 3 main words that come to your mind when you think about snow leopard”

This table was use through CopilotIA to produce the figure of word cloud (Figure 12)

Table 7: answer to the question what are 3 first word that come to your mind when you think about snow leopard

Standardised description	anonymised	Perception of the Snow Leopard
Charles, scientific director, affiliated with an international snow leopard conservation NGO.		national pride for Kyrgyz, meet people from country range together. Also converge 13 UNDP sustainable goals → collateral benefits
Jules, director, affiliated with a national snow leopard conservation NGO.		1 SL is killed by day due to human activities, so mostly sad things and threats. Hope to see it during tours and having good picture
Michel, programme coordinator, affiliated with a national snow leopard conservation NGO.		Beautiful, incredible resilient, champions of ecosystems, can't emphasize how important are this big predator for the ecosystem and how they regulate the ungulate.
Arthur, biodiversity management specialist, affiliated with an international conservation NGO active in Central Asia.		lot of attention, top of trophic chain, elusive, magic.
Antoine, researcher affiliated with a national academy of sciences, specialising in vertebrate zoology.		grace, dexterity and courage
Benjamin, educator involved in a citizen science conservation programme and livestock herder.		Espèce symbolique et mythique, enfin qui ne laisse pas indifférente. Espèce qu'on peut facilement mettre en avant, attachante et belle
Aurore, researcher specialising in ornithology, affiliated with an international research institute.		Very symbolic and beautiful for KG people. Rangers like it a lot. Beauty of this animal attract lot of people and learn about nature and flora and fauna of Kyrgyzstan. top of ecological chain. Elegant animal, cat, how it's walk, noble. [19] fantastic, associated to mountain and snow. Challenge to see it, condition, place, price.

	Predator will be always on top because they are noble. Argali and ibex are its food prey
Benoît, director of a hunting company operating in a protected area context.	First nothing come to his mind but with several minutes end up with: “good impression and honours if seeing one closely”
Yann, director of a hunting company operating in a protected area context.	“a great cat”
Morgane, director and educator involved in a citizen science programme on snow leopard conservation.	Discret, haute montagne, prédateur. Coté chasseur, prédateur, rareté, patriote et fierté des KG se retrouve dans cet emblème : « elle est hyper rare et nous on en a »
Thibault, farmer and livestock herder, member of a local association supporting the management of a protected area.	beauty, dexterity. “No negative image of Snow leopard, people are understanding if sometimes it kills domestic animal” and « Everyone understand they are important and on the top of ecological chain”
Tibor, director, working in protected area management.	Very rare species and national symbol
Mael, vice-director, working in protected area management.	In general, everybody understands the value of snow leopard but like in everything there is some exception
Vladimir, senior administrative officer, involved in biodiversity conservation and protected area governance at the national level.	to transform the perception of snow leopards from being seen as predators that threaten livestock to valuable assets that can provide sustainable economic opportunities for local communities. The snow leopard symbolizes courage, dignity, endurance, and harmony with nature in Kyrgyz culture. “Protecting snow leopards equals protecting entire mountain ecosystems” and frames conservation as a moral responsibility for future generations.
Charlotte, community programme manager, involved in a community-based conservation initiative in a village adjacent to a protected area.	rare species that we have to protect and its beautiful, I admire it when I see it.
Urs, livestock herder, resident of a village adjacent to a protected area.	beauty of our nature and mountain, it is good
Marc, ranger, working in protected area management.	positive thought and should protect them, now we saw them more not only faeces or footprints
Edward, head of rangers, working in protected area management.	feel joy because their number are increasing

Mathilde, schoolteacher, resident of a village adjacent to a protected area.	Living being
Christine, school staff member, resident of a village adjacent to a protected area.	treasure of the nature thanks to its physical appearance
Amélie, cook and social support worker, working in a village boarding school.	most beautiful creature in higher mountain and I hope to preserve them for future generation, and it is not only for SL but every animal
Camille, vice-director and teacher, working in a village school adjacent to a protected area.	admire it, associated to their land, proud of sharing the same land with such beautiful animal
Nicolas, art teacher, resident of a village adjacent to a protected area.	beauty, length of tail longer than body, just cannot imagine it aside beauty, cannot and would never imagine it as a beast [36] Strong aesthetic and symbolic appreciation of snow leopards (beauty, freedom).
Adri, ranger, working in protected area management.	admire the beauty, proud that SL live in KG, glad that SL live in SE and walk around us
Narcisse, biology teacher, resident of a village adjacent to a protected area.	Need to protect it and increase their number
Gaspard, mine worker, employed in an extractive industry operating near a protected area.	beauty, little bit of excitement but never seen closely. SL Very different from wolves: they make 10 puppies and increase so fast; different style of hunting SL kills 1 and wolves kill as much as they can to eat 1; SL easily to eliminate don't run away directly, wolves are really smart, hard to hunt
Diego, ranger, working in protected area management.	first beautiful creature. Second value because it is rare. Too much increasing SL will be dangerous, because not enough food base and will start kill livestock and then retaliatory elimination if too much attack
Esteban, ranger, working in protected area management.	Not thinking about it... but just to show it to tourists
Julien, ranger, working in protected area management.	Beautiful things of course but at the same time it's a predator

4. SENSR socio-ecological system

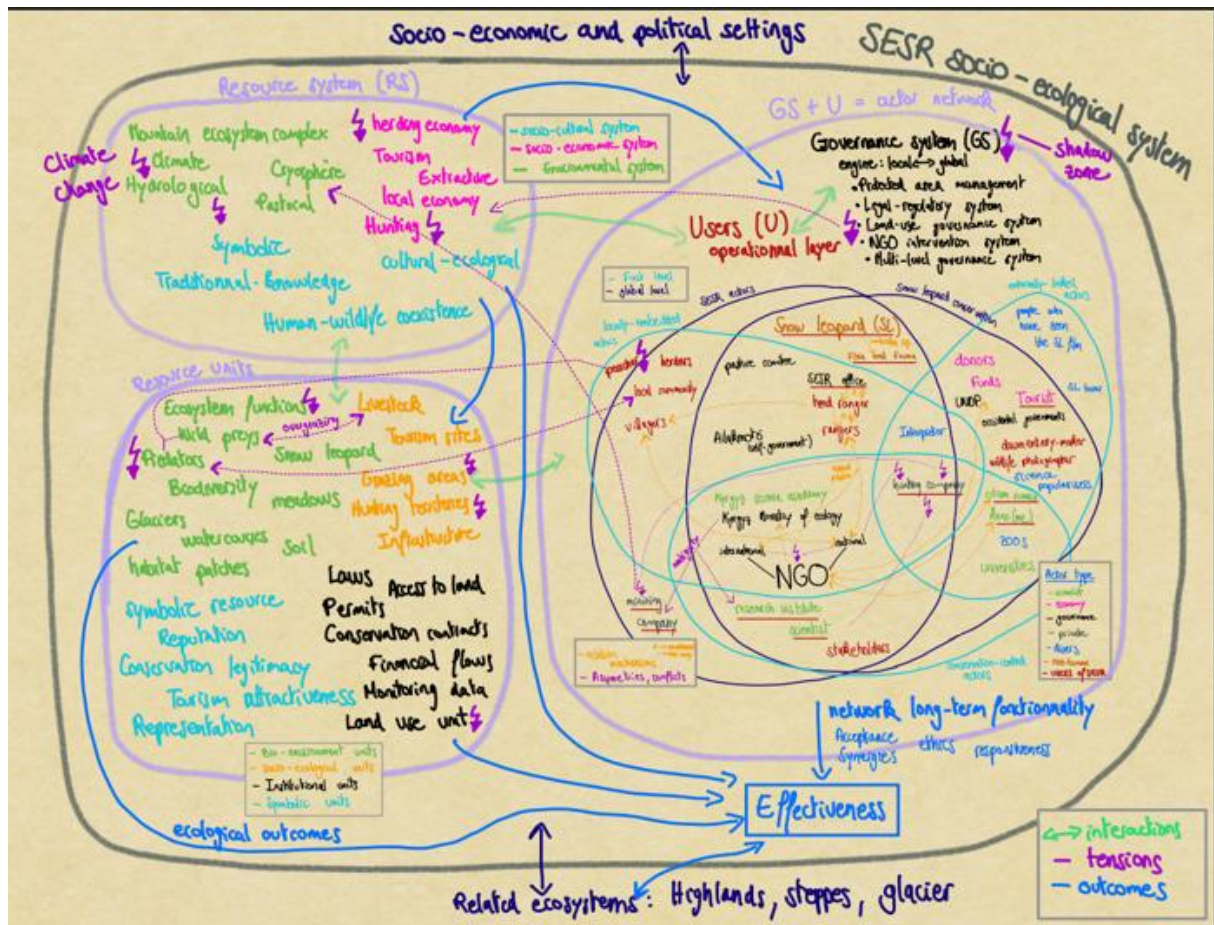


Figure 19: Original handwritten socio-ecological system of SENSR based on work of Ostrom (2009)