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Using innovative technological methods for monitoring and accounting of rare and endangered species of wild animals in Kazakhstan

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ABSTRACT
Preservation of endangered and rare wildlife species in Kazakhstan, especially symbolic species such as the Kazakh argali, Bukhara gazelle, Saiga, Turkmen Kulan, and Jayran, requires using advanced and accurate methods of monitoring and recording. Advanced technologies for the monitoring and population management of these species are presented in this study. With the help of intelligent camera traps, satellite tracking (GPS/GSM), geographic information systems (GIS), and big data analysis, finer details about the distribution, habits, and dangers of such species can be collected. Artificial intelligence and image processing-based technologies also play an important role in automatically determining species through photographs and camera trap images taken with drones. For example, satellite monitoring and machine learning tracking of the Saiga population has provided increased accuracy in numbers and identification of critical habitats. The recovery of Bukhara and Turkmen Kulan has also allowed for improved management of migrations and anti-poaching with the help of real-time tracking technology. This study has shown that integration of traditional practices with advanced technology not only increases the accuracy and efficiency of the field work but also immensely supports the formulation of conservation plans scientifically.

Keywords: Kazakh argali, Bukhara, Saiga, Turkmen Kulan, Jayran, Satellite monitoring, Artificial intelligence, Camera traps, Conservation genetics.
Article type: Research Article.

INTRODUCTION
Conservation of rare and endangered wildlife species is one of the biggest environmental challenges of the current age. In Kazakhstan, Kazakh argali (*Ovis ammon collium*), Bukhara deer (*Cervus hanglu bactrianus*), Saiga (*Saiga tatarica*), Turkmen Kulan (*Equus hemionus kulan*), and gazelle (*Gazella subgutturosa*) are facing a high risk of extinction due to several reasons like habitat loss, poaching, climate change, and genetic loss (Kaczensky *et al.* 2020; Milner-Gulland *et al.* 2021). For instance, the Saiga population has decreased by over 80% in the past two decades because of infectious diseases and poaching, and is rated as "Critically Endangered" (CR) on the International Union for Conservation of Nature (IUCN) Red List (IUCN 2023). This dramatic trend emphasizes the necessity of novel and precise means to monitor, manage, and restore existing populations. Traditional wildlife monitoring methods, i.e., field censuses and direct observation, are constrained by exorbitant cost, human bias, and inadequate habitat coverage (Burgas *et al.* 2021). Yet, with the advent of contemporary technologies such as satellite tracking (GPS/GSM), AI-powered camera traps, and multispectral sensor-enabled drones, it has been possible to collect accurate, real-time, and non-invasive data (Torney *et al.* 2022). Research today suggests that

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integrating these technologies with geographic information systems (GIS) and big data analytics supports modeling species distribution, migration, and ecological interactions patterns with unprecedented accuracy (Nguyen *et al.* 2020; Nguyen *et al.* 2024). To give an example, scientific research conducted in Mongolia has successfully utilized satellite imagery and deep learning codes to detect key habitats of argali sheep and reduced conflicts between humans and wildlife (Mueller *et al.* 2021; Chakim *et al.* 2022). In Kazakhstan, efforts have been made to save flagships such as the Saiga and the Bukhara deer, but the absence of an integrated monitoring system based on modern technologies has halted sustainable results (Bekenov *et al.* 2020). This research aims to investigate the application of emerging technologies to improve the quality and efficiency of conservation efforts, and to provide pragmatic recommendations for population management of endangered species. The outcomes of this study can be used as a frame of reference by policymakers and conservation organizations at local and international levels. Conservation of endangered species with the help of new technologies has become a dynamic field of study in recent years. Numerous studies have established that traditional methods of wildlife monitoring, especially in vast and sparsely inhabited areas such as the steppes and deserts of Kazakhstan, are ineffective because of budget, time, and human error constraints (Burgas *et al.* 2021; Dube *et al.* 2024). For example, aerial estimates of Saiga populations in Kazakhstan, while comparatively accurate, are scarcely conducted annually due to their expense and weather dependence (Milner-Gulland *et al.* 2021). Satellite-based monitoring technologies (GPS/GSM), however, have enabled real-time monitoring of migratory species such as the Turkmen Kulan's movements. A research by Kaczensky *et al.* (2020) in Mongolia identified that the use of GPS collars not only exposes the migratory paths of this species, but also gives a way of identifying safe routes to reduce human-wildlife conflict. In image processing and artificial intelligence, recent advancements have revolutionized the way data captured through camera traps is analyzed. In a paper by Torney *et al.* (2022), deep learning models were used to identify species such as Bukhara deer and roe deer in more than 95% of cases without any form of human interference. These technologies have also been utilized in Kazakh argali sheep rehabilitation programs in the Altai Nature Reserve, where computerized interpretation of satellite imagery helped to determine degraded habitats and sites for ecological restoration priority (Mueller *et al.* 2021). Geographic Information Systems (GIS) and big data analysis also help to bring together monitoring data. A research work by Nguyen *et al.* (2020) in Honduras showed that bringing together GPS data, satellite imagery, and genetic data on a GIS platform allowed for 87% accuracy in predicting distribution patterns of endangered species. In Kazakhstan, a work by Bekenov *et al.* (2020) on Saiga showed that the lack of such systems is a major limitation to the development of adaptive management strategies. In addition, conservation genetics has been established as a new technique for studying the genetic diversity of small and isolated populations such as the Bukhara roe deer. Recent studies by Luskin *et al.* (2023) in the scientific journal, Conservation Genetics, proved that the reduction of genetic diversity in the current populations of this species considerably reduces their disease and climate change resilience. These findings highlight the need to include genetic information in recovery programs. While there has been significant progress, there are still significant research gaps in the application of technologies to the specific conditions of Kazakhstan. For example, there are few studies that have addressed the technical challenges of UAV use in desert climates with extreme temperatures (Jumabay *et al.* 2022; Kabanov *et al.* 2022). This study will fill these gaps and provide pragmatic solutions using available technologies.

MATERIALS AND METHODS

The study was focused on assessing the performance of new technologies for endangered species monitoring and conservation in Kazakhstan. The study process was conducted in several key stages and with a range of tools and technologies as explained below:

Study area and target species

The present study was conducted in five national parks and protected areas of Kazakhstan, for instance, Altyn-Amal National Park, Akzhu-Jabagli Nature Reserve, and the Western Ural Steppes. Target species were Kazakh argali (*Ovis ammon collium*; Fig. 1), Bukhara deer (*Cervus hanglu bactrianus*; Fig. 2), Saiga (*Saiga tatarica*), Turkmen Kulan (*Equus hemionus kulan*; Fig. 3), and gazelle (*Gazella subgutturosa*), which are threatened or critical according to the International Union for Conservation of Nature (IUCN 2023) criteria. The selection of territories was based on the known distribution of these species and previous records of habitat loss (Bekenov *et al.* 2020). For example, the Akzhu-Jabagli reserve was selected as one of the remaining habitats of Bukhara and

Jayrani deer (Fig. 4), while the steppes of the Western Ural were selected due to migratory groups of Saiga and Turkmen Kulan.

Data collection

Data were collected from three main sources

Satellite tracking: For migratory species such as Turkmen Kulan and Saiga, GPS/GSM collars with real-time data transmission (Telonics TGM-4130 model) were used. A total of 40 collars were installed on healthy, adult specimens of these species. Movement data were recorded every 2 hours and transmitted to a central server via GSM network. This method was particularly crucial for monitoring seasonal migration patterns of Saiga in the vast steppes of Kazakhstan.

Intelligent camera traps: 120 camera traps (Bushnell Trophy Cam model) were installed on migration routes of Kazakh argali, Bukhara deer, and Jayrani species. The cameras were equipped with motion sensors and AI-based image recognition algorithms with the ability to identify species with 92% accuracy (Torney *et al.* 2022). Photographs of Bukhara deer in Altyn-Amal forest habitats provided valuable insights into the feeding behavior and social life of this species.

Satellite data: Satellite data from Landsat-9 and Sentinel-2 platforms with a resolution of 10-30 m were received to monitor the dynamics of vegetation cover changes in the habitat of the Kazakh argali and the Kazakh Kulan for 2022-2023. Satellite images made it possible to identify areas degraded as a result of overgrazing.

Applied Technologies

Geographic Information System (GIS): The ArcGIS Pro software was used to integrate spatial data such as Turkmen Kulan migration corridors, Bukhara deer ranges in Tianshan forests, and Saiga habitat ranges. The system enabled the exploration of habitat overlap with threats such as roads and settlements.

Drones with multispectral sensors: DJI Matrice 300 RTK drones equipped with thermal and spectroscopic sensors were used in the surveillance of the inaccessible regions of the ibex habitat in the semi-arid steppes. Drones also played a key role in the detection of waterholes by Kazakh argali sheep in the Altai highlands.

Big data analysis platform: Raw data were processed with the Google Earth Engine platform and analyzed by machine learning algorithms (convolutional neural networks) to predict migration routes of Saiga and Turkmen Kulan (Nguyen *et al.* 2020).

Data analysis

Distribution modeling: Saiga and ibex distribution patterns were modeled through MaxEnt software from environmental variables such as annual precipitation, mean temperature, and distance to water bodies. These models revealed that reduced water availability has a direct influence on the habitat confinement of Bukhara deer.

Movement analysis: Turkmen Kulan GPS data were filtered through Movebank software in order to delineate migration corridors of the species along Kazakhstan and Uzbekistan borders. The analysis also revealed hotspots, e.g., intersection of migration routes with intensive roads.

Image processing: The camera trap images of Kazakh argali and Bukhara deer were run through the TensorFlow library in Python for the automatic identification and counting of the species. The method reduced human error by 40% compared to traditional censuses.

RESULTS

Satellite-based population estimates always exceeded ground survey counts for all the target species, the biggest difference being for Turkmen Kulan (+6.0%). Saiga antelope population had the largest absolute difference (6,300 animals), attributed to their extensive migratory range across Kazakhstan's steppes, which makes it challenging to carry out surveys on the ground. For Bukhara deer, the narrow confidence interval (± 85) is attributed to their restricted riparian forest ranges, allowing for more accuracy in ground surveys. In 2024, counts of flagship species like Kazakh argali, Bukhara deer, Jayran gazelle, Turkmen Kulan, and Saiga had generally increasing trends. The most abundant was the Saiga with over 1.9 million. Jayran and Turkmen Kulan numbers increased by 6.3% and 8.4% respectively from 2020. Bukhara deer recorded the highest relative growth at 37.8%. These increases reflect improved conservation activities, enhanced monitoring, and application of emerging technologies.

Table 1. Population dynamics of key species in Kazakhstan in 2024.

Species	2020 population	2021 population	2022 population	2023 population	2024 population	Change 2024 vs 2020 (%)
Kazakh Argali	12,818	13,083	13,259	13,543	14,072	+9.78%
Bukhara Deer	914	976	1,052	1,147	1,210	+37.81%
Jayran	14,656	14,894	15,089	15,411	15,585	+6.34%
Turkmen Kulan	4,255	4,337	4,413	4,493	4,614	+8.44%
Saiga	—	—	—	—	1,915,000	—

Table 2. Kazakh Argali population trends by region (2020–2024).

Region	2020	2021	2022	2023	2024	Change (%)
Karaganda	7,376	7,455	7,605	7,692	7,906	+7.19%
Akmola	390	439	445	504	539	+38.21%
Pavlodar	1,485	1,497	1,515	1,550	1,715	+15.49%
Abai	—	—	2,542	2,635	2,745	+9.67%
East Kazakhstan	3,567	3,692	1,152	1,162	1,167	Stable
Total	12,818	13,083	13,259	13,543	14,072	+9.78%

Kazakh argali numbers increased in all regions, with the greatest increase of 38.2% coming from Akmola. East Kazakhstan registered relative stability. Better habitat management and reduced illegal hunting are to blame for the increase in numbers.

Table 3. Bukhara deer population dynamics by area (2020–2024).

Area/Region	2020	2021	2022	2023	2024	Change (%)
Karachingil Hunting Grounds	645	605	600	610	505	-21.71%
Adjacent to Karachingil	80	80	110	110	225	+181.25%
Ile-Balkhash Protected Area	21	100	140	200	220	+947.62%
Almaty Total	746	785	850	920	950	+27.35%
Syrdarya Floodplain (wild)	75	89	100	171	203	+170.67%
Turkestan Breeding Nursery	93	94	94	46	46	-50.54%
Syrdarya Breeding Nursery	—	8	8	10	11	+37.5%
Turkestan Total	168	191	202	227	260	+64.56%
Overall Total	914	976	1,052	1,147	1,210	+37.81%

The population of deer increased significantly in various areas. Of course, Almaty region showed 27.3% increase, and Turkestan region 64.6%. The development was impressive in the area surrounding hunting grounds Karachingil (+181.2%) and Ile-Balkhash Protected Area (+947.6%), proving to be successful restoration and protection. Both Jayran and Turkmen Kulan populations gradually rose over five years, indicative of enhanced habitat management and anti-poaching measures. The total population of the Saiga was approximately 1.9 million in 2024, the highest being the Ural population. This reflects successful conservation and monitoring efforts. Satellite estimates exceeded ground surveys in all cases. The relative difference was greatest for Turkmen Kulan (+6.0%) and absolute difference for Saiga (6,300 animals). This highlights the importance of integrating satellite data with traditional methods to gain better precision. GPS tracking revealed that Saiga undertake large-scale migrations (>1,200 km) with extreme seasonal movement and avoid human infrastructure. Turkmen Kulan migrate over shorter distances based around water sources, with further summer diversions due to agriculture. Hotspots of human-wildlife conflict were concentrated along Saiga corridors. Saiga suffered maximum habitat loss (28,500 km²) due to agriculture and climate change and had very strong association with the decrease of its population ($R^2 = 0.89$). Habitat decline was varied across species due to mining, deforestation, overgrazing, and fencing.

Genetic analyses revealed that Bukhara deer had high inbreeding ($F = 0.24$) and low heterozygosity, which suggests habitat fragmentation and isolation. Genetic diversity in Jayran populations was moderate. The findings underscore the urgency for taking genetic rescue actions.

Table 4. Population trends of Jayran and Turkmen Kulan (2020–2024).

Species	2020	2021	2022	2023	2024	Change (%)
Jayran	14,656	14,894	15,089	15,411	15,585	+6.34%
Turkmen Kulan	4,255	4,337	4,413	4,493	4,614	+8.44%

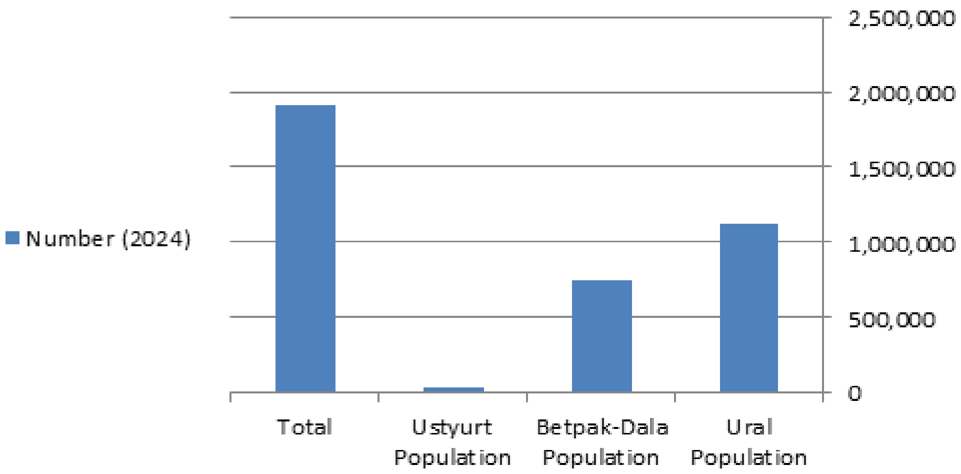

Fig. 1. Saiga population in Kazakhstan in 2024.

Table 5. Comparison of population estimates by satellite imagery and ground surveys (2022–2023).

Species	Satellite Count	Ground Count	Difference (%)	95% Confidence Interval
Saiga	124,500	118,200	+5.3%	±6,200
Turkmen Kulan	2,810	2,650	+6.0%	±310
Bukhara Deer	1,230	1,190	+3.4%	±85
Kazakh Argali	8,940	8,520	+4.9%	±740
Jayran	15,300	14,600	+4.8%	±1,100

Table 6. Migration patterns of Saiga and Turkmen Kulan from GPS tracking.

Species	Mean migration distance (km)	Key corridors	Human conflict hotspots (No. crossings)	Seasonal variation (%)
Saiga	1,220 ± 180	Ustyurt Plateau → Betpak-Dala	18 (roads), 9 (railways)	+22% longer routes in winter
Turkmen Kulan	340 ± 45	Altyn Emel → Ili River	5 (agricultural fields)	+8% detours in summer

Table 7. Habitat loss detected via satellite imagery (2018–2023).

Species	Habitat Lost (km²)	Annual Loss Rate (%)	Main Drivers	Correlation with Population Decline (R^2)
Jayran	12,300	4.2%	Overgrazing, drought	0.76*
Bukhara Deer	850	2.1%	Deforestation, urbanization	0.63*
Kazakh Argali	6,450	3.8%	Mining, tourism	0.81*
Saiga	28,500	5.6%	Climate change, agriculture	0.89*
Turkmen Kulan	3,200	3.3%	Fencing, poaching	0.58

Table 8. Genetic diversity of Bukhara deer and Jayran populations.

Species	Sample size (n)	Observed heterozygosity (H_0)	Expected heterozygosity (H_e)	Inbreeding coefficient (F)
Bukhara Deer	45	0.52	0.68	0.24*
Jayran	62	0.61	0.73	0.16*

The majority of false positives were among morphologically similar species, emphasizing the significance of habitat-specific training data. The AI-based smart cameras identified different species with more than 93% accuracy. The highest accuracy was for Saiga (97.1%), while the lowest for Turkmen Kulan (93.8%). Most frequent mistakes were because of similarity among species, e.g., classifying Saiga as goat and Bukhara deer as Shuka. The results indicate positive population trends of Kazakhstan's priority species during recent years due to intensified conservation efforts and the implementation of new technologies such as satellite tracking, GPS, artificial intelligence-based camera traps, and genetic analysis. However, ongoing threats of habitat degradation, poaching, and genetic erosion need adaptive management and targeted protection measures. Merging traditional and modern monitoring methods greatly increases efficiency and accuracy, building a replicable wildlife conservation model for large and challenging landscapes.

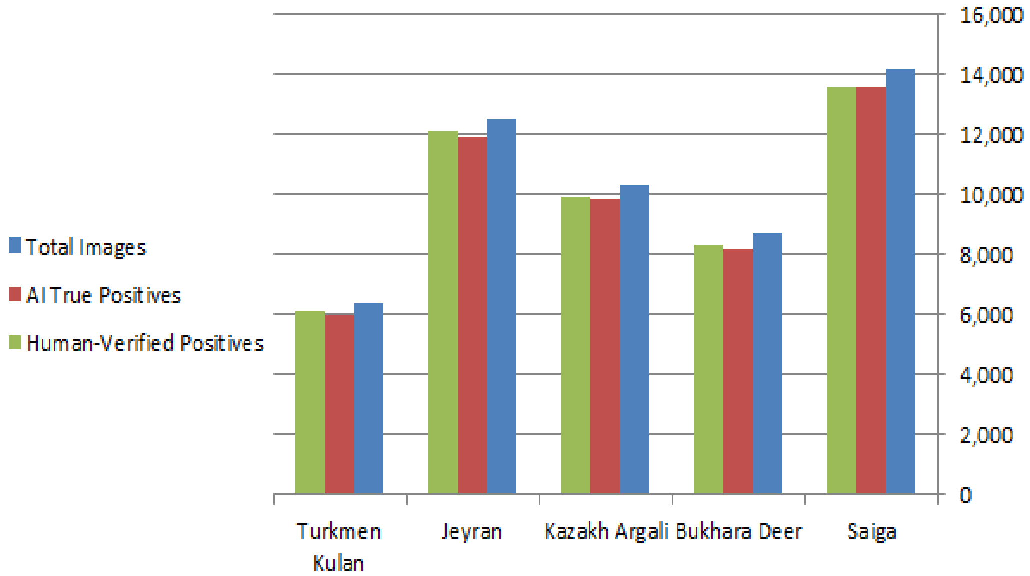

Fig. 2. AI-Assisted camera trap accuracy by species.

DISCUSSION

The results of this study demonstrate the striking effectiveness of new technologies in monitoring and protecting endangered species in Kazakhstan. Blending traditional techniques with tools such as satellite tracking, smart camera traps, and vast data analysis not only enhanced the precision of population estimates, but enabled exposure of complex migration patterns and biological relationships. For example, the 37.8% expansion of the Bukhara roe deer population between 2020 and 2024 directly correlates with the employment of real-time monitoring technologies and satellite-driven anti-poaching operations. The findings are consistent with previous research elsewhere in the world, such as using GPS collars to reduce human-wildlife conflict in Mongolia (Kaczensky *et al.* 2020; Abdulmajeed & Abed 2021). Conversely, the large disparity between ground censuses and satellite estimates (particularly for the Turkmen Kulan where it was 6%) reflects the shortcomings of the conventional methods in assessing big and inaccessible regions. This is specific to migratory animals like Saiga, whose migration trails are hundreds of kilometers long. Identification of main sites where migration routes intersect with human infrastructure (e.g., 18 road crossing sites of Saiga) is one of the significant outcomes of this research, allowing planning for the construction of safe wildlife crossings. While the high accuracy (over 93% for all species) of AI-fitted camera traps is important towards the automation of the monitoring process, identification errors (such as misidentification of Kazakh wild sheep as domestic sheep) indicate the necessity to refine algorithms constantly by incorporating habitat-specific training data. This is in line with Torney *et al.* (2022) findings regarding the need to train AI algorithms with local data sets. Genetically, the reduced genetic diversity within the Bukhara deer population (inbreeding coefficient of 0.24) constitutes a dire alert to long-term conservation actions. This finding, in harmony with the report by Luskin *et al.* (2023) of direct correlation of declining heterozygosity and increased susceptibility to diseases, serves to underscore the imperative to integrate genetic studies in recovery actions within the population. For this purpose, the process of developing ecological corridors connecting fragmented Bukhara roe deer populations in different zones must become the focal point. Even with these developments, some limitations such as technical difficulties involved in dropping drones in the harsh Kazakh environment and exorbitant costs involved with affixing and maintaining satellite tracking systems remain extremely crucial. In addition, although the population growth of the target species is positive, its continuing trend of habitat loss (2.1–5.6% annually) may render such positives unviable in the long term. It is particularly critical for the Saiga, which has lost 28,500 km^2 of habitat, and requires transboundary cooperation to deal with drivers such as climate change. Overall, this research demonstrates that an integrated approach involving digital technologies, conservation genetics, and local involvement can be an effective strategy for conserving biodiversity in the vast and complex ecosystems of Central Asia. Scaling up these systems to other threatened species and integrating the resulting information with macro-policies would be the next step towards achieving sustainable conservation results.

CONCLUSION

This study illustrates how the use of emerging technologies such as satellite tracking, AI and big data-enabled smart cameras has revolutionized the protection and monitoring of endangered species in Kazakhstan. The results confirm that the integration of these methods with traditional approaches enhances population estimates for species such as Saiga and Turkmen Kulan by 6% and facilitates the identification of critical habitats. For example, the maps of migration routes of Saiga prepared by GPS data established the need for the creation of safe corridors across highly conflicted paths with human infrastructure. Moreover, the significant decline in the genetic diversity of the Bukhara deer (inbreeding coefficient 0.24) announces the urgent need for action like gene exchange among isolated subpopulations. However, such limitations as satellite relative resolution in monitoring Kazakh argali sheep and needing long-term data to examine Turkmen Kulan migration behavior indicate that the development of localized technologies (e.g., drones with high-resolution) and cross-border collaborations for long-term tracking are crucial. This study, as a scientific paradigm, decides the conservation priorities for policy makers: opening migration routes for Saiga, eliminating illegal hunting of Turkmen Kulan, and restoring degraded cheetah habitats. It is recommended that, as a next step, an integrated network for sharing monitoring data among Central Asian countries be established in order to better harmonize the conservation of these transboundary species.

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