

Article

Railway and Road Infrastructure in Saiga Antelope Range in Kazakhstan

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Abstract: The saiga antelope (*Saiga tatarica*), a keystone migratory species of the Central Asian steppes and deserts, is increasingly threatened by habitat fragmentation due to the rapidly expanding transport infrastructure in Kazakhstan, which hosts approximately 95% of the species' global population. This study provides a spatial assessment of railway and road infrastructure across the contemporary ranges of the Betpaqдала, Ustyurt, and Ural saiga populations. Using the literature and our field data from the 1980s to the present day, combined with geographic information system (GIS)-based analysis of 80,427 km of roads and 4021 km of railways, we have quantified infrastructure densities and identified critical barriers to saiga migration using kernel density and minimum convex polygons (MCP) estimations. The results reveal a negative connection between infrastructure density and occurrences of saiga herds, particularly in the Ustyurt population, where a high railway density coincides with severely reduced migratory activity and a reduction in this population's winter range by 79.84% since 2015. Major railways such as Sekseuildi–Zhezqazgan, Zhezqazgan–Zharyk, and Shalqar–Beineu intersect essential migratory pathways and have contributed to significant range contraction, subpopulation isolation, and northward shifts in seasonal habitats. In contrast, the Ural population (subject to minimal railway infrastructure interference) has shown robust demographic recovery. While roads are more widespread, their impact is less severe due to greater permeability. However, upcoming projects such as the China–Europe transit corridor and the “Center–West” regional development corridor could amplify future threats. We recommend immediately implementing wildlife-friendly infrastructure, including overpasses and ecological corridors, to preserve the connectivity of saiga ranges and support the long-term conservation of this ungulate species.

Keywords: habitat fragmentation; linear infrastructure; migration barriers; railway ecology; road ecology; *Saiga tatarica*; steppe conservation



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1. Introduction

Kazakhstan is home to 95% of saiga antelopes (*Saiga tatarica*), a typical migratory species that regularly changes its habitats throughout the year within the steppe, semi-desert, and desert zones in the Betpaqdala (Betpak Dala), Ustyurt, and Ural regions [1–3]. The territorial distribution of animals varies from year to year, depending on natural conditions, abundance, and the anthropogenic transformation of the environment. As their populations recover from historical declines [4], conservation efforts are increasingly focused not only on poaching and disease control but also on the impacts of landscape fragmentation and habitat accessibility. In particular, the saiga is a species that is known to form large herds, especially during spring–autumn migrations [5,6].

One of the emerging threats to saiga migration is the rapid development of linear infrastructure across the species' range [7]. Roads, railways, and associated fencing can create significant barriers to movement, impede access to critical seasonal habitats, and increase mortality due to vehicle collisions for this and other ungulate species [8]. Moreover, infrastructure development often precedes or accompanies industrial expansion, further intensifying anthropogenic pressure on saiga habitats.

Despite the recognized importance of maintaining landscape connectivity for saiga conservation [9], comprehensive assessments of the distribution, density, and potential impact of linear transport infrastructure across their current range in Kazakhstan remain limited. This study aims to evaluate the impacts of linear infrastructure on saiga antelope distribution and habitat fragmentation in Kazakhstan by (i) mapping and quantifying road and railway densities within the current saiga range, (ii) analyzing the spatial overlap between linear infrastructure and saiga distribution, and (iii) identifying potential fragmentation effects, with a particular focus on comparing the differential impacts of roads and railways.

2. Materials and Methods

This study used geospatial analysis to assess the distribution of road and railway infrastructure across the saiga range in Kazakhstan. The methodology was divided into three main components: determining the range and spatial structure of saiga populations, obtaining and categorizing layers of linear infrastructure, and GIS data processing.

2.1. Determining Saiga Range

To study the current distribution of saiga populations, we used field data collected over a 15-year period (2011–2025). We also relied on previous data collected in the 1980s and 1990s [1,2,10], as well as data extracted from the literature [11–13].

Field studies were conducted using motor vehicles in limited areas, as well as light aircraft [14–16]. Annual aerial surveys of saigas, initiated by the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan, are conducted in April. Flight routes are laid every 5–10 km and carried out at an altitude of approximately 120 m, while the width of the counting strip is 1600 m (800 m on each side). The spatial analysis of saiga distribution includes materials from a survey conducted in April 2024, where 30,000 km of flight routes were covered during a flying time of 215 h. These routes included all regions of Kazakhstan where saigas are found, ensuring a high level of data completeness. All observations were recorded using satellite navigation devices.

Thus, the estimation of the total combined saiga range of three main populations (Betpaqdala, Ustyurt, and Ural) was conducted based on data collected from the 1980s to the present day. The ranges of these populations were digitized and standardized using GIS tools to produce a unified shapefile of the saiga distribution for analysis.

To determine winter habitats, we recorded the spatial distribution of saigas from the first half of October to the end of March (a six-month period) and, for summer habitats, from the first half of April to the end of September [17]. Given that the timing of seasonal movements may vary by year, we used the mean of the distribution indicators of animals over the past 5 years to delineate winter and summer habitats within the overall species distribution.

2.2. Layers of Linear Infrastructure

Data on linear transport infrastructure were obtained from multiple sources, including OpenStreetMap 1.0 (OSM, OpenStreetMap Foundation, Cambridge, UK) [18], the Global Roads Inventory Project (GRIP, Netherlands Environmental Assessment Agency, Hague, The Netherlands) [19], and national infrastructure databases. Layers were filtered and categorized into major (paved highways and regional roads) and secondary roads and tracks (Figure A1), and major railways (national and regional) (Figure A2). We did not take into account pedestrian roads or similar smaller in-city roads, nor railway junctions shorter than 5 km, as they are all located within larger cities with no saiga occurrence. Each layer was projected into a common coordinate system for spatial analysis.

2.3. GIS Data Processing

We processed all spatial data using ArcGIS Pro 3.4 (Esri, Redlands, CA, USA) [20] and Quantum Geographic Information System (QGIS) 3.10 [21]. The saiga range polygons were intersected with linear infrastructure layers to extract segments of roads and railways within the current distribution. The metrics that were calculated included the total length (km) of infrastructure within the saiga range, infrastructure density (km per 100 km²), and directionality of major infrastructure corridors. Visual outputs were generated using kernel density and line direction analysis to understand fragmentation patterns and dominant movement barriers.

2.4. Saiga Herding Sites vs. Infrastructure Density Analysis

We calculated the density of roads and railways (km per 100 km²) within the delineated saiga ranges (winter and summer habitats). We overlaid spatial data of saiga observations (from aerial surveys in April 2024)—specifically, the locations of large herds (saiga herding sites)—with the kernel density maps of infrastructure to identify patterns of avoidance or presence [22]. We interpreted the absence of saiga in high-density infrastructure zones, alongside known migration routes and historical data (1980s–2025), as indicative of avoidance behavior and habitat fragmentation [23]. We also used qualitative evidence, including mortality records (e.g., April 2025 incidents on the Zharyk–Zhesqazgan line) and lack of post-2016 mass crossings at newly constructed railways (e.g., Zhezqazgan–Sekseuldi), to support the conclusion that railways act as significant barriers.

We used minimum convex polygons (MCP) [24]—in particular, convex hulls—to determine the borders of the saiga antelope's range and to evaluate if there is an overlap between saiga herding sites and linear infrastructure in the example of the Ustyurt population. This population has experienced a complete blockage of the migratory route due to the construction of the Shalqar–Beineu railway in 2015. We selected three time periods of saiga observations for the estimation: two years before and after the railway construction to ensure an accurate assessment, and the present situation—2012 (pre-construction period), 2017 (post-construction period), and 2024 (current conditions).

3. Results

3.1. Description of Saiga Range in Kazakhstan

The spatial structure of the saiga has historically tended to fluctuate in response to environmental and anthropogenic factors. Over the past 100 years, the saiga range in Kazakhstan has undergone alternating periods of contraction and expansion. Subsequently, gaps between the main population centers became more pronounced, which led to the fragmentation of the saiga range in Kazakhstan into three separate populations: Ural, Ustyurt, and Betpaqdala (Figure 1). We have estimated the total combined area of the saiga range in Kazakhstan to be 1,062,458 km². The saiga population's distribution areas in Ural, Ustyurt, and Betpaqdala are 107,588 km², 297,194 km², and 657,676 km², respectively. The spatial structure of the saiga historically tends to change based on environmental and human factors.



Figure 1. Map of saiga population distribution in Kazakhstan.

At present, the Kazakhstan part of the saiga's range partially covers the territories of 13 administrative regions. The range of the Ural population is located within the West Kazakhstan and Atyrau regions; the range of the Ustyurt population is within the Aktobe, Atyrau, and Mangystau regions; and the range of the Betpaqdala population is within the Karaganda, Ulytau, Akmol, Kostanay, Aktobe, Kyzylorda, South Kazakhstan, and Zhambyl regions, and also covers small areas on the outskirts of the Almaty region.

As illustrated in Figure 1, saigas migrate annually between wintering and summering areas during the spring and autumn. These migrations are driven by the need to change pastures due to drying vegetation in summer or food inaccessibility due to deep snow cover in winter. Taking into account the seasonal changes in habitat use, we approximately divided the map of the saiga's population distribution in Kazakhstan into winter and summer ranges for further analysis of the impact of transport infrastructure. The general direction of spring migrations is toward the north or northwest, while autumn migrations tend to follow a southern or southeastern route. The timing, routes, distances, and speed of migration can vary across years and regions, depending on weather and climate conditions, pasture quality, availability of water sources, levels of human disturbance, and the presence of artificial barriers [25].

3.2. Analysis of Linear Transport Infrastructure in Saiga Range in Kazakhstan

The spatial analysis revealed the significant presence of both road and railway infrastructure intersecting saiga habitats in Kazakhstan (Figure 2). The growing density of transport infrastructure within the saiga's range has significantly reduced the availability of suitable habitats for this ungulate. This effect is especially pronounced in the Betpaqdala and Ustyurt populations, where the densities of the transport network are estimated at 0.342 km/100 km² and 0.55 km/100 km², respectively. In these regions, saiga herds are primarily observed in areas unaffected by transport infrastructure. In the Ural population's range, where the density of transport infrastructure is much lower (estimated at 0.128 km/100 km²), despite the gathering of animals in the northwestern part of the range, saiga dispersal is still observed throughout the range. According to aerial surveys and ground observations, a year after the construction of the Zhezkazgan–Sekseildi (Betpaqdala population) and Shalqar–Beineu (Ustyurt population) lines in 2015, no mass animal migrations across these railways were recorded from 2016 to 2025.

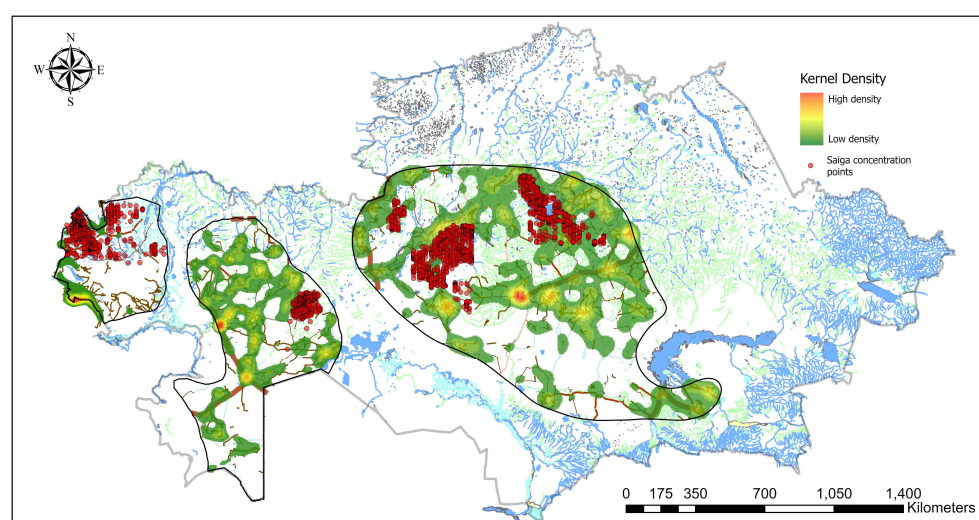


Figure 2. Map of kernel density of railway and road infrastructure in the saiga's range in Kazakhstan with saiga herding sites during an aerial survey in April 2024.

The main linear infrastructure density cores are located in Zhanibek (Ural population), Kulsary (Ustyurt population), and Satbayev (Betpaqdala population). In total, 4021.54 km of railway lines cross the current saiga range (Table 1).

Table 1. Major railway infrastructure influence on saiga habitats.

Populations	Railways					
	Name	Length, km	Direction, North (N), East (E), South (S), West (W)	Habitat Intersection	Degree of Negative Influence	Infrastructure Density, km/100 km ²
Ural	Saratov–Astrkhan	137.3	N–S	Westernmost area: partially winter and summer habitats	Low	0.128
Subtotal		137.3				0.128
Ustyurt	Beineu–Aqtau	280	NE–SW	Southwest area: winter habitats	Medium	
	Beineu–Shalqar	440	NE–SW	Winter habitats: significantly cuts off migration route to winter habitats (including Uzbekistan)	High	
	Maqat–Turkmenabat	434	N–S	Westernmost area: partial winter and summer habitats	Low–medium (more clarification needed)	
	Qandyagash–Atyrau	482.4	NE–SW	Summer habitats	High	

Table 1. Cont.

Populations	Railways					
	Name	Length, km	Direction, North (N), East (E), South (S), West (W)	Habitat Intersection	Degree of Negative Influence	Infrastructure Density, km/100 km ²
Subtotal		1636.4				0.55
Betpaqdala	Khromtau–Qostanay	198.7	NE–SW	Northwestern area: summer habitats	Low	
	Esil–Kyzylzhar	510	N–S	Divides the population into distinct eastern and western population groups	High	
	Zhezqazgan–Sekseuildi	462.7	E–W	Winter habitats: significantly cuts off migration route to winter habitats	High	
	Zhezqazgan–Aibat	130	N–S	Central area, located in winter habitats	Medium	
	Zharyk–Zhesqazgan	443.14	E–W	Winter habitats: significantly cuts off migration route to winter habitats	High	
	Qaraghandy–Shu	447.9	N–S	East and southeast areas: winter habitats	Medium	
	Qarazhal	70.6	N–S	Central area, located in winter habitats	Medium	
	Aqsuiek	61.6	E–W	Southeast area: winter habitats	Medium	
	Moiynty–Balkhash	31.1	NW–SE	Eastern area: winter habitats	Low	
	Zhezqazgan internal	118.1	N–S	Central area, located in winter habitats	Medium	
Subtotal		2247.84				0.342
TOTAL		4021.54				0.378

The main corridors include the Zhezqazgan–Sekseuildi line (Betpaqdala) and the Beineu–Shalqar line (Ustyurt). These lines run predominantly in the NE–SW and NW–SE directions, potentially disrupting seasonal north–south saiga migrations. The total density of railway infrastructure is estimated to comprise 0.378 km of lines per 100 km² in saiga habitats. Among these, the highest railway density can be observed in the Ustyurt population’s habitat and the lowest in that of the Ural population.

As seen in Table 1, the Ustyurt population, with an infrastructure density of 0.55 km/100 km², is facing an existing negative influence of the railway network, which has increased in recent years due to the construction of the Beineu–Shalqar railway (Figure 3).

The construction of railways resulted in a 79.84% decline in the Ustyurt population’s critically important wintering grounds in Kazakhstan, from 157,912.61 km² to 31,834.57 km², indicating blocking access to the wintering grounds south of the mentioned railway and avoidance behavior of antelopes towards the infrastructure. In the Betpaqdala population, despite the construction of the Zhezqazgan–Sekseuildi railway in 2015—similar in structure and length to the Beineu–Shalqar railway—this infrastructure does not completely block the migration route to the wintering grounds but significantly reduces their accessibility.

Interestingly, roads are more widespread than railways, with 80,427.556 km of highways and primary and secondary roads within the saiga’s range in Kazakhstan (Table 2).

The road density is estimated to be 7.569 km per 100 km² in all Kazakhstani saiga habitats. Throughout the country’s saiga range, the highest road density can be observed in the Ural populations (12.94 km/100 km²), where there are major highways such as Chapaev–Kaztalovka–Zhanibek (about 350 km) and Chapaev–Zhanakala–Saykhin (about 420 km), located at the intersection of the population’s winter and summer habitats.

The overall density of linear transport infrastructure within the saiga range was calculated as 8.013 km/100 km². Fragmentation appears to be most severe in the Ustyurt area (Figure 3) and, partially, the Betpaqdala area, where overlapping roads and railways create complex movement barriers.

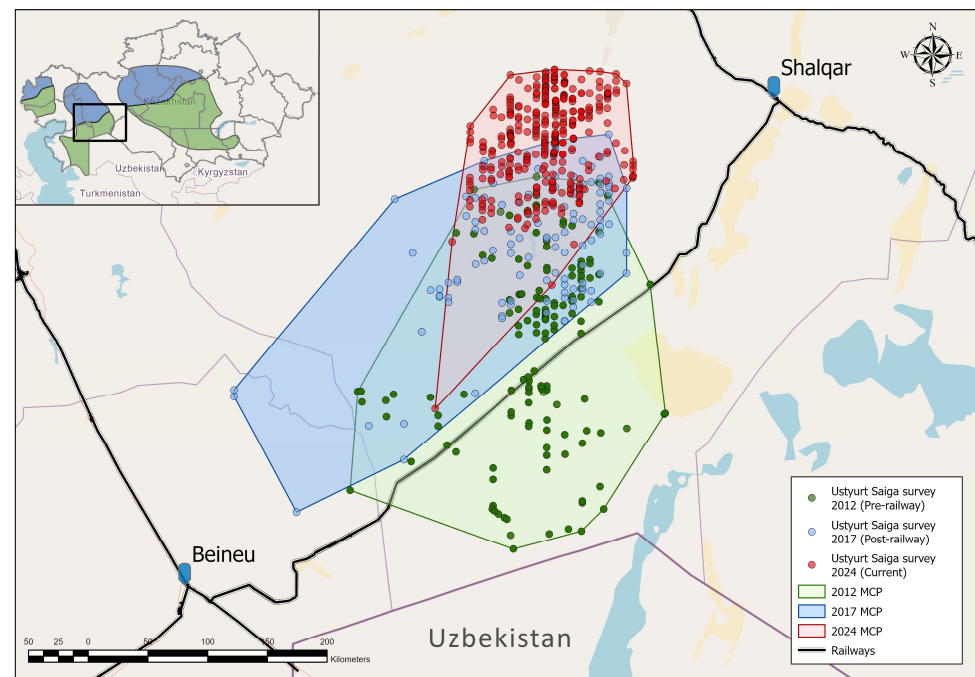


Figure 3. Convex hull-based polygons (Minimum convex polygons) representing Ustyurt saiga antelope herding in 2012 (pre-railway construction), 2017 (post-railway construction), and 2024 (current conditions) in relation to the Shalqar–Beineu railway.

Table 2. All road infrastructure on saiga habitats.

Road Type	Betpaqdala, km	Betpaqdala, Infrastructure Density, km/100 km ²	Ural, km	Ural, Infrastructure Density, km/100 km ²	Ustyurt, km	Ustyurt, Infrastructure Density, km/100 km ²
Path, i.e.,	172.0478027	0.02616	308.5592	0.286797	93.92054	0.031602
summer habitats	15.44823413	0.00689	7.0650844	0.018471	2.1525464	0.001641
winter habitats	156.59956854	0.03634	35.981423	0.054511	91.767998	0.058113
Primary, i.e.,	1741.837165	0.264847	-	0	508.1813	0.170993
summer habitats	713.5166390	0.31837	-	0	1156.3330	0.88162
winter habitats	1028.001603	0.23858	-	0	-	0
Residential, i.e.,	2581.978515	0.392591	719.3635	0.668628	1285.733	0.432624
summer habitats	1156.333099	0.51596	497.38299	1.300415	960.40188	0.732237
winter habitats	1428.3004516	0.33148	153.77575	0.232968	325.09546	0.205871
Secondary, i.e.,	2549.672958	0.387679	488.7311	0.454262	425.787	0.143269
summer habitats	1020.8328	0.455501	457.76452	1.196832	404.2399	0.308203
winter habitats	1517.706030	0.352231	-	0	21.547093	0.013645
Service, i.e.,	3245.201358	0.493435	71.78363	0.066721	1925.295	0.647824
summer habitats	1304.492315	0.582071	25.146703	0.065746	1148.0225	0.875284
winter habitats	1942.7043969	0.450866	25.314717	0.038351	729.50831	0.461971
Tertiary, i.e.,	6057.923224	0.921111	968.8612	0.900529	1803.744	0.606925
summer habitats	2366.036218	1.055738	376.51739	0.984411	1450.1803	1.105657
winter habitats	3691.685269	0.856772	532.03946	0.806035	353.43203	0.223816
Track, i.e.,	13,505.43834	2.053509	8621.897	8.013809	11,455.43	3.854528
summer habitats	4203.112250	1.875451	550.51227	1.439323	5575.8501	4.251182
winter habitats	9229.787567	2.142063	4685.456	7.098423	5781.098	3.660962
Steppe track, i.e.,	1047.458603	0.159267	-	0	914.471	0.307702
summer habitats	473.1846065	0.211137	-	0	426.37863	0.325083
winter habitats	574.2739896	0.133278	-	0	468.9296	0.296956
Trunk, i.e.,	1504.70543	0.228791	-	0	719.565	0.24212
summer habitats	420.0208878	0.187415	-	0	233.54176	0.17806
winter habitats	1084.693935	0.251737	-	0	469.22363	0.29714
Unclassified, i.e.,	10,257.96337	1.559729	2742.175	2.548774	4709.833	1.584767
summer habitats	3576.625473	1.595909	1395.8204	3.649394	2924.0176	2.229351
winter habitats	6682.388006	1.550859	913.13843	1.383396	1774.2123	1.123545
Subtotal, summer habitats	15,249.60252	6.804456	3310.2093	8.654594	14,281.118	10.888318
Subtotal, winter habitats	27,336.14081	6.344214	6345.7057	9.613686	10,014.814	6.342022
TOTAL	42,664.22677	6.487119	13,921.37	12.93952	23,841.96	8.022354

4. Discussion

4.1. Description of Saiga Range in Kazakhstan

The global range of saiga antelopes covers the territories of Kazakhstan, Uzbekistan, Russia, and Mongolia in Central Asia [26], with the largest part located within Kazakhstan. In the last century, the range of the saiga in Kazakhstan extended from the Caspian Sea in the west to Lake Zaysan in the east and from the border with Russia in the north to the foothills of the Tien Shan in the south [11]. Later, the range decreased, and the saiga disappeared from the vicinity of Lake Zaysan and the Alakol Basin [12]. Currently, three separate populations live within the saiga range in Kazakhstan: Betpaqdala (between Lake Balkhash and the Aral Sea), Ustyurt (between the Aral and Caspian Seas), and Ural (between the Ural and Volga rivers) [1].

The Ustyurt and Ural populations are transboundary; the Ustyurt population partially migrates in the autumn–winter period to the border regions of Uzbekistan, while the Ural population partially migrates in the spring–summer period to the neighboring regions of Russia. The winter and summer habitats of the Betpaqdala population are located entirely within Kazakhstan. The length of the annual saiga migration routes (from south to north) is 200–300 km in the Ural–Volga interfluvium, 300–600 km in the Ustyurt, and 600–1200 km in Central Kazakhstan [1].

After the restoration of the saiga's range and population numbers by the early 1950s, the spatial structure of the species' populations changed many times in the following decades [3], and it is still changing. Since the mid-1990s, a decline in saiga numbers due to mass poaching has led to its range shrinking once again. By the end of the century, saigas had practically disappeared from the Northern and Southern Balkhash regions, Betpaqdala, Muyunkum, Kyzylkum, the Aral Sea, the area north of the Emba River, and the Eastern and Southern Caspian regions. By the beginning of the 21st century, the saiga's range had decreased by about half compared with the 1980s [27,28]. This reduction occurred mainly in the peripheral parts of the range. Although the overall habitat remained quite extensive, it became fragmented in most areas, with very sparse populations. Habitat and population restoration began in 2004–2005, after significant improvements in saiga protection on both national [29] and international scales [30]. Thus, according to government legislation, the saiga is included in the national "List of valuable animal species that are objects of hunting and fishing", and the seizure of saigas was banned up to 2023, except for their use for scientific purposes [31–36]. Internationally, the species was listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Convention on Migratory Species (CMS), as well as being listed as critically endangered (CR) in the International Union for Conservation of Nature (IUCN) Red List from 2002 to 2023, and it had become as rare as many other mammalian species in Central Asia [37–44]. Over the following years, the species' habitat has alternated between periods of expansion and contraction, depending on various factors. In current conditions, the rate of saiga habitat restoration depends primarily on the effectiveness of protection measures. Among natural factors, the distribution of animals is obviously affected by climate change (in particular, global warming) [45]. Winters have become milder and less snowy, resulting in saiga wintering grounds noticeably shifting north. During unusually mild winters in the past, saigas occasionally remained further north than usual, such as in the vicinity of Lake Shalkarteniz or within the Korgalzhyn Reserve [13]. However, such occurrences used to be an exception, whereas they are now common. In the Ural–Volga interfluvium, the saiga's wintering grounds have also shifted noticeably northward, from the Volga–Ural sands to the vicinity of Lake Aralsor and farther north. Similarly, calving grounds have moved to areas near the villages of Borsy and Sverdlovo, close to Kazakhstan's northwestern border with Russia.

4.2. Influence of Linear Infrastructure on Saiga in Kazakhstan

The main threats to saigas in the past included heavy snow, ice, diseases, and poaching [2,46,47]. Saigas are also threatened by competition with livestock, both for forage and habitat [48,49]. Currently, highways and railways have increasingly become significant limiting factors for saigas and other ungulates by impeding their movement [3,50–52]. Saigas migrate south to north and northwest in the spring and in the opposite direction in the autumn. Therefore, the main obstacles for animals are roads that intersect migration routes, particularly those laid from west to east [53–56].

Fences along transport routes also negatively impact saiga antelopes, especially when these structures intersect their migration corridors. In some road sections, transport routes are fenced to prevent domestic livestock from accessing highways, and while they are used here to reduce livestock–vehicle collisions, they also serve as barriers to movement and may limit accessibility to resources for wild ungulates [57,58]. These exclusion fences are typically located near human settlements [59]; based on our observations, saigas tend to avoid such places, and the mortality rate here is not high. However, in April 2025, a small group of saigas died during the spring migration due to recently installed fences along the Zharyk–Zhesqazgan railway. During the Soviet era, the widespread use of so-called “cultural pastures” involved fencing off agricultural lands for managed grazing [60]. This practice had adverse ecological consequences, disrupting the natural movement patterns of wildlife, and was eventually phased out. In recent years, however, the issue has resurfaced in Kazakhstan due to an increase in saiga abundance, and their presence in private rangelands and croplands has led to conflicts with agricultural producers [61,62]. Consequently, there are proposals to reintroduce fencing as a means of exclusion, and in the future, this could become a threat to the species.

During fieldwork, our inability to continuously monitor the area—especially during migration periods—has limited our ability to fully document saiga mortality and movements across fences along railways and highways. As a result, we continue to gather data and are currently unable to accurately assess the scale of the impact that these barriers have on saiga populations.

4.2.1. Railways

Animal movements are typically shorter in areas with high human impact, likely owing to changed behaviors and physical limitations [63]. These include linear transport infrastructure, especially railways, which can cause habitat fragmentation and genetic isolation for ungulates and other migratory species [64].

As shown in Table 1, with the highest railway density being in the Ustyurt, saiga abundance in the area is also the lowest, with numbers declining to 1300 individuals in 2015, coinciding with the construction of the Shalqar–Beineu railway [26]. They have not increased significantly since. As most of the railways in the Ustyurt intersect saiga seasonal migration routes and key lodging habitats, this infrastructure type may be one of the main factors affecting these ungulates. For instance, the main railways of concern for saiga migrations are Beineu–Shalqar and Zhezqazgan–Sekseildi in the Ustyurt and Betpaqdala, respectively. Despite their route lengths being shorter than some of the other railways, these lines partially or fully cut off the saiga’s routes [9,25]. Conversely, the infrastructure density in the Ural population is the lowest among the three (0.128 km/100 km²), and their numbers have skyrocketed to over 1.62 million individuals as of 2024 [65].

The migration routes of saigas primarily run from south to north and back, making railways laid in a latitudinal direction (west to east) significant obstacles. In the Betpaqdala population’s range, these include the long-established Zhezqazgan–Zharyk railway line,

443 km in length, and the recently constructed Zheqazgan–Sekseildi road (462 km), as well as the Shalqar–Beineu line in the Ustyurt population’s range, which is 440 km long.

No wildlife crossings were built along the Zheqazgan–Zharyk railway and saigas tend to cross it at locations where the embankment is either absent or very low. However, this consistently poses difficulties for the animals: saigas often hesitate to cross immediately, moving along the railway in search of suitable crossing points, gathering in large groups, and eventually running across the line as a herd, sometimes being struck by passing trains. Based on an analysis of departmental data and a survey of the railway and environmental protection industries, the deaths of dozens of saigas resulting from collisions on railways in recent years have been periodically noted. The last case was in January 2024 along the Shubarkol–Kyzylzhar railway in the Ulytau region, where 25 dead saigas were found due to a collision with a diesel locomotive. The reason for hesitation could be due to the higher visibility of linear infrastructure in open areas [66]. Xia et al. [67] found that the Tibetan antelope also does not cross railways because of hesitation, most likely because of the slope of the rail bed. Calves often die during mass crossings after lambing when large groups of animals move across the railway in a continuous stream and train drivers are unable to stop in time.

According to our observations, in recent years, saigas have not crossed these roads during their autumn migrations, meaning that traditional wintering grounds for the animals have become inaccessible. Saiga antelopes may have started to avoid railways in the Ustyurt due to behavioral changes in response to intense railway development in this area, as was shown for other ungulate species [68]. Thus, Sawyer et al. [68] suggest that mule deer can migrate through moderate levels of infrastructure development without any noticeable effects on migratory behavior. However, in areas with more intensive development, these mule deer frequently deviate from traditional pathways, move at a faster pace, and spend less time at stopover sites, resulting in a decline in both the overall usage and breadth of migration corridors.

The recently built Zheqazgan–Sekseildi and Shalqar–Beineu railways cross saiga migration routes and currently pose significant barriers. Previously, the maximum length of saiga migration routes reached approximately 1200 km in the Betpaqdala population, 600 km in the Ustyurt population, and 300 km in the Ural population. Currently, these migration routes have been reduced by about half. Since the construction of the Zheqazgan–Sekseildi and Shalqar–Beineu railways in 2015, saiga wintering grounds have shifted farther north, and sightings south of the roads have been only isolated incidents. In particular, the construction of the Shalqar–Beineu railway in the range of the Ustyurt population led to a reduction in its essential winter habitats on the Ustyurt Plateau by approximately 80%. This may explain why the Ustyurt population, unlike the continually and exponentially growing populations in the Ural and Betpaqdala, has not recovered after the catastrophic decline of the 1990s and early 2000s. For instance, the Ural population—least affected by roads and railways—increased from 6500 individuals in 2003 to 1.62 million in 2024, while the Betpaqdala population grew from 1800 individuals in 2003 to 1.15 million in 2024 [65]. In contrast, the Ustyurt population has grown insignificantly, from 1900 individuals in 2016 (following the railway’s construction in 2015) to 63,600 in 2024. The highest number of the Ustyurt population was in 1989, which was estimated at 265,000 individuals [1]. As is known, the number of saiga depends on the availability of food resources during winter [17].

On the recently built Zheqazgan–Sekseildi (Betpaqdala population) and Shalqar–Beineu (Ustyurt population) railways, it was recommended that crossings for migrating saigas be built in the form of gentle earthen embankments, at rail level and 50 m wide. However, their effectiveness remains uncertain. Additional stations have been built along

new railways, which will increase the human population and traffic. As a result, the threat to saigas is likely to intensify.

4.2.2. Highways and Roads

There are many roads within the saiga's habitat, most of which lack side curbs. The animals regularly cross them during migration, although fatalities do occur, typically due to drivers' fault. A planned high-speed highway from China to Europe (China's Belt and Road Initiative) will intersect some ungulate habitats [69], including saiga migration routes in Central Kazakhstan. Similar to mortality on railways, calves are vulnerable on highways and secondary roads. For instance, during our research, we identified 11 cases of newborn saiga calves being killed by vehicles during the calving season in Western Kazakhstan on dirt roads in May 2024. According to archival and literary data, in June 1988, of the 90 dead saigas (calves and adults) discovered, 44 died on railways and roads in Central Kazakhstan [1].

Similar to the New Eurasia Land Bridge Economic Corridor [70,71], the Belt and Road Initiative has potential negative impacts on both animal populations and their habitats [72,73]. This initiative, and more to come, would require special and detailed consideration for migrating animals, including planning and creating wildlife crossings [74]. Curbs are to be installed along this road, making wildlife crossings essential to allow saigas to pass. Kazakhstan currently has no experience in constructing wildlife crossings over such highways and would need to analyze successful examples from other countries in implementing them [69,75], and consider developments in green technologies for construction of sustainable structures [76]. Given that saigas inhabit open steppe environments, overpasses are the most suitable solution [77,78], including promoting their movements across fenced highways [79,80]. This is supported by the example of the Trans-Canada Highway in Canada's Banff National Park [81], as well as pronghorn antelopes in the United States, which also inhabit open plains [82,83]. On a 21 km section of road, six underpasses and two overground crossings were constructed [9]. The antelopes quickly learned to use the overpasses but largely ignored the underground ones. At present, the implementation of these measures in Kazakhstan has been postponed to a later date, but it is crucial to ensure that these recommendations are implemented.

As shown in Table 2, despite the total density of road infrastructure in saiga habitats being much higher than that of railways, most highways have a low to average influence on saiga migrations. Nevertheless, new highways planned for construction in the saiga's range (i.e., the proposed "Center–West" Regional Development Corridor project [84]) need to be analyzed and prepared according to the seasonal key habitats and migration routes of the saiga and other species.

5. Conclusions

The severity of the threat posed to the saiga by roads and railways has not been assessed in detail [27,28] despite the ongoing and planned construction of significant infrastructure projects. Thus, the continued development of linear infrastructure may pose a major threat to the saiga, and this topic is becoming more relevant every year. Our analysis assessed the dispersal and density of roads and railways in saiga habitats, indicating their impact on the distribution of saiga populations, thus significantly complementing existing knowledge. These results can be used to assess potential fragmentation effects, informing mitigation and planning efforts.

As a species whose survival depends on seasonal migrations across vast rangelands, saigas are increasingly threatened by habitat fragmentation caused by the rapid expansion of roads and railways. Despite encouraging trends in population recovery, especially in the

Ural region, the long-term viability of the species is at risk due to growing barriers within its habitat.

Our analysis revealed that more than 4000 km of railway lines and over 80,000 km of roads intersect Kazakhstan's current saiga range, with particularly high infrastructure densities in the Betpaqdale and Ustyurt regions. These areas show clear signs of disrupted migration and range contraction, including the halving of traditional migration distances and the northward shift of wintering grounds. Railway lines in the E–W or NE–SW direction significantly bisect key migratory routes and have led to observable shifts and population isolation. Some of the most impactful barriers include the Sekseildi–Zhezqazgan, Zhezqazgan–Zharyk, and Shalqar–Beineu railways, which bisect critical seasonal migration pathways. The Ustyurt population has the highest infrastructure density and shows the lowest saiga abundance. Since 2015, large railways have reduced the winter range by 79.84% in Ustyurt and limited access in Betpaqdale, implying intense barrier effects and avoidance by saiga. In contrast, the Ural population is relatively free from such barriers and has experienced exponential population growth.

While roads are more prevalent than railways, their impact varies by design. Many uncurbed roads are still crossed by saiga, although vehicle collisions and avoidance behaviors are common. However, future infrastructure projects (especially large-scale initiatives like the Belt and Road) pose severe risks unless wildlife movement is actively considered. Kazakhstan currently lacks practical experience in building wildlife-friendly transport infrastructure, yet successful international examples offer applicable solutions. Overpasses, in particular, have proven effective for open landscape species and should be prioritized over underpasses.

To preserve one of the last great terrestrial migrations in the temperate zone, Kazakhstan must urgently integrate wildlife-friendly design principles into the planning and development of infrastructure. This includes constructing overpasses, implementing ecological corridors, and conducting rigorous environmental impact assessments in areas of ecological sensitivity. Protecting the connectivity of saiga habitats is not only essential for this emblematic species but also critical to the health and resilience of Central Asia's steppe ecosystems.

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Abbreviations

The following abbreviations are used in this manuscript:

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMS	Convention on Migratory Species of Wild Animals
CR	Critically endangered
E	East direction
GIS	Geographic Information System
GRIP	Global Roads Inventory Project
IUCN	International Union for Conservation of Nature
N	North direction
OSM	OpenStreetMap
QGIS	Quantum Geographic Information System
S	South direction
W	West direction

Appendix A

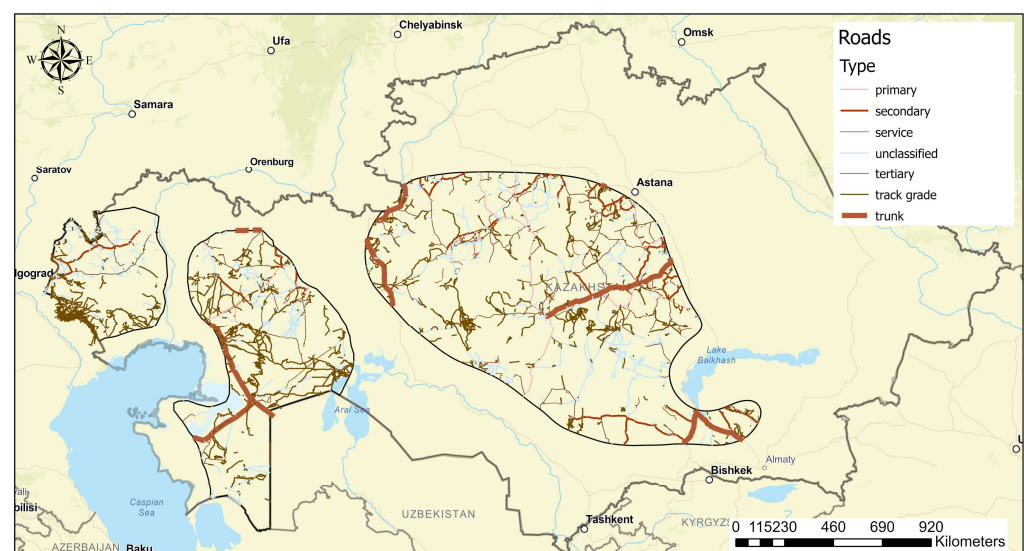


Figure A1. Road infrastructure in the saiga's range in Kazakhstan. Footnote: In the Ural population's range, linear transport infrastructure includes the Atyrau–Astrakhan railway and the Chapayev–Kaztalovka highway; in the Ustyurt population's range, this includes the Kandygash–Atyrau and Shalqar–Beineu railways; and in the Betpaqdala population's range, this includes the Zharyk–Zhezqazgan and Zhezqazgan–Sekseuildi railways, as well as the planned Astana–Arkalyk–Torgai–Irgiz highway section of the Western Europe–Western China International Highway and the Kyzylorda–Zhezqazgan–Pavlodar–Uspenka highway. The recently built Zhezqazgan–Sekseuildi and Shalqar–Beineu railways have practically “cut off” the southern part of the saiga's winter habitats, depriving the animals of very important feeding grounds in their wintering areas. The gently sloping earthen embankments (“slopes”) constructed on both sides of the road for saiga crossings are not yet being used by the animals; alternative solutions may thus be needed.

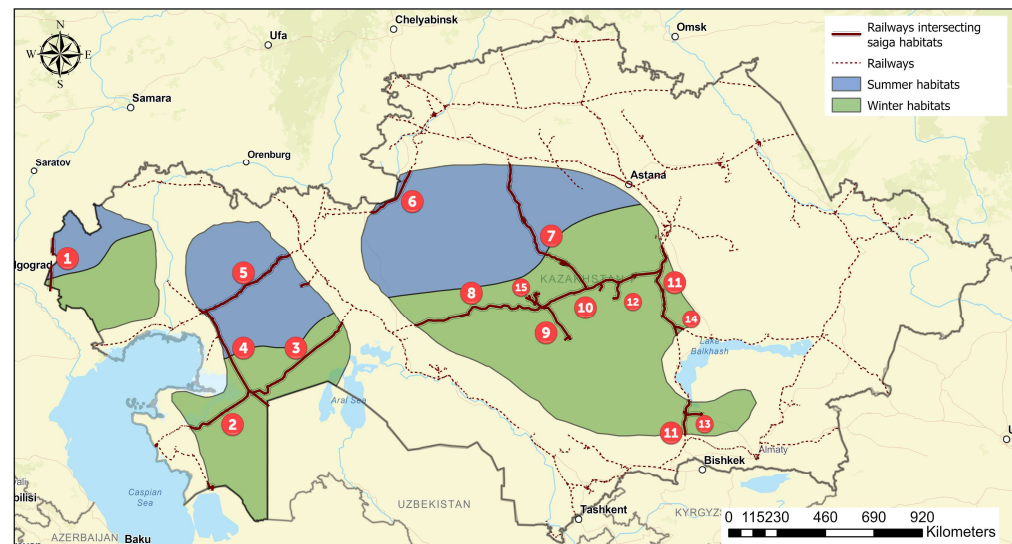


Figure A2. Railway infrastructure in the saiga's range in Kazakhstan. Ural population's range: 1—Saratov—Astrakhan. Ustyurt population's range: 2—Beineu—Aqtau, 3—Beineu—Shalqar, 4—Maqat—Turkmenabat, and 5—Qandyagash—Atyrau. Betpaqдала population's range: 6—Khrontau—Qostanay, 7—Esil—Kyzylzhar, 8—Zhezqazgan—Sekseuildi, 9—Zhezqazgan—Aibat, 10—Zharyk—Zhesqazgan, 11—Qaraghandy—Shu, 12—Qarazhal, 13—Aqsuiek, 14—Moiynty—Balkhash, and 15—Zhezqazgan internal.

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