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Article

Wildfires in the Altyn Dala State Nature Reserve and their potential impact on ungulate migrations

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Abstract. Steppes and semi-deserts are arid ecosystems with seasonal climate, limited water resources, and a high risk of wildfires. The Altyn Dala State Nature Reserve is located in the South Turgai physico-geographical province of the Eurasian steppe, encompassing the northwestern range of the Betpak-Dala saiga population which is the largest in terms of distribution area. The region includes traditional calving grounds and saigas' migration routes, and during winters with low snow cover, part of the population remains in the area year-round. In addition, reintroduction programs for Przewalski's horse and kulan are being implemented in the arid and desertified steppes of Kazakhstan. Therefore, studying the ecological situation in the region is both important and timely. The aim of this study is to analyze wildfires in the Altyn Dala State Nature Reserve and assess their potential impact on ungulate migrations. The objectives are comprehensive analysis of wildfire frequency and of burned areas sizes within the reserve during the period 2000–2025 using remote sensing methods. During the study period, 51 wildfires were recorded within the boundaries of the reserve, with a total area of 1376299 hectares have been burnt. An increase in the population of the Betpak-Dala saiga, combined with droughts and wildfires, have led to mass migrations of saiga to the northern parts of Kostanay Region, resulting in significant damage to grain crop fields. To reduce wildfire-related damage, early detection based on modern satellite monitoring technologies is strongly required.

Keywords: steppe wildfires; remote sensing; satellite-based research; Altyn Dala State Nature Reserve; adjacent territories; pyrogenic factor; ungulate migrations; Kazakhstan.

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1. Introduction

Wildfires are natural phenomena that may have significant consequences for ecosystems, climate, and human livelihoods (Stavi, 2019). Pyrogenic factors include both natural causes (lightning strikes, accumulation of dry biomass, drought, etc.) and anthropogenic drivers (agricultural burning, careless fire handling, grassland burning) (Kamp et al., 2016; Bragina et al., 2018; He et al., 2019; Dara et al., 2020; Jones et al., 2022; Shi et al., 2022; Venkatesh et al., 2022; Bragina et al., 2025). Steppe fires are often characterized by high rates of spread and the capacity to cover extensive areas. The probability of fire occurrence increases with rising wind speed and decreasing relative air humidity (Domènech et al., 2025). A long-term analysis of fire dynamics (2000–2025) in the Naurzum State Nature Reserve and adjacent territories (Kostanay Region, Kazakhstan) was conducted using satellite remote sensing (Bragina et al., 2025). In the dry steppes and semi-deserts where the Altyn Dala State Nature Reserve is located, wildfires exert a substantial influence on biota. They may significantly affect the migration patterns of ungulate mammals (e.g., saiga antelope, kulan, wild horses) (Gutiérrez & de Miguel, 2021). Fires compromise habitat safety for many animal species and reduce the availability of forage and water resources. In the short term, grass cover is destroyed during fires, forcing animals to leave burned areas, sometimes migrating tens or even hundreds of kilometers (Geraskina et al., 2022). A reduction in available forage resources may result in overgrazing and degradation of remaining pastures, causing conflicts with domestic livestock, or incursions into cultivated lands and subsequent crop damage, causing significant economic losses and undermining local livelihoods (Koshkina et al., 2026). Furthermore, the burning of vegetation around watering sites increases evaporation and/or leads to the desiccation of water sources, while also degrading shelter quality due to the loss of protective vegetation. Such fires may cause direct mortality, particularly among juveniles and weakened individuals. Thermal stress, food shortages, and increased predation pressure resulting from the loss of cover are also important factors. In the long term, the effects of frequent fires manifest in soil and vegetation cover erosion, land desertification, degradation of traditional grazing areas, and reduced forage security, potentially altering established animal migration routes.

Study Area and History of Establishment of the Altyn Dala State Nature Reserve. The study area encompasses the Altyn Dala State Nature Reserve (hereinafter referred to as the Reserve), located in the southern part of Kostanay Region, Republic of Kazakhstan (Bragina & Bragin, 2017). The establishment of a large, specially protected natural area in the Turgai region was first proposed in 2003 by Professor T.M. Bragina. In August 2005, at an interministerial working meeting dedicated to the interim results of the UNEP/GEF/WWF project "Development of an Ecological Network (Econet) for the Long-Term Conservation of Biodiversity in the Ecoregions of Central Asia (Econet–Central Asia)," Professor T.M. Bragina (regional and national project coordinator) proposed including in the official protocol the creation of a Nature Reserve named "Altyn Dala" as one of the key outcomes of the project in Kazakhstan. The meeting was attended by representatives of Kazakhstan Parliament, state environmental authorities (the Ministry of Environmental Protection; the Forestry and Hunting Committee), international and national conservation organizations (World Wide Fund for Nature – WWF; Frankfurt Zoological Society – FZS; Royal Society for Protection of Birds – RSPB), and the Association for the Conservation of Biodiversity of Kazakhstan (ACBK), as well as the Ministry of Foreign Affairs, the Water Resources Committee of the Ministry of Agriculture, the Ministry of Finance and Budget Planning, the Agency for Land Resource Management, and other relevant institutions and stakeholders. A parallel consultative meeting with representatives of WWF, FZS, and RSPB addressed the establishment of a joint long-term international conservation initiative, also named "Altyn Dala" (Altyn Dala Conservation Initiative, ADCI). Professor T.M. Bragina served as the first coordinator of ADCI (2005–2007), in agreement with WWF, FZS, and RSPB within the framework of the Association for the Conservation of Biodiversity of Kazakhstan. This initiative significantly accelerated the preparation of documentation for the establishment of the Reserve and the development of the "ADCI Strategy until 2030." The establishment of the Altyn Dala State Nature Reserve was incorporated into the "Program for the

Development of the Network of Specially Protected Natural Areas in the Republic of Kazakhstan for 2007–2009" and the "Program for the Conservation and Sustainable Use of Wildlife Resources and the Development of the SPNA Network until 2010" (approved by Resolution of the Government of the Republic of Kazakhstan No. 914 of October 8, 2007), aimed at the conservation and restoration of steppe and semi-desert landscapes, as well as populations of rare and endangered large mammals (saiga antelope, kulan) and bird species (Bragina, 2006a, 2006b; ENO, 2008). In 2007, Professor T.M. Bragina led a comprehensive scientific field expedition, supported by FZS, to select and describe the territory proposed for the Reserve and to prepare the "Scientific Justification for the Establishment of the Altyn Dala State Nature Reserve, which successfully passed the state environmental review process. The Altyn Dala State Nature Reserve was officially established in 2012, covering an area of 489.766 hectares within the Amangeldy and Zhangeldi districts in southern Kostanay Region (Resolution of the Government of the Republic of Kazakhstan No. 1496 of November 27, 2012).

Geographically, the territory of the Altyn Dala State Nature Reserve (49°36′00″ N, 65°10′45″ E) is located within the South Turgai physico-geographical province of the Eurasian steppe zone, in the subzone of dry steppes and semi-deserts. The soils are predominantly light chestnut and chestnut types, interspersed with solonetz and solonchak complexes, as well as lake and river systems. The reserve is characterized mainly by plains of various origins with residual erosional landforms. Distinctive features include the picturesque steep clayey slopes along the Uly-Zhylanshik River near the former settlement of Rakhmet, gently undulating clayey residual hills in the northwestern part of the Ulyzhylanshik sector of the reserve, the dune sands of Tosynkum and Akkum, the southern part of the Sarykopa lake system, and the reaches of the Uly-Zhylanshik and Kabyrga rivers. Southern Turgai belongs to the continental arid regions of the temperate zone and is characterized by a higher degree of aridity compared to the semi-deserts of Central Kazakhstan. This is due to its location in a circulation shadow behind the Mugodzhar Hills and, conversely, its broad exposure to the deserts of the Aral region. The sum of active temperatures during the growing season reaches 2800–3100°C. The mean annual air temperature is +4.1°C. Winters are cold, with mean January temperatures down to –17°C, while summers are hot, accompanied by dry winds and frequent droughts (mean July temperatures approximately 24–25°C). The mean annual precipitation in the Turgai semi-desert ranges from 150 to 200 mm, and the moisture coefficient does not exceed 0.2–0.3 (Figure 1).

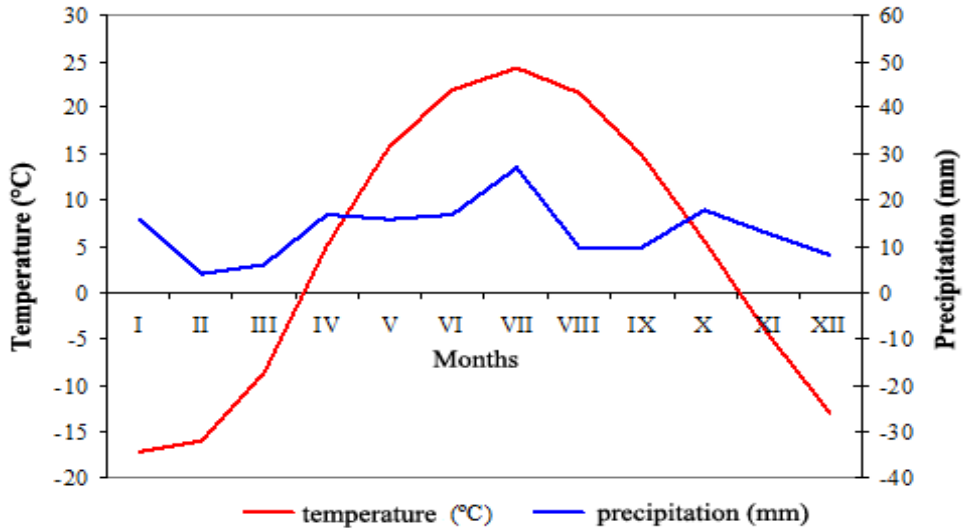

Figure 1. Climatogram of the territory of the Altyn Dala State Nature Reserve (based on data from the Turgai weather station, Zhangeldy District, Kostanay Region; source: ENO, 2008)

The aim of this study was to analyze wildfires within the boundaries of the Altyn Dala State Nature Reserve during the period 2000–2025 and to review their potential impact on ungulate

migration patterns. The objectives of the study include a comprehensive analysis of fire frequency and burned areas over a 26-year period, with the recording of fire ignition points and observation data using remote sensing (RS) methods.

The results of the study comprise the mapping of wildfire events in the reserve based on thermal anomaly data obtained through RS, providing reliable and detailed information on burned areas across a long-term observation period.

For the first time in the southern part of Kostanay Region, within the largest specially protected natural area, remote sensing methods were applied to detect, analyze, and produce multitemporal maps for the assessment of fire frequency, intensity, and spatial dynamics of burned territories over recent decades (2000–2025).

2. Materials and methods

Remote sensing methods based on satellite data were employed in this study. To detect wildfires over a multi-year period, satellite monitoring data were utilized. Fire ignition points for the 26-year period (2000–2025) were obtained from the NASA FIRMS (Fire Information for Resource Management System) database for the territory of the Altyn Dala Reserve. NASA FIRMS provides coordinates of thermal anomalies detected by MODIS and VIIRS sensors. These data served as a primary indicator of potential fire events and as an additional validation layer for the temporal and spatial localization of wildfires. Fire occurrence time and location were determined based on fire ignition points' records. Additionally, satellite imagery from the Sentinel Hub cloud platform was downloaded for each year under analysis (2000–2025). Imagery from the Landsat series (7, 8–9) and Sentinel-2 satellites was used, with data for later years providing higher spatial resolution. All images underwent standard preprocessing, including spatial resolution harmonization and reprojection to a unified coordinate system. After the data had been prepared, spectral indices required for burned area detection were calculated for each year. The general workflow of data processing and analysis is illustrated in Figure 2.

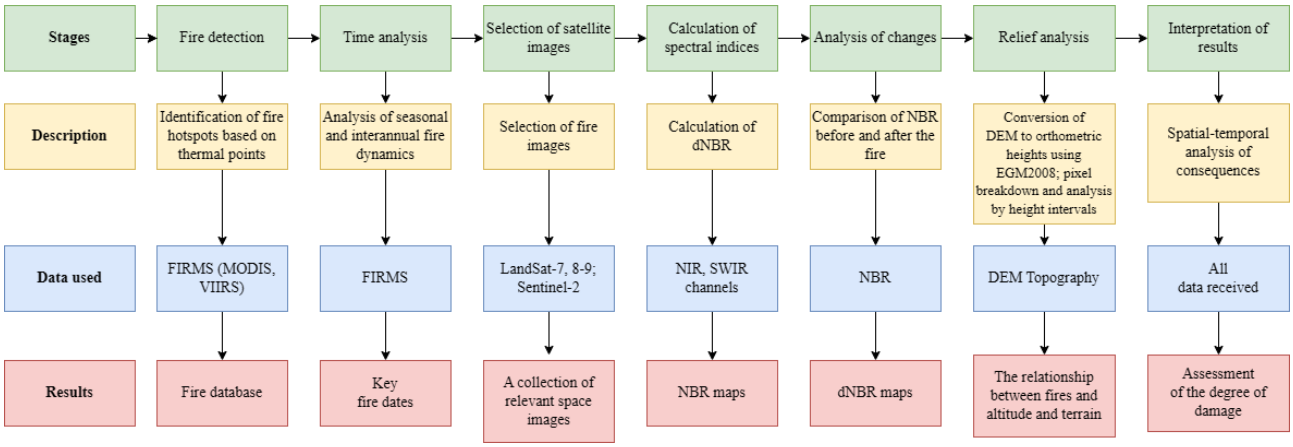

Figure 2. General workflow of data processing and material analysis (Source: developed by the authors)

The key tool for assessing wildfire impact was the Normalized Burn Ratio (NBR), calculated for each satellite image. To identify areas affected by fire, the NBR-RAW index was used, which is based on Sentinel-2 bands 8 and 12 and enables reliable delineation of large burned areas. The degree of fire impact was assessed by calculating the difference between pre-fire and post-fire NBR values (Kabdulova et al., 2020; Suresh Babu, K. V. et al., 2024; Suresh Babu, K. V. et al., 2025). In this approach, darker pixels on the resulting image correspond to areas of more severe burning. Based on NBR calculations, dNBR maps (difference in NBR values before and after fire events) have been generated. The maps allowed to detect burned areas and the assessment of vegetation damage intensity.

NBR index for the assessment of burned areas:

Sentinel-2: NBR = (B8 – B12) / (B8 + B12) (1)

Landsat 8/9: NBR = (B5 – B7) / (B5 + B7) (2)

Landsat 7: NBR = (B4 – B7) / (B4 + B7) (3)

The main criteria for burnt areas are determined by high dNBR values and a sharp decline in NBR following a fire. The NBR index ranges from -1 to +1.

To assess the consequences of a fire, the difference in NBR before and after the fire is used:

dNBR = Pre-fireNBR – Post-fireNBR (4)

NBRpre-fire – pre-fire index;

NBRpost-fire – post-fire index.

Table 1. Standard dNBR scale

dNBR	Burn Severity	Description of the condition
< -0.25	High post-fire regrowth	Significant regrowth or new vegetation growth following a fire
-0.25 to -0.1	Low post-fire regrowth	The regrowth or establishment of new vegetation following a fire
-0.1 to +0.1	Unburned	The vegetation has remained virtually unchanged or has not been affected by the fire
0.1 to 0.27	Low-severity burn	Minimal damage; mainly the undergrowth and the lower layer were burnt, whilst the tree canopies remain intact
0.27 to 0.44	Moderate low-severity burn	Partial damage to the tree stand, significant scorching of the undergrowth and shrubs
0.44 to 0.66	Moderate to high severity burn	Severe damage to the forest canopy, charring or complete destruction of needles/foliage
>0.66	High-severity burn	Total destruction of vegetation, severe soil degradation

Table 1 shows that the NBR index classifies the severity of burnt areas into several categories. The NBR index uses values from the near-infrared (NIR) and short-wave infrared (SWIR) bands. Higher dNBR values indicate more severe damage. Low and negative values indicate the absence of fire or an increase in vegetation. Areas with negative dNBR values may indicate an increase in vegetation productivity following a fire.

The dNBR raster was classified using a thresholding method in accordance with the MTBS/USGS scale. The dNBR values were classified into vegetation damage classes: low (0.1–0.27), medium (0.27–0.44), medium-high (0.44–0.66) and high (>0.66).

Figure 2 uses a color gradient ranging from green to dark red, which reflects the increasing severity of land degradation.

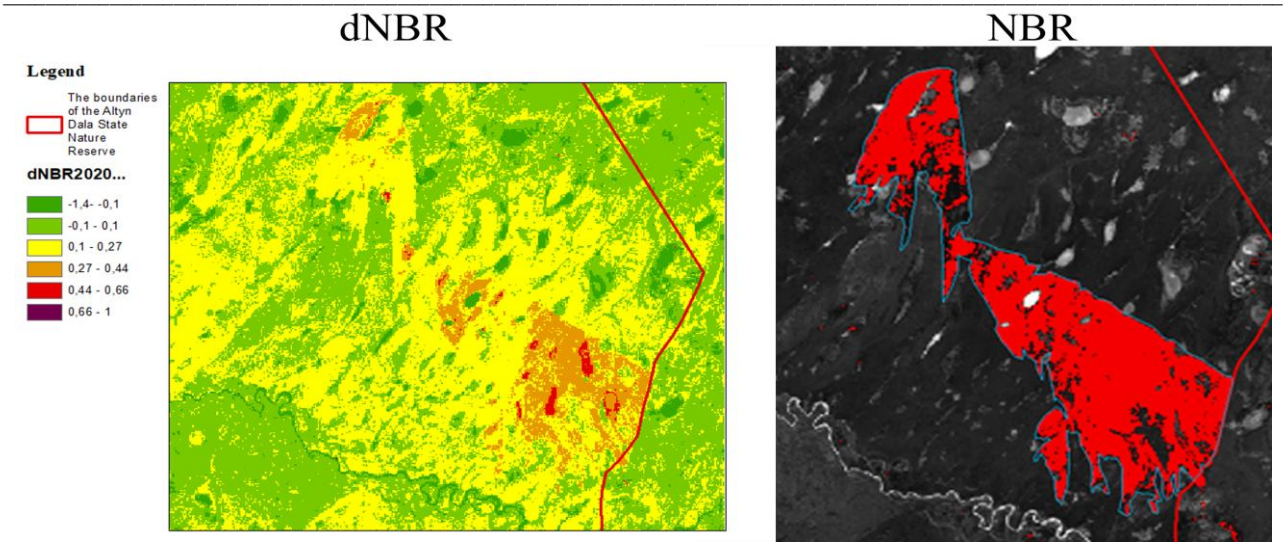

Figure 3. Soot mask based on the spectral index of NBR and dNBR (Source: developed by the authors)

To digitize vector polygons of fire boundaries based on NBR imagery, a personal geodatabase was created in ESRI ArcMap, with approximately 50 wildfire events from 2000 to 2025 having been analyzed. Fire areas were determined using polygon delineation of burned territories. Fire ignition points data were integrated into the database as an auxiliary layer to verify fire occurrence, refine the event dates, and confirm that observed NBR changes were attributable to fire activity rather than seasonal vegetation dynamics. To obtain elevation values corresponding to fire occurrences, the Copernicus GLO-30 Digital Elevation Model (DEM) based on ellipsoidal height was employed. Figure 4 presents the fire boundaries digitized on the NASA SRTM GL1 DEM Global 30 m dataset with a spatial resolution of 30 m.

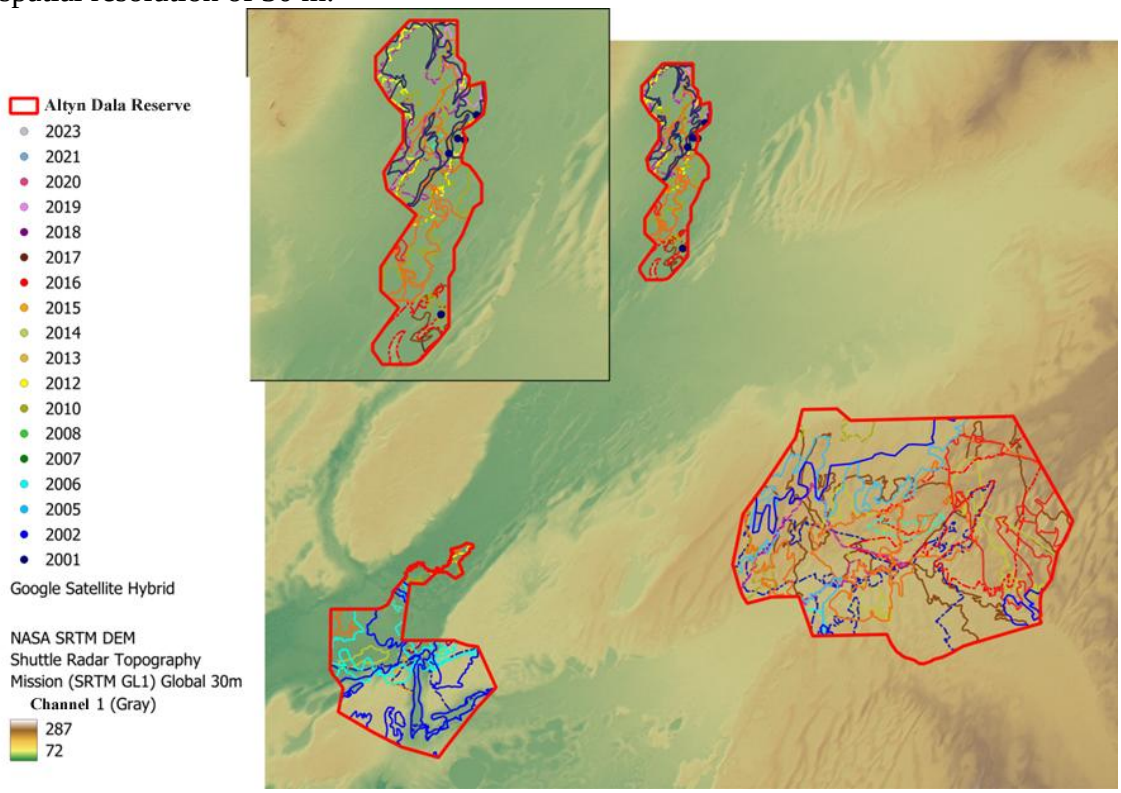

Figure 4. Fire boundaries mapped on the NASA SRTM GL1 DEM Global 30 m dataset (spatial resolution 30 m) (Source: developed by the authors)

The Copernicus GLO-30 DEM was reprojected to the WGS84 UTM Zone N41 coordinate system. To obtain true elevation values, the EGM2008 geoid model was downloaded and subsequently reprojected and clipped to the boundaries of the Reserve polygon. Orthometric heights were calculated using raster calculator tools. Orthometric heights represent surface elevations relative to mean sea level (MSL), taking into account the geoid, i.e., the physical approximation of the Earth's mean ocean surface. Orthometric heights were computed using the following formula:

$$H = h - N \quad (5)$$

h – ellipsoidal height (original DEM);
H – orthometric height (result obtained after Raster Calculator processing);
N – geoid height (geoid undulation) derived from the EGM96/EGM2008 geoid model.

In QGIS, pixel classification by elevation was performed using the "raster analysis" tool (Table 2). Area calculations by class were carried out using the "zonal histogram" tool. To obtain real area values, the resulting pixel count was multiplied by 900 (for a 30×30 m pixel size) and divided by 10 000 to convert the area into hectares. Thus, the distribution of areas across different altitude intervals within the Altyn-Dala Nature Reserve is shown.

Table 2. Distribution of burned area across different altitude intervals within the Altyn Dala State Nature Reserve, calculated by classifying raster pixels according to elevation (hectares)

Years	Burned area at an altitude of up to 100 m, ha	Burned area at the altitude of 100–200 m, ha	Burned area at the altitude of 200–300 m, ha	Total burned area per year, ha
2025	0	0	0	0
2024	0	0	0	0
2023	0	516.42	0	516.42
2022	0	0	0	0
2021	2.97	38237.22	70041.15	108281.30
2020	0	11979.45	32578.47	44557.92
2019	0	1950.57	0	1950.57
2018	0	1018.26	0	1018.26
2017	0	109146.06	29636.55	138782.61
2016	1.26	15409.71	59683.23	75094.2
2015	0	3077.64	0	3077.64
2014	0.18	37220.13	18395.1	55615.23
2013	0	1070.55	4312.53	5383.08
2012	0.18	24378.57	0	24378.75
2011	0	0	0	0
2010	0.09	35198.19	2635.29	37833.57
2009	0	0	0	0

2008	1.71	59632.92	48218.49	107853.12
2007	1.53	916.11	55396.08	56313.72
2006	0.27	79826.4	9.27	79835.94
2005	3.24	101897.46	169836.48	271737.18
2004	0	0	0	0
2003	0	0	0	0
2002	3.6	177071.4	170098.02	347173.02
2001	0	16796.79	0	16796.79
2000	0	0	0	0
Total	14.67	715344.03	660840.66	1376199.36

The analysis of fire frequency dynamics and burned areas was conducted using remote sensing methods and processing of satellite imagery from Landsat 7, 8-9 and Sentinel-2 over a 26-year period (2000–2025) within the territory of the Altyn Dala Reserve. Fire ignition points within the study area were identified following thematic processing of satellite imagery results. The data were statistically processed using Microsoft Excel (version 365).

3. Results

The analysis demonstrated that within the territory of the Altyn Dala State Nature Reserve, 51 wildfire events occurred during the period 2000–2025, resulting in a total burned area of 1376299 ha (Table 3, Figure 5), and 6 176 fire ignition points were detected (Figure 6).

Table 3. Wildfires within the boundaries of the Altyn Dala Reserve (2000–2025), Kostanay Region, Kazakhstan.

Year	Fire ignition points/satellite	Date	Burned area, ha/satellite	% of burned territory
2000	-	-	-	-
2001	5/Terra	2001-04-06-06:54	16804.94/ Landsat 7	3.43
2002	655/Aqua, Terra	2002-07-24-09:05	293658.88/ Landsat 7	70.88
		2002-08-02-18:27	53514.8/ Landsat 7	
2003	-	-	-	-
2004	-	-	-	-
2005	299/Terra	2005-06-30-18:30	271739.05/ Landsat 7	55.48
2006	237/Terra, Aqua	2006-04-12-07:33	24213.32/ Landsat 7	16.3
		2006-05-23-09:10	53500.2/ Landsat 7	
		2006-05-27-16:34	2134.96/ Landsat 7	

Year	Fire ignition points/satellite	Date	Burned area, ha/satellite	% of burned territory
2007	59/Terra	2007-08-23-07:21	308.28/Landsat 7	11.49
		2007-09-15-07:27	56007.99/Landsat 7	
2008	354/Terra, Aqua	2008-05-01-17:18	145.01/Landsat 7	22.02
		2008-05-16-07:03	5742.33/Landsat 7	
		2008-08-11-08:55	10634.47/Landsat 7	
		2008-08-21-21:26	3597.37/Landsat 7	
		2008-06-16-08:05	2090.3/Landsat 7	
		2008-08-22-06:51	246.28/Landsat 7	
		2008-05-27-06:45	39157.88/Landsat 7	
		2008-07-28:22:15	23319/Landsat 7	
		2008-07-27-06:14	13321.74/Landsat 7	
		2008-07-24-17:49	9608.61/Landsat 7	
2009	-	-	-	
2010	97/ Terra, Aqua	2010-06-20-06:32	23034.75/Landsat 7	7.72
		2010-08-30-08:24	792.47/Landsat 7	
		2010-06-18-06:44	3279.91/Landsat 7	
		2010-06-15-08:00	2735.518/Landsat 7	
		2010-06-18-06:44	330.96/Landsat 7	
		2010-06-16-18:07	7661.017/Landsat 7	
2011	-	-	-	
2012	983/VIIRS SUOMI	2012-07-19-23:14	23749.634/Landsat 7	4.97
		2012-09-19-08:18	639.742/Landsat 7	
2013	22/VIIRS SUOMI	2013-07-31-20:27	4879.337/ Landsat 8-9	1.09
		2013-09-07-09:43	221.19/Landsat 7	
		2013-09-22-08:21	282.289/ Landsat 8-9	
2014	104/VIIRS SUOMI, Aqua	2014-05-29-07:18	14377.629/Landsat 7	11.35
		2014-07-09-09:06	41238.972/Landsat 7	
2015	35/ Terra	2015-08-28-06:39	3077.39/ Landsat 8-9	0.62

Year	Fire ignition points/satellite	Date	Burned area, ha/satellite	% of burned territory
2016	205/ VIIRS SUOMI	2016-07-07-20:09	69229.9/Landsat 7	15.33
		2016-04-16-07:12	5865.96/ Landsat 8-9	
2017	1067/VIIRS SUOMI, Terra	2017-07-24-17:00	13776.2/ Landsat 8-9	28.33
		2017-06-08-16:47	31329.45/ Landsat 8-9	
		2017-06-06-21:05	58114.21/Landsat 7	
		2017-07-04-17:24	35563.55/ Sentinel-2	
2018	11/ Terra	2018-08-08-17:25	1022.06/ Landsat 8-9	0.20
2019	99/VIIRS SUOMI	2019-06-30-20:27	1953.47/ Sentinel-2	0.39
2020	292/VIIRS J1V-C2, VIIRS SUOMI, Aqua	2020-08-06-08:07	4874.92/ Sentinel-2	9.09
		2020-08-06-21:11	11609.98/ Sentinel-2	
		2020-08-06-08-07	2713.99/ Sentinel-2	
		2020-08-06-17:18	2561.778/ Sentinel-2	
		2020-07-26-08:11	22803.3/ Sentinel-2	
2021	1633/VIIRS J1V-C2	2021-05-18-22:07	2597.82/ Sentinel-2	22.10
		2021-07-01-20:53	89324.02/ Sentinel-2	
		2021-07-05-21:18	1804.24/ Sentinel-2	
		2021-07-03-09:43	14561.35/ Sentinel-2	
2022	-	-	-	-
2023	19/VIIRS SIOMI	2023-08-01-22:15	516.27/ Sentinel-2	0.10
2024	-	-	-	-
2025	-	-	-	-

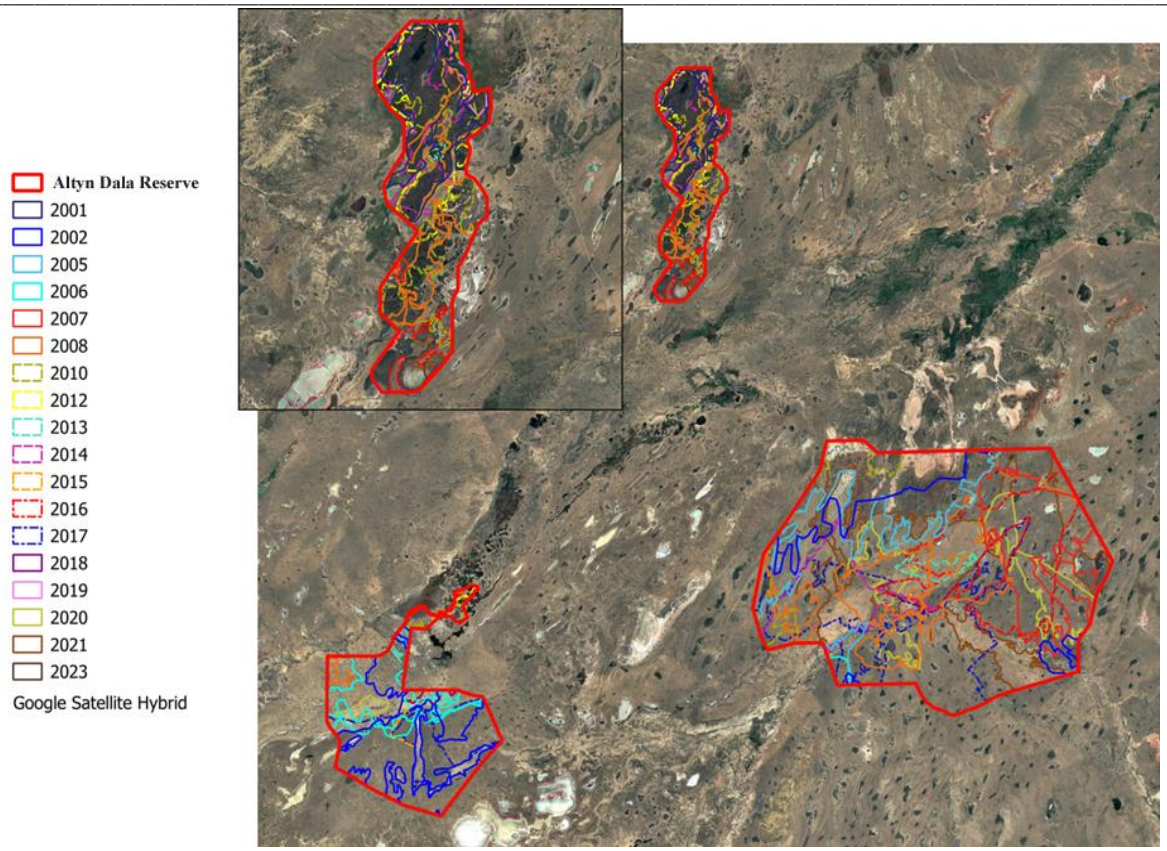

Figure 5. Burned areas within the boundaries of the Altyn Dala State Nature Reserve during the period 2000–2025, Kostanay Region, Kazakhstan (Source: developed by the authors)

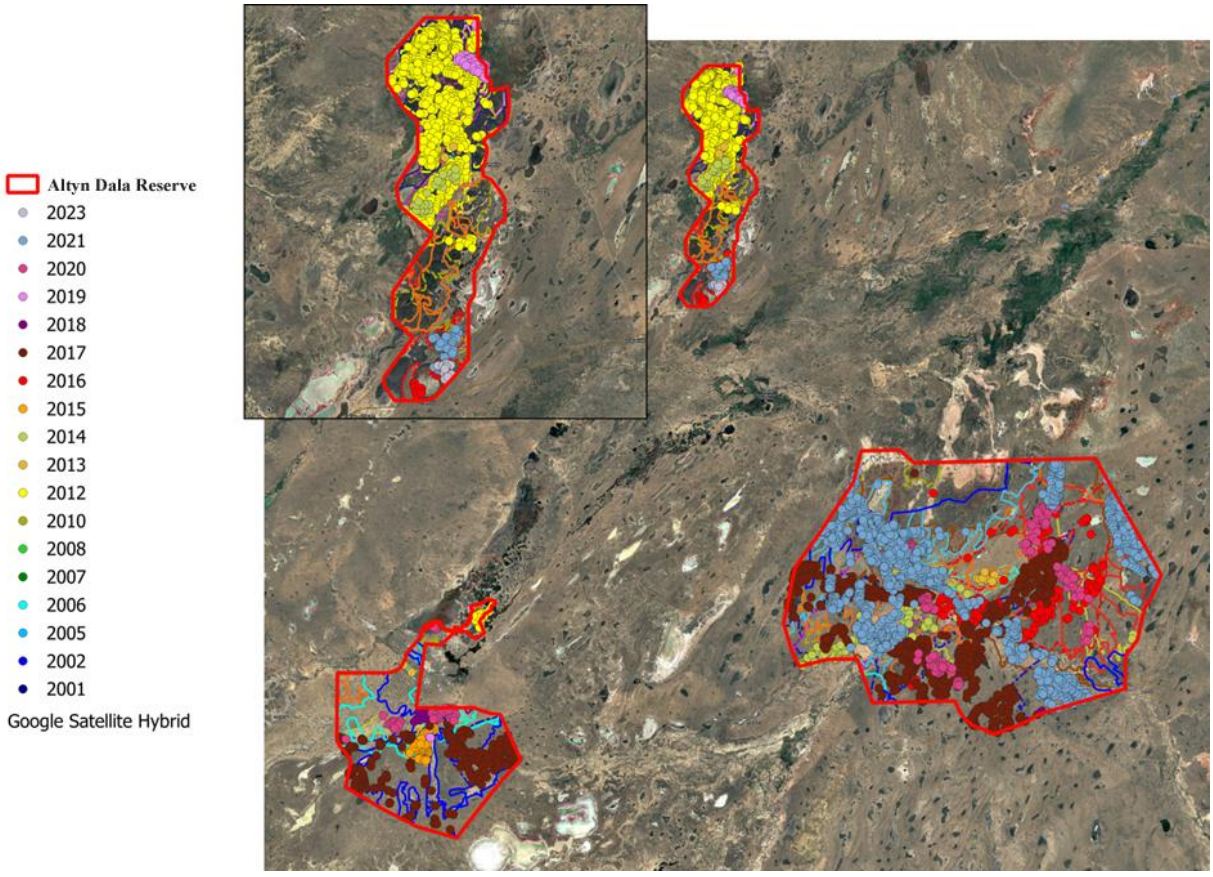

Figure 6. Fire ignition points of wildfires within the territory of the Altyn Dala State Nature Reserve for the period 2000–2025, Kostanay Region, Kazakhstan (Source: developed by the authors)

An analysis of Table 3 reveals the following. The maximum burned area within the boundaries of the planned Reserve was recorded on 24 July 2002, amounting to 293 658 ha, or 70.8 % of the study area, with 655 detected fire ignition points. The highest number of fire ignition points (1 633) was registered in 2021, when the total burned area for that year reached 108 287 ha. The greatest number of wildfire events (10 incidents) occurred in 2008, during which 22.02 % of the territory designated for the Reserve was burned.

The dynamics of burned areas within the boundaries of the Altyn Dala State Nature Reserve for the period 2000–2025 by year are shown in Figure 7.

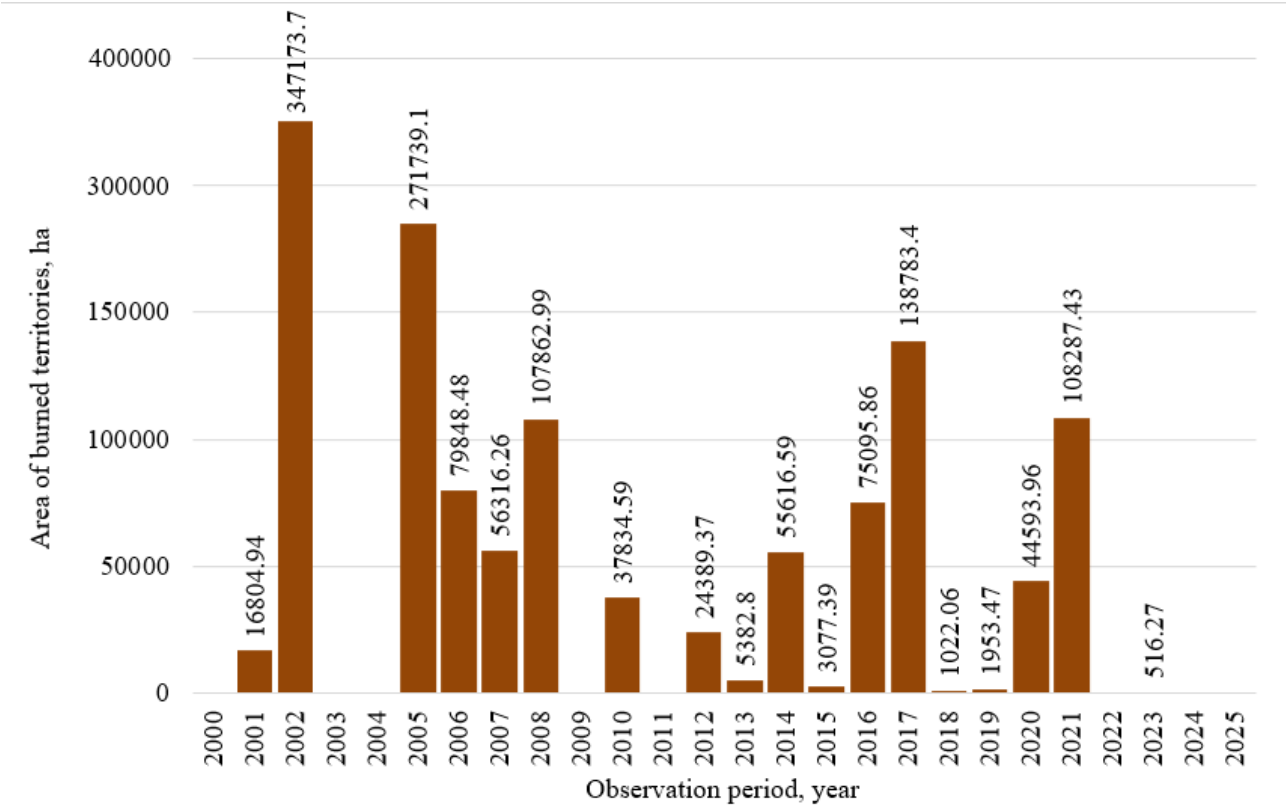

Figure 7. Comparative diagram of burned area distributions by year (2000–2025) within the boundaries of the Altyn Dala State Nature Reserve, Kostanay Region, Kazakhstan (Source: developed by the authors)

As shown in Figure 7, the largest wildfires during the study period occurred in 2002 (347174 ha) and in 2005 (271739 ha), prior to the establishment of the State Nature Reserve “Altyn Dala”. During the study period, the largest wildfires occurred in 2001 (351904 ha) and in 2005 (275208 ha), before the establishment of Altyn Dala State Nature Reserve.

Topography represents an important factor influencing fire development. Figures 8–10 illustrate the distribution of the relative burned area of the Reserve (in %) across elevation intervals (0–100 m, 100–200 m, and 200–300 m).

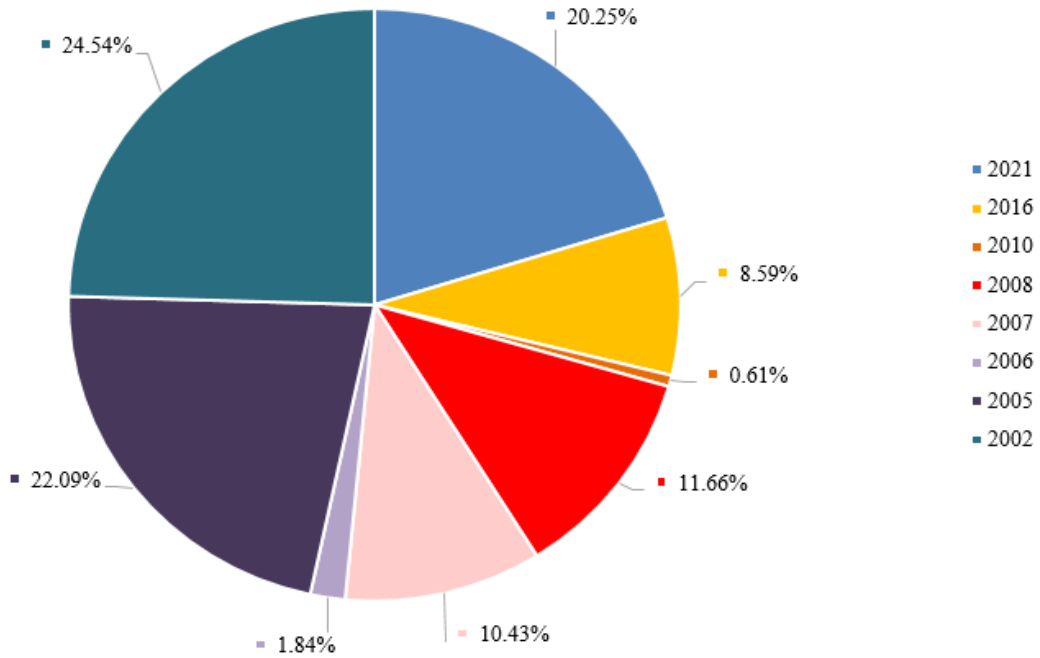

Figure 8. Distribution of burned area across the 0–100 m elevation interval within the territory of the Reserve (Source: developed by the authors)

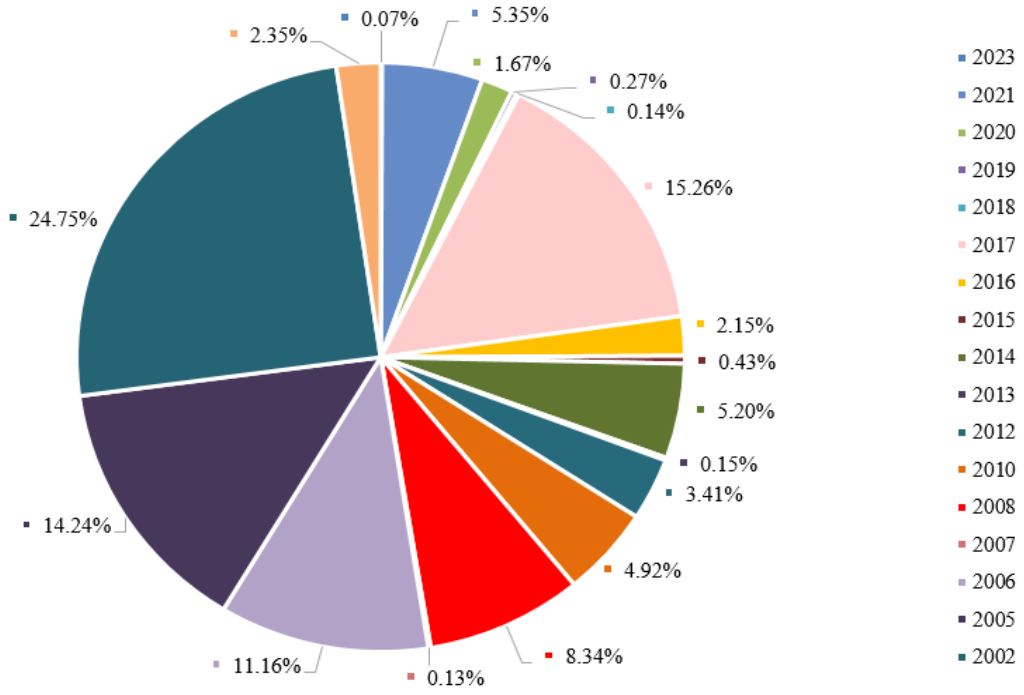

Figure 9. Distribution of burned area across the 100–200 m elevation interval within the territory of the Reserve (Source: developed by the authors)

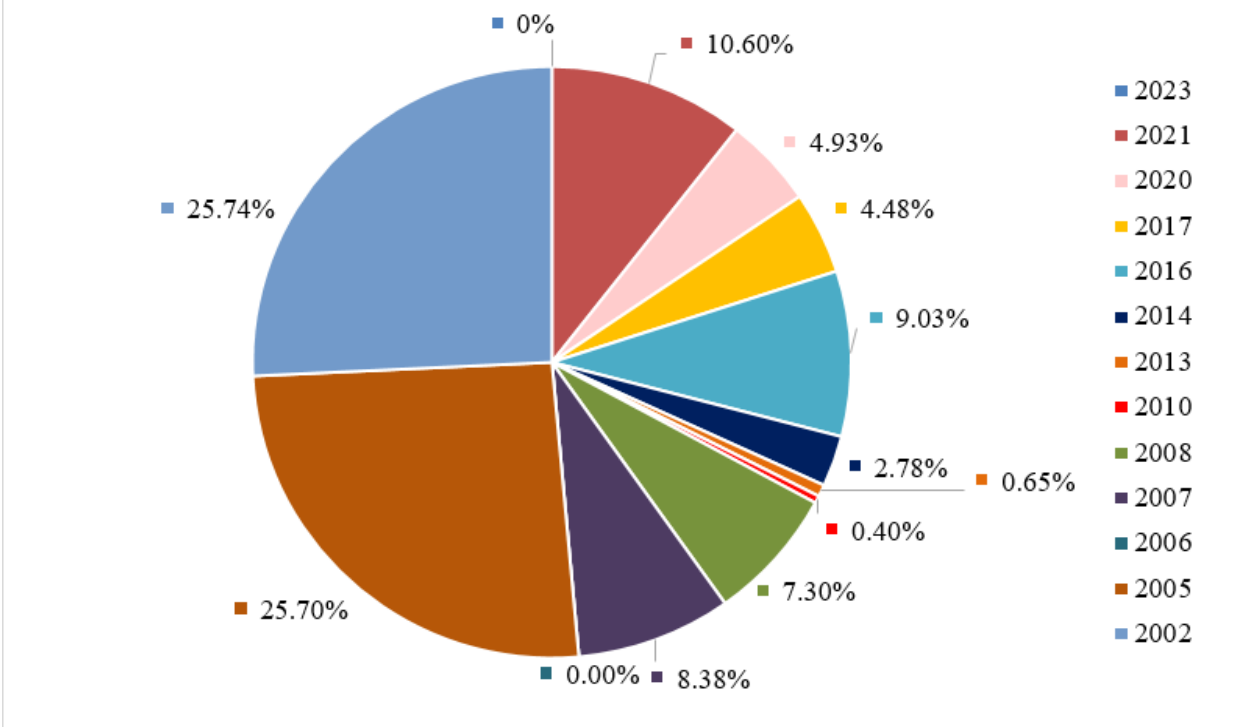

Figure 10. Distribution of burned area across the 200–300 m altitude interval within the territory of the Reserve (Source: developed by the authors)

Figure 11 shows the results of an analysis of data from the Reserve, which demonstrated that in the flat territories of the dry steppes and semi-deserts of Kazakhstan, the burned area within the 100–200 m elevation interval was slightly higher (52.0 %) than within the 200–300 m elevation interval.

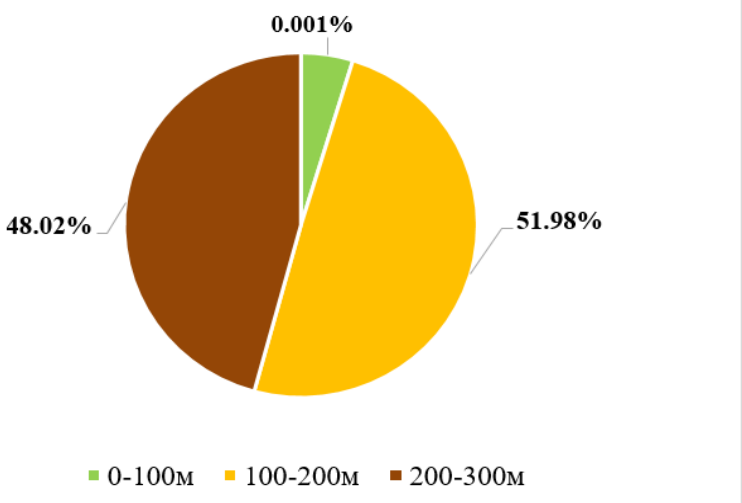

Figure 11. Distribution of burned area across elevation intervals within the territory of the Reserve during the period 2000–2025 (Source: developed by the authors)

To assess the relationship between topographic conditions and wildfire characteristics, a spatial statistical analysis was conducted using QGIS. The input datasets included a polygon layer of burned areas and a digital elevation model (DEM). Zonal statistics were used to calculate the mean elevation values (DEM_mean) for each burned polygon. Fire size was defined as the polygon area (area_ha), calculated directly based on the geometric properties of the objects.

The resulting attribute table was exported and further analyzed in Microsoft Excel. Pearson's correlation analysis was used to assess the relationship between elevation above sea level (mean DEM value) and the area of the burned territory (area_ha).

In Figure 12, a correlation analysis revealed a weak positive correlation between altitude and the area of burnt land (Pearson's correlation coefficient r = 0.1392)

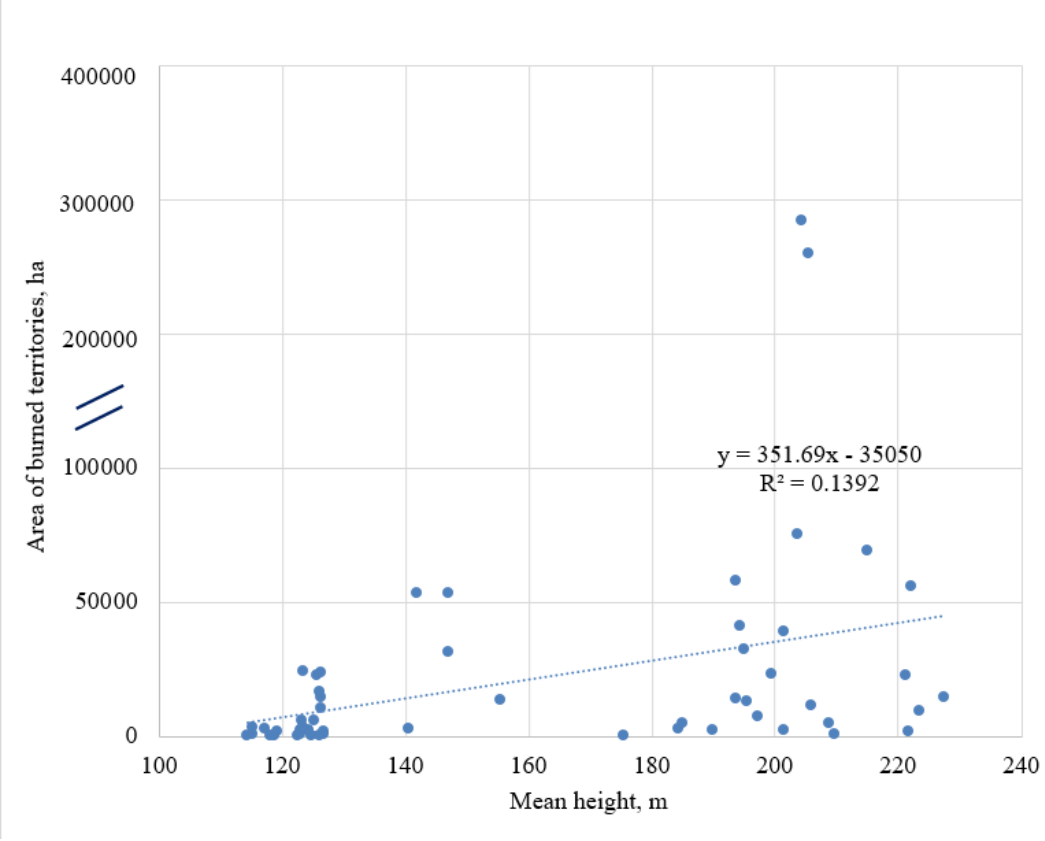

Figure 12. Correlation plot between the area of burned land and the mean DEM elevation within the boundaries of the reserve (Source: developed by the authors)

The correlation coefficient indicates a very weak positive relationship between elevation and the area affected by wildfires. The weak correlation may be due to the fact that fire spread is determined not only by terrain but also by a combination of other factors, such as weather conditions (temperature, wind, precipitation), etc. The results of the analysis indicate that topography has a limited influence on the spatial distribution of fires in the study region.

This relationship is shown in Figure 13, which illustrates the correlation between surface slope and the number of fires. The coefficient of determination, $R^2 = 0.0029$, indicates a weak correlation between slope and the number of fires.

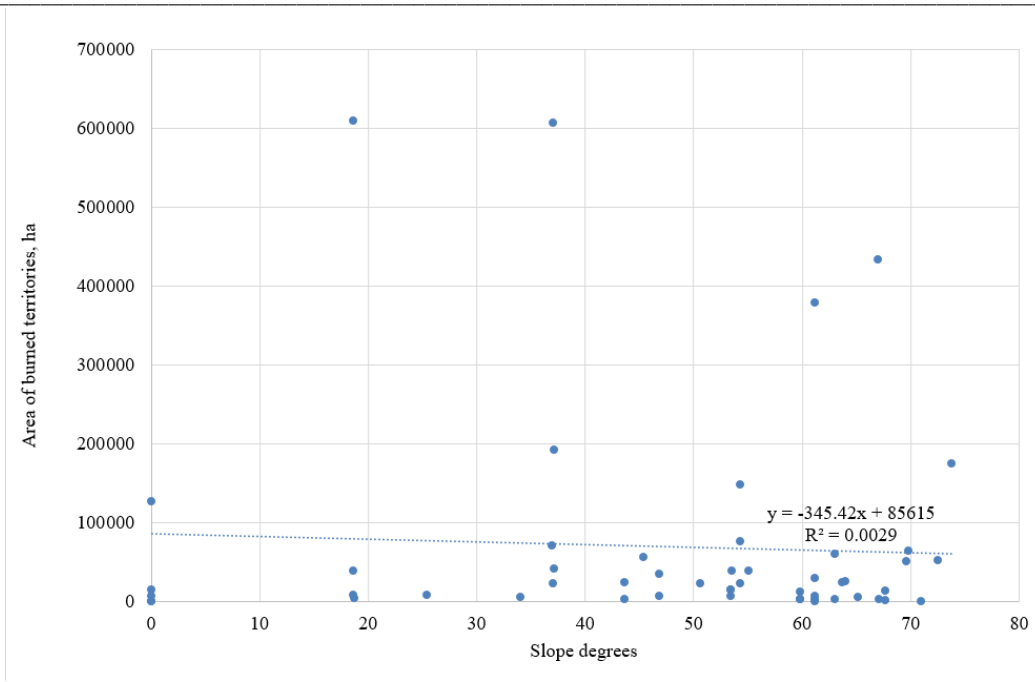

Figure 13. Correlation scatter plot of surface slope and the area of the burned territory in the Altyn Dala State Nature Reserve and surrounding areas (Source: developed by the authors)

The results indicate that topography has a limited influence on the spatial distribution of fires. This may be due to the fact that fire spread is determined not only by the slope of the terrain but also by other factors. Despite the weak correlation observed, topographic characteristics remain an important factor in spatial modeling of fire risk and should be considered in conjunction with climatic and anthropogenic variables.

Figure 14 presents a comparative analysis of burned areas in the Reserve and in the Naurzum State Nature Reserve over the long-term study period, revealing a higher frequency and larger burned areas in the Reserve compared to the Naurzum State Nature Reserve: 29 wildfire events were recorded in the Naurzum Reserve (Bragina et al., 2025) versus 51 in the Altyn Dala Reserve. Only in 2010 did the burned area in the Naurzum Reserve exceed that of the Altyn Dala Reserve.

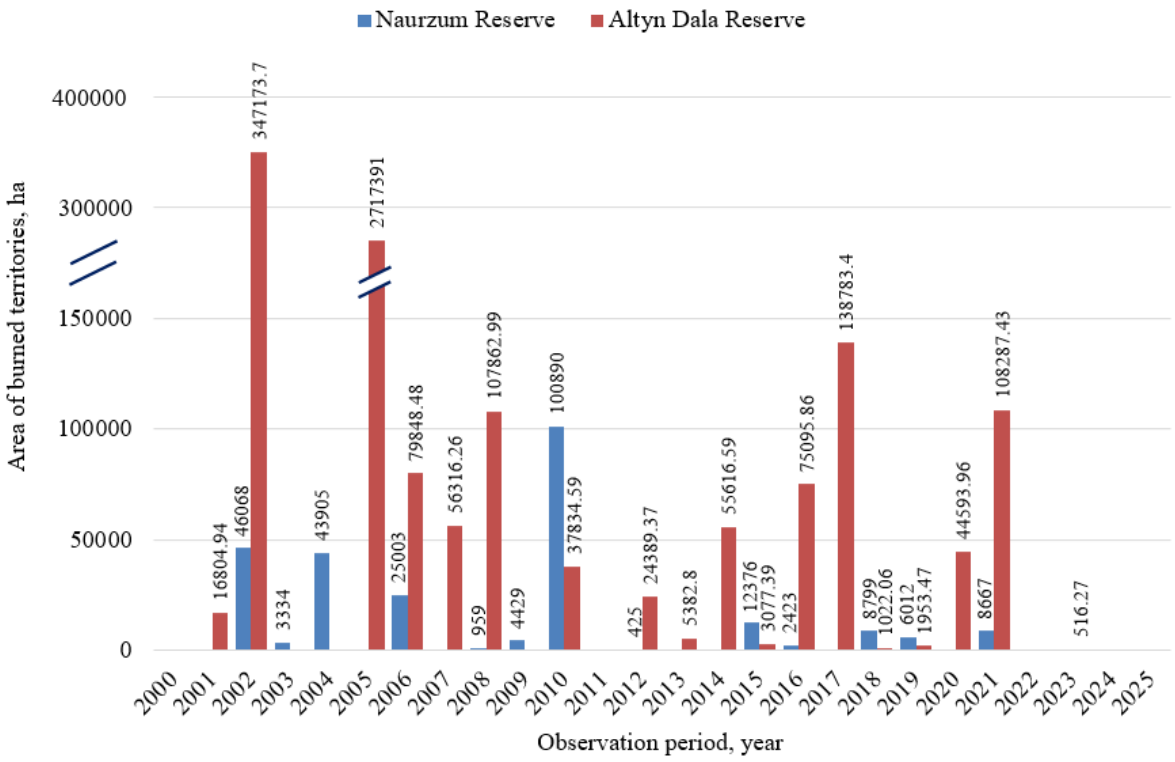

Figure 14. Comparative diagram of burned area distributions in the Altyn Dala Reserve and in the Naurzum Reserve over the observation period 2000–2025, Kostanay Region, Kazakhstan (Source: developed by the authors)

4. Discussion

The study indicates that in the flat steppes and semi-deserts of the Turgai region, wildfires in certain years affected extensive areas of the Reserve–up to 347174 ha (Table 3, Figure 5). According to several authors, Kazakhstan has been the country most affected by wildfires in Central Asia, particularly in its central regions, with fires characterized by high intensity (Yin, 2013). Under flat terrain conditions, fire spreads rapidly, especially under strong winds, advancing along a broad front. Such events may exert both direct and indirect impacts on ungulates by altering forage conditions in the short and long term. Although single fire events may have only transient effects and, with the emergence of fresh grass, may temporarily improve forage quality (Dusaeva & Kalmykova, 2021), frequent fires unequivocally exert negative effects on steppe vegetation and fauna (Rachkovskaya & Bragina, 2012), including ungulate migration patterns. Aerial surveys and collar-based tracking have identified multiple factors influencing ungulate migration routes (Nowak et al., 2013). The unprecedented growth of the saiga population in Kazakhstan necessitates a detailed study of forage availability and its changes, including those associated with wildfire events, to ensure the sustainable management and conservation of populations (Position Statement, 2025), as well as the emerging herds of kulan and Przewalski's horse in the region. Steppe fires compel ungulates to move in search of fresh pastures and water sources, thereby exacerbating pressures in newly occupied territories and potentially provoking human–wildlife conflicts. As it is emphasized by several authors (Kamp et al., 2016; Bragina et al., 2018; Yin et al., 2021; Bragina, Kabdulova et al., 2025), comprehensive long-term analyses of fire frequency, burned areas, and their dynamics provide valuable quantitative data to assess and forecast wildfires as a major driver of ecosystem change within the Altyn Dala State Nature Reserve and adjacent steppe regions.

5. Conclusion

The results of the study and the conducted analysis allow us to conclude that wildfires in steppe and semi-desert habitats constitute a powerful factor influencing natural ecosystems. Under

conditions of climate change and the difficulties associated with fire suppression in flat, arid landscapes–particularly during strong winds–fires can spread over vast areas, altering forage resources, destroying watering sites, and reducing the availability of shelter for wildlife. Such disturbances may cause the redistribution of ungulate herds, modifications in migration strategies, increased migration distances, and incursions into human-developed territories. Wildfires may also result in elevated mortality rates among affected animal groups due to stress, direct fire exposure, pasture degradation, and intensified competition for limited forage resources. The study area encompasses the largest specially protected natural area in Kostanay Region– the Altyn Dala State Nature Reserve, which includes key saiga calving grounds as well as areas designated for the restoration of kulan and Przewalski's horse populations. To mitigate the negative impacts of fire hazards, early detection and prevention are essential, employing advanced remote sensing strategies and incorporating assessments of pyrogenic pressure into the management framework for migratory ungulates.

6. Supplementary Material: No supplementary material is provided.

7. Author Contributions

Conceptualization - T.B., G.K.; methodology - G.K., D.Ch.; software - A.Sh., G.Zh., D.M., E.M.; validation - A.Sh., D.Ch.; formal analysis - D.Ch.; investigation - T.B.; resources - D.Ch.; data curation - G.K.; writing-original draft preparation - T.B., G.K.; writing–review and editing - A.B.; visualization - A.Sh.; supervision - G.K.; project administration - D.Ch.; funding acquisition - D.Ch. All authors have read and approved the published version of the manuscript.

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«Алтын Дала» мемлекеттік табиғи резерватындағы өрттер және олардың тұяқты жануарлардың көші-қонына ықтимал әсері

Татьяна Брагина, Гульжиян Кабдулова, Даникер Чепашев, Арсен Шингужинов, Гульсезим Жусупова, Диас Мерекеев, Елизавета Максимкина, Анар Байтелиева

Аңдатпа. Далалар мен шөлейттер – маусымдық климатымен, су ресурстарының шектеулілігімен және өрт қаупінің жоғарылығымен ерекшеленетін аридті экожүйелер. «Алтын Дала» мемлекеттік табиғи резерваты Еуразия даласының Оңтүстік Торғай физикалық-географиялық провинциясында орналасқан. Мұнда аймағы бойынша ең ірі саналатын бетпақдалалық ақбөкен популяциясы ареалының солтүстік-батыс бөлігі таралған. Аймақта ақбөкендердің дәстүрлі төлдеу орындары мен көші-қон жолдары орналасқан, ал қары аз түсетін қыс мезгілдерінде жануарлардың бір бөлігі осында қыстап қалады. Сонымен қатар Қазақстанның құрғақ және шөлейттенген далаларында Пржевальский жылқысын және құландарды қайта жерсіндіру жұмыстары жүргізілуде. Осыған байланысты өңірдің экологиялық жағдайын зерттеу өзекті әрі маңызды болып табылады. Зерттеудің мақсаты – «Алтын Дала» МТР аумағындағы өрттерді және олардың тұяқты жануарлардың көші-қонына ықтимал әсерін талдау. Жұмыстың міндеттері 2000–2025 жылдар аралығында «Алтын Дала» МТР шегінде орын алған өрттердің жиілігі мен өртенген аумақтарының көлемін Жерді қашықтан зондтау әдістері негізінде кешенді талдауды қамтыды. Зерттелген кезеңде резерват аумағында 51 өрт тіркеліп, 1376299 га жер өртенген. Бетпақдалалық ақбөкен популяциясының санының артуы, құрғақшылық және өрттер – ақбөкендердің Қостанай облысының солтүстік өңірлеріне жаппай көшуіне себеп болып, астық дақылдары егістіктеріне айтарлықтай зиян келтірді. Өрттен келетін залалды азайту үшін спутниктік бақылаудың заманауи технологияларын қолдана отырып, алдын ала диагностика жүргізілуі қажет.

Түйін сөздер: дала өрттері; қашықтан зондтау; спутниктік зерттеулер; «Алтын Дала» МТР; іргелес аумақтар; пирогендік фактор; тұяқты жануарлардың көші-қоны; Қазақстан.

Пожары в государственном природном резервате «Алтын Дала» и их возможное влияние на миграции копытных

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Аннотация. Степи и полупустыни являются аридными экосистемами, которые отличаются сезонным климатом, ограниченными водными ресурсами и высоким риском возгораний. Государственный природный резерват «Алтын Дала» расположен в Южно-Тургайской физико-географической провинции степной Евразии, где находится северо-западная часть наиболее крупной по ареалу бетпакдалинской популяции сайгака. В регионе располагаются традиционные места окота и пути миграций сайгака, а в малоснежные зимы часть животных остается и в зимний период. Кроме того, проводятся работы по реинтродукции лошади Пржевальского и куланов в сухих и опустыненных степях Казахстана. Поэтому изучение экологической обстановки в регионе является важным и актуальным. Цель данной работы - анализ возгораний в ГПР «Алтын Дала» и возможного их влияния на миграции копытных. В задачи работы входил комплексный анализ частоты и площадей пожаров в ГПР «Алтын Дала» в период 2000-2025 гг. методами дистанционного зондирования Земли. В изучаемый период в границах резервата произошёл 51 пожар, выгорело 1376299 га площади. Увеличение численности бетпакдалинской популяции сайгаков, засухи и пожары вызвали массовые

миграция сайгаков в северные регионы Костанайской области, нанесшие значительный урон полям зерновых культур. Для снижения ущерба от пожаров необходима ранняя диагностика на основе применения современных технологий спутниковых наблюдений.

Ключевые слова: степные пожары; дистанционное зондирование; спутниковые исследования; ГПР «Алтын Дала»; прилегающие территории; пирогенный фактор; миграции копытных; Казахстан.