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RESEARCH ON THE IMPACT OF WAR ON PROTECTED AREAS OF SOUTHERN UKRAINE

Purpose. To conduct an integrated analysis of the dynamics and ecological consequences of wildfires on Biriuchyi Island (Azovo-Syvash National Nature Park) between 2014 and 2024 using satellite monitoring tools. The study aims to identify spatial and temporal patterns of fire occurrence, assess their impact on vegetation and fauna, and highlight the environmental threats exacerbated by the ongoing occupation and lack of fire management.

Methods. The study utilized NASA FIRMS (MODIS and VIIRS sensors), Sentinel-2 data, Google Earth Engine, and weather archives (RP5) to detect and map fire anomalies. Temporal-spatial analysis was performed based on fire radiative power (FRP), thermal brightness, fire coordinates, and weather parameters. Multisource data were integrated to validate fire events, and Sentinel-based NDVI changes were analyzed to assess vegetation damage.

Results. Two primary fire peaks were identified: June and August 2024. The highest FRP (35.15 MW) and temperature (367 K) were recorded on June 10. Fires exhibited clear diurnal patterns– higher intensity during the day and more detections at night. Vegetation loss and fire scars were confirmed via Sentinel imagery. Occupation-related factors (lack of suppression, military activities) were linked to increased fire spread. Post-fire satellite data showed significant degradation of native vegetation and fragmentation of habitats for deer, amphibians, and migratory birds.

Conclusions. The fires on Biriuchyi Island have caused severe disruption to ecosystems through soil erosion, vegetation loss, and trophic imbalance. Restoration requires urgent actions: wildlife population monitoring, reforestation with native species, erosion control, and regulation of ungulate density. The use of satellite tools proved essential for detecting small-scale fires and monitoring ecological dynamics in inaccessible territories. Without active intervention, cascading degradation is likely, including microclimatic shifts and invasion of alien species. A long-term management plan is needed to restore and protect this unique ecological area.

KEY WORDS: *Biriuchyi Island, wildfire monitoring, satellite remote sensing, FRP, NDVI, ecosystem degradation, ungulates, vegetation loss, fire dynamics, occupation, Google Earth Engine*

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Introduction

The consequences of the full-scale invasion of Ukraine have significantly impacted various aspects of the environment, particularly the condition of protected natural areas. Nature reserves, national parks, and other ecosystems under special protection have come under threat of destruction, degradation, or severe disruption of natural balance. Military actions have caused soil, water, and air pollution, habitat destruction, changes in the range of animal species, and the extinction of rare flora and fauna species.

In wartime conditions, there is an increasing need for comprehensive studies on the consequences of anthropogenic impact on natural resources and the preservation of biodiversity. Such research is vital for developing strategies for environmental restoration, adapting conservation activities to crisis conditions, and ensuring ecological security in the post-war period.

The Azov-Syvash National Nature Park is a unique natural site that plays a key role in preserving the biodiversity of Ukraine's southern region. Its territory includes important ecosystems– lagoons, lakes, steppes, and salt marshes– which serve as habitats for rare and endangered plant and animal species, as well as a globally significant bird migration zone. Due to military operations, the park has suffered direct impacts such as combat damage, landmines, pollution, disruption of the hydrological regime, and uncontrolled human intervention.

Researching the consequences of war on this protected area is extremely relevant for assessing the current state of natural complexes, identifying the most vulnerable zones, and developing scientifically based rehabilitation measures. Furthermore, the results of such studies can serve as a foundation for updating nature protection policies in the context of post-war recovery, increasing environmental awareness, and integrating ecological safety into national security overall.

Biryuchyi Peninsula, which is part of the Azov-Syvash National Nature Park, is located in the southern part of Kherson Oblast. This area holds exceptional conservation value due to its unique ecosystems, rich flora and fauna, and its importance for bird migration routes. As a result of the Russian occupation, monitoring the ecological condition of the Biryuchyi Peninsula and responding promptly to environmental threats has become nearly impossible. This creates conditions for potentially irreversible losses to the natural environment.

Objects and Research Methods

The object of the study is the Biryuchyi Peninsula, part of the Azov-Syvash National Nature Park, specifically its coastal-steppe ecosystems that have been affected by wildfires since the beginning of the full-scale invasion. Due to the temporary occupation of the NNP's territory, the study of wildfires was conducted using Sentinel-2 satellite imagery via NASA’s observation tools through the Google Earth Engine platform. This enabled the identification of areas with increased thermal impact [1-2].

The main tool for data processing is Google Earth Engine (GEE)– a cloud-based platform that allows users to work with large volumes of satellite images and conduct real-time analysis. The study utilized fire data from NASA’s FIRMS (Fire Information for Resource Management System), which provides up-to-date information on thermal anomalies detected by MODIS and VIIRS satellites.

The methodology for wildfire detection using satellite data is a complex, multi-stage process that includes the collection, processing, and analysis of data from various sensors, such as MODIS, VIIRS S-NPP, VIIRS NOAA-20, and VIIRS NOAA-21. Each of these satellite instruments has unique characteristics that influence the accuracy, completeness, and timeliness of fire detection.

For example, the VIIRS satellite has a higher spatial resolution compared to MODIS, enabling it to detect even smaller fire sources. Additionally, VIIRS observes both during the day and at night, unlike MODIS, which mainly focuses on daytime imaging. This gives VIIRS the ability to record fires across a wider time range. Furthermore, VIIRS sensors have increased sensitivity to thermal radiation, enhancing their capability to detect even relatively low-intensity fires.

The MODIS satellite, in turn, has a somewhat lower spatial resolution but compensates for this with a wider field of view, which allows it to conduct global wildfire monitoring. One of MODIS’s advantages is its long history of observations, as the satellite has been operating since 2000, enabling the analysis of multi-year data. Additionally, MODIS has better radiometric accuracy and calibration characteristics, which enhance the reliability of the measurements obtained. Despite its advantages, MODIS still falls short of VIIRS in certain aspects, such as resolution and observation frequency.

The analysis of satellite data on fires is based on evaluating several key parameters. One of the main ones is surface temperature, recorded in Kelvins, which serves as an indicator of fire intensity. The higher the temperature, the more powerful the fire. Another important indicator is FRP (Fire Radiative Power), measured in megawatts. It reflects the thermal radiation power of a fire. FRP values are considered directly proportional to fire intensity. High FRP values indicate large-scale fires, while low values point to less intense fire outbreaks. FRP can also be used to estimate the rate of vegetation burning and carbon emissions into the atmosphere during fires. This information is important for modeling the impact of fires on ecosystems and the global climate. It should also be noted that FRP values may vary depending on many factors, such as weather conditions, vegetation types, and others. Therefore, it is necessary to consider the specific context when interpreting this parameter.

The analysis was carried out by processing satellite data and subsequently visualizing them in Google Earth Engine. The geometry of the study area was created, and key fire activity zones were identified. To assess the dynamics of fires, data were filtered by year, which made it possible to track changes in fire intensity in the area under study. The results were visualized using color coding: red indicated high fire intensity, orange – medium, and yellow – low.

Additionally, spatial analysis methods were used to identify patterns in the distribution of fires. This made it possible to determine potential factors influencing fire occurrences and to assess the scale of their spread. Thanks to the integration of satellite data and Google Earth Engine tools, an objective picture of fire activity in the region was obtained, which is important for making management decisions in the field of environmental protection.

Results and Discussion

The Azov-Syvash National Nature Park was established by the Decree of the President of Ukraine dated February 25, 1993, No. 62/93, on the basis and within the existing boundaries of the Azov-Syvash nature and hunting reserve and its protected zone with the water areas of the Central Syvash and the Sea of Azov. Administratively, the Azov-Syvash National Nature Park is subordinated to the State Administration of Affairs of the President.

The idea of reserving these territories arose at the end of the 19th century due to their unique natural significance. In 1927, a separate reserve “Seaside Spits” was created under the Askania-Nova reserve, which later turned into the Azov-Syvash Reserve. In 1933, the reserve was divided into the Black Sea and Azov-Syvash. In 1957, the latter was reorganized into a nature and hunting reserve, and in 1975 its territory received international status as an important nesting site for waterfowl. In 1993, based on the nature and hunting reserve, the modern national park was created.

The territory of the park is located in the southeast of the administrative Kherson region within the Henichesk and Novotroitsk administrative districts and has an elongated east-west configuration, which is also defined by the configuration of the coastline of the Syvash Bay and the Sea of Azov. Geographically, the territory of the park consists of two parts separated from each other – the Syvash and the Azov. The Syvash part occupies the northern part of the Central Syvash and borders in the south with the Crimean Peninsula, and in the north along the shoreline of the Syvash Bay. An exception is the Serhiivsky and Novodmytrivsky estuaries and a number of ponds that are separated from the main water area by dams. The lands adjacent to the park along the shoreline, as well as parts of the Churyuk and Kuyuk-Tuk islands, are used by village and farming households. The Azov part is located in the water area of the Sea of Azov and is represented by the Biryuchyi Peninsula and a one-kilometer strip around it. In 2018, during the development of the “Territory Organization Project...” the area of the Azov-Syvash National Nature Park was clarified, which now amounts to 52581.6774 ha. The entire territory of the park, according to the latest “Territory Organization Project,” is divided into the following functional zones: 1) reserve – 39196.07 ha. Any economic and recreational activity is prohibited here, with rare exceptions. It includes: a) Churyuk Island – 898.7 ha, b) Kuyuk-Tuk Island – 255.3 ha, c) Martynyachyi Island – 7 ha, d) part of the Syvash Bay – 37785 ha, e) Biryuchyi Spit – 250 ha; 2) regulated recreation – 618 ha. It includes the territory: a) Biryuchyi Spit – 318 ha, b) water area of the Sea of Azov around Biryuchyi Spit – 300 ha; 3) stationary recreation – 49 ha of the Biryuchyi Spit. The last two zones are intended for recreation. Here it is allowed to establish tourist routes, ecological trails; 4) economic zone – 12718.6 ha (mostly located on the territory of the Biryuchyi Spit).

Here shooting and trapping of wild animals, sports, hunting and nature tourism, fishing, limited subsidiary farming, construction, grazing of livestock are allowed – in other words, economic activity within reason. It also includes the water areas of the estuaries adjacent to Biryuchyi: Muzhychyi, Yamkivskyi, Olen, Ozerskyi, Vershynskyi, Bukhta with a total area of 632 ha, part of the water area of the Syvash Bay and a one-kilometer strip of the water area of the Utliuk estuary and the Sea of Azov. According to the landscape zoning scheme, the territory of the Azov-Syvash National Nature Park belongs to the Prysyvash-Pryazov dry steppe lowland landscape area. The landscape structure of this area has formed under the influence of climatic conditions, vegetation characteristics, air mass action, relief, composition of underlying rocks, soil-forming processes, and geological-geomorphological activity of the sea. This area is distinguished by the following features: minimal atmospheric precipitation, high evaporation rates, low relative air humidity, and almost complete absence of surface runoff.

The Azov-Syvash National Nature Park is one of the most valuable natural areas of the Azov region. Its landscape combines steppe areas, salt flats, and significant water areas of the Sea of Azov, Syvash Lake, and the Utliuk estuary. Only one-sixth of the territory is land, and the rest is occupied by aquatic ecosystems that are of great importance for the region’s biodiversity. The climatic conditions of the park are characterized by a long hot summer with temperatures up to +40°C and a short winter with minimal precipitation. The average temperature in January is -3°C, although it can drop to --34°C. The territory of the park is one of the driest in Ukraine, with an average annual precipitation of about 260 mm. This creates specific conditions for the formation of steppe and salt-marsh vegetation adapted to the arid climate. The reserve zone of Central Syvash is represented by lagoon ecosystems that are periodically flooded by sea waters, forming a complex hydrological regime.

Accordingly, the vegetation of this part of the park includes saltmarsh grass, spreading glasswort, half-shrub sea lavender and other halophilic species. This territory is also an important site for bird concentrations, especially during seasonal migrations. Biryuchyi Island, which is actually a spit with an area of 7232 ha and stretches for 20 km, was formed by the accumulation of sand and shells. Its coastline is indented by numerous bays and lagoons, creating favorable conditions for the development of aquatic flora and fauna. Small lakes are located along the coast, and the island's climate is moderately continental with a long hot summer. The soils of the island are mainly meadow, sod and saline, and the vegetation cover is represented by littoral, sandy-steppe, salt-meadow, coastal-aquatic communities, as well as artificial forest plantations. It should be noted that Biryuchyi is more appropriately considered a peninsula, as it has a permanent land connection with the mainland via the Fedotov Spit. This connection is only occasionally interrupted for a short time due to storm events.

The plant world of Biryuchyi is mainly represented by meadow and sandy-steppe species, among which vascular plants dominate – reed, rush, couch grass. In the 1970s-80s, artificial forest plantations were created here with a total area of 232 ha, which included narrow-leaved oleaster, elm, robinia, and ash. The fauna of the island includes various species of even-toed ungulates, in particular red deer, fallow deer, kulans, mouflons, and even domestic horses. In addition, foxes and raccoon dogs live here, and among birds – pheasants. It is important to note that most of the species were acclimatized, since by the beginning of the 20th century the fauna of Biryuchyi was relatively poor. On Biryuchyi Island, some animal species were successfully acclimatized, in particular fallow deer and pheasants, as well as reacclimatized Askanian steppe deer, mouflon, and saiga. Thanks to favorable natural conditions, these species have adapted well to local ecosystems, enriching the biodiversity of the park. Given the limited economic activity, which is constrained both by natural factors (isolation of the territory, saline soils, lack of permanent population) and by environmental restrictions (protected zone status), the natural landscapes of the Azov-Syvash National Nature Park remain almost untouched. An exception is part of the Biryuchyi Peninsula – the territory around the lighthouse, the village of Sadky, and the border areas, where park employees carry out limited management: haymaking, livestock grazing, cultivation of household plots. In addition, the area of artificial forest plantations on Biryuchyi should be considered transformed, as forest ecosystems are not typical for local landscape conditions. At the same time, these plantations enrich the natural structure of the territory, creating new ecological niches for the habitation and concentration of living organisms. Afforestation on the Biryuchyi Peninsula has a long history. The first plantings, including pyramid poplar and Bolle poplar, white mulberry, black locust, and narrow-leaved oleaster, were planted as early as 1914. Although the initial results were promising, further greening efforts were resumed only in 1957. Then, in addition to the already mentioned species, many new trees were planted – common quince, small-leaved elm, box elder, western plane, balsam poplar, green ash, as well as several species of willows (brittle, Babylonian, and white).

Among the shrubs were planted privet, felt cherry, Tatar honeysuckle, cornelian cherry, white dogwood, smoke tree, and golden currant. However, due to the unsuccessful choice of plots and the use of standard technologies in difficult natural conditions, the desired result was not achieved. In 1958, under the leadership of Professor O.L. Belgard, O.A. Fedorko began work on creating protective coverts for pheasants in the form of ribbon-rectangular forest plantations 20–50 meters wide. Within this project, 116 species of woody-shrub plants were tested, including 53 tree species and 63 shrub species.

The planting method involved forming clumps of trees, with strips of shrubs placed along the edges. At that time, valuable forest areas were formed on an area of 650 hectares. Over the past 40 years, about half of such coverts have disappeared. Of the 51 tree and shrub species that have survived, most are in depressed or only satisfactory condition. The best preserved are plantings of silver and narrow-leaved oleaster, common black locust, various species of poplar (white, Bolle, Canadian, black), common oak, eastern plane tree, Virginia juniper, common ash, black mulberry, and smooth elm. In addition to the coverts, separate forest areas and park zones were established on the territory of the Sadky village estate. The largest areas – over 200 hectares – are occupied by monocultures of narrow-leaved and silver oleaster. In general, the condition of plantations created in the period 1965–1980 (common oak, green ash, narrow-leaved oleaster, smooth elm, four-stamen tamarisk) is assessed as satisfactory.

The occupation of the territory and military actions since 2022 have caused irreparable damage to the natural ecosystems of the national park in general and to the Biryuchyi Peninsula in particular. The loss of protected status, destruction of fauna and flora, as well as interference in natural processes may have long-term consequences that will require significant efforts for restoration in the future. Some consequences of the war's impact have been studied by us in the works. In order to determine the impact of fires on the ecosystem of the Biryuchyi Peninsula since the beginning of the full-scale invasion, we conducted studies of thermal anomalies using satellite data.

Within the framework of the study, satellite data on thermal anomalies recorded in the period from 2014 to 2024 in the area of the northern coast of the Sea of Azov, in particular in the vicinity of Biryuchyi Island, were systematized. The data were obtained from the open NASA FIRMS (Fire Information for Resource Management System) platform and cover key parameters of each hotspot: date and time of detection, geographic coordinates, brightness and temperature of radiation, FRP (Fire Radiative Power), as well as the part of the day. The analysis of the obtained indicators makes it possible to assess the dynamics of fire occurrences, their intensity and potential connection with weather conditions, economic activity, or other anthropogenic factors. Tables 1 and 2 presented form the basis for further spatiotemporal analysis of fire activity in the study area during 2014–2021.

The analysis of Tables 1 and 2 showed that during the period from 2014 to 2021, wildfires occurred at certain locations (with observable recurrence) but were of short duration. They took place both in the steppe zone of the island and within its territory.

Particular attention should be paid to the period from 2022 to 2024, since the territory, as noted, was occupied, and it was appropriate to analyze the situation specifically during this time. From 2022 to 2024, a number of wildfires of varying intensity, spread patterns, and temporal dynamics were recorded in the area near Biryuchyi Island.

Figure 1 shows the spatial intensity of thermal anomalies recorded in 2022 within the northern coast of the Sea of Azov, with a focus on Biryuchyi Island and adjacent areas of Henichesk District. The data are visualized based on satellite observations from the NASA FIRMS platform, which detects thermal radiation sources (wildfires) through spectral analysis.

The color gradation of pixels (from yellow to red-orange) indicates the density and frequency of thermal events. A high concentration of anomalies is observed in the northwestern part of the image – this indicates a significant number of fires or thermal processes of technogenic or natural origin. Biryuchyi Island, marked with a green square, is relatively less affected; however, several hotspots have also been recorded in its northeastern part, suggesting a potential spread of wildfire activity into the nature reserve area.

Google Earth Engine (GEE) is a cloud-based platform that allows working with large volumes of satellite imagery and performing real-time analysis. Within the framework of the study, a dataset was used MODIS and VIIRS.

The use of fire data from NASA's FIRMS (Fire Information for Resource Management System) did not provide information on wildfire characteristics during 2022. This may be due to the absence of data on thermal anomalies recorded by the VIIRS satellite.

At the same time, the application of the data processing tool Google Earth Engine (GEE), which provides information on burned areas detected by MODIS and VIIRS satellites, made it possible to identify the following results throughout 2022 (Fig. 2).

In 2022, it was not possible to obtain data for the winter months– January and February– due to the lack of suitable satellite images with low cloud cover. The first signs of burning were recorded in March, with an estimated burned area of approximately 0.14 km². In April, fire activity increased, and the burned area reached 0.66 km², making it the second most intense month of the year. In May and June, activity decreased, with burned areas of 0.006 km² and 0.014 km², respectively. The highest level of fire activity was observed in July, when the burned area exceeded 1.19 km²– this was the peak month by all indicators. In August, the burned area significantly decreased to 0.012 km², and from September to December, only isolated or minor fire outbreaks were recorded, with monthly burned areas of less than 0.01

Table 1

Thermal anomalies (wildfires) based on NASA FIRMS satellite monitoring in the northern Pryazovia region (Biryuchyi Island) during 2014–2018 (Suomi NPP satellite, VIIRS instrument)

Date	Time	Coordinates	Brightness, °K	Temperature, °K	FRP, MW	Time of Day
2014 year						
25.02.2014	09:36	35.19423°, 46.08587°	332.82	299	4.7	day
16.05.2014	09:38	35.09446°, 46.07539°	339.2	311.24	11.14	day
2015 year						
30.04.2015	10:33	35.12894°, 46.1455°	339.14	314.05	6.21	day
08.05.2015	23:45	35.19014°, 46.07806°	304.62	284.49	2.16	night
22.05.2015	22:42	35.05461°, 46.07613°	309.18	291.54	1.1	night
11.06.2015	23:07	35.15404°, 46.15062°	317.6	290.53	1.18	night
13.09.2015	09:42	35.20778°, 46.09476°	348.46	321.08	17.22	day
2016 year						
29.05.2016	10:24	35.1572°, 46.18586°	346.56	318.99	8.78	day
10.06.2016	22:20	35.14247°, 46.15843°	301.18	289.29	0.7	night
07.06.2016	22:50	35.15163°, 46.20123°	312.53	293.86	1.36	night
23.11.2016	22:07	35.07772°, 46.07906°	332.95	275.25	4.45	night
25.11.2016	09:08	35.13446°, 46.19335°	326.63	289.93	2.56	day
2017 year						
13.06.2017	22:18	35.16241°, 46.15647°	313.29	310.29	0.93	night
17.06.2017	22:44	35.13104°, 46.15343°	302.91	303.91	0.71	night
20.06.2017	09:26	35.16985°, 46.17682°	355.30	356.30	17.54	day
01.07.2017	09:19	35.15219°, 46.14613°	342.98	343.98	7.49	day
03.12.2017	23:16	35.03753°, 46.17597°	304.54	305.54	1.00	night
2018 year						
20.06.2018	10:22	35.16138°, 46.1436°	344.08	317.47	8.44	day
03.07.2018	23:40	35.20909°, 46.09457°	320.98	298.63	3.72	night
07.07.2018	22:25	35.15823°, 46.14952°	304.76	292.12	1.25	night
03.08.2018	22:19	35.15622°, 46.10986°	305.0	294.92	0.99	night
03.09.2018	10:16	35.12032°, 46.08723°	350.08	321.3	16.53	day
13.09.2018	22:51	35.2088°, 46.18575°	314.69	293.33	1.38	night

Compiled by the authors based on source [1].

km². Thus, the main fire activity occurred in the spring-summer period, with a peak in July.

Similar studies were continued for 2023.

Figure 3 presents satellite mapping of thermal anomalies in the southern part of Zaporizhzhia and the eastern part of Kherson regions for the period from January to December 2023. The image was created using NASA FIRMS data, which reflect active fire hotspots (thermal anomalies) with spatial distribution of intensity. As in the previous image, the green square marks the area of Biryuchyi Island – a nature reserve site. Regarding the protected zone– Biryuchyi Island– thermal anomalies were also recorded within or near it, posing a threat to natural ecosystems. This expansion of fire activity may be linked to changes in climatic conditions (an increase in average daily temperature, a decrease in precipitation), as well as complications in environmental monitoring during wartime. Therefore, the year 2023 is characterized by increased intensity and territorial coverage of wildfires, which creates

Table 2

Thermal anomalies (wildfires) based on NASA FIRMS satellite monitoring in the northern Pryazovia region (Biryuchyi Island) during 2019–2021 (Suomi NPP satellite, VIIRS instrument)

Date	Time	Coordinates	Brightness, °K	Temperature, °K	FRP, MW	Time of Day
2019 year						
02.06.2019	22:38	35.16323°, 46.15553°	307.07	307.07	0.92	night
14.06.2019	09:51	35.11017°, 46.11028°	367.00	367.00	15.15	day
14.06.2019	22:13	35.08490°, 46.12121°	341.50	341.50	7.48	night
15.06.2019	09:32	35.09468°, 46.11148°	347.75	347.75	24.35	day
16.06.2019	10:54	35.09716°, 46.08716°	341.01	341.01	11.94	day
04.08.2019	10:35	35.16127°, 46.17272°	348.12	348.12	6.90	day
14.08.2019	10:48	35.19474°, 46.16037°	367.00	367.00	26.60	day
13.09.2019	22:06	35.21069°, 46.11153°	330.11	330.11	4.33	night
2020 year						
26.06.2020	22:25	35.08144°, 46.09064°	318.21	297.2	4.23	night
28.06.2020	09:25	35.0776°, 46.11045°	344.38	316.5	18.68	day
28.06.2020	21:47	35.06363°, 46.12894°	312.27	294.85	3.36	night
30.06.2020	08:48	35.08916°, 46.15711°	334.11	334.11	21.39	day
30.06.2020	22:50	35.06333°, 46.15044°	310.4	348.17	1.38	night
30.06.2020	23:53	35.0659°, 46.07281°	307.77	346.34	4.73	night
01.07.2020	09:57	35.12608°, 46.19098°	367.00	336.21	8.69	day
2021 year						
09.04.2021	22:43	35.16703°, 46.10798°	311.59	282.03	1.24	night
24.04.2021	10:41	35.16858°, 46.14602°	367.00	316.51	3.35	day
25.04.2021	10:22	34.98259°, 46.17447°	333.37	308.06	4.36	day
25.04.2021	22:43	34.9863°, 46.08393°	304.83	288.38	0.57	night
04.06.2021	21:53	35.14074°, 46.16631°	315.01	291.81	1.94	night
05.06.2021	09:13	35.13234°, 46.16674°	341.16	315.91	2.34	day
24.06.2021	09:57	35.13001°, 46.19447°	367.00	327.22	8.69	day
25.06.2021	09:38	35.17773°, 46.21025°	321.02	351.61	13.9	day
21.07.2021	22:13	35.06557°, 46.09747°	312.12	299.18	3.01	night
22.07.2021	09:32	35.06585°, 46.1017°	351.87	320.45	10.16	day

Compiled by the authors based on source [1].

additional environmental risks for coastal and protected areas of the Azov-Black Sea region.

Satellite data recorded a wildfire on the southeastern coast of the Biryuchyi Peninsula from July 4 to July 10, 2023. The affected zones are clearly visible in the imagery using NDVI, indicating vegetation cover degradation. The results of the conducted analysis indicate a significant deterioration in the ecological condition of the study area due to military occupation. Since the occupation began, the effectiveness of fire suppression has noticeably decreased, and systematic care of protected areas, particularly in the Biryuchyi Island region, has almost completely ceased. This has created preconditions for large-scale seasonal wildfires affecting both natural and agricultural landscapes.

During the analysis of satellite data from NASA's FIRMS system, two main periods of fire activity were recorded in the study area – in June and September (Table 3).

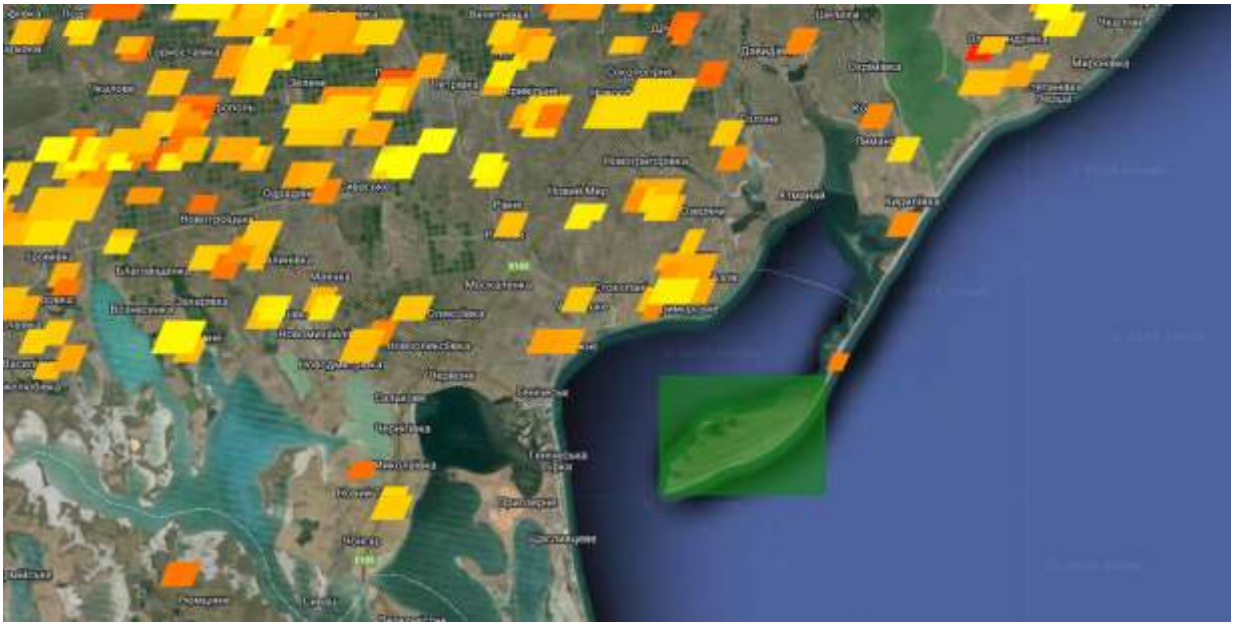

Fig. 1 – Condition of the selected area from January 2022 to December 2022.
Compiled by the authors based on source [2].


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Fig. 2 – Burned Area in 2022

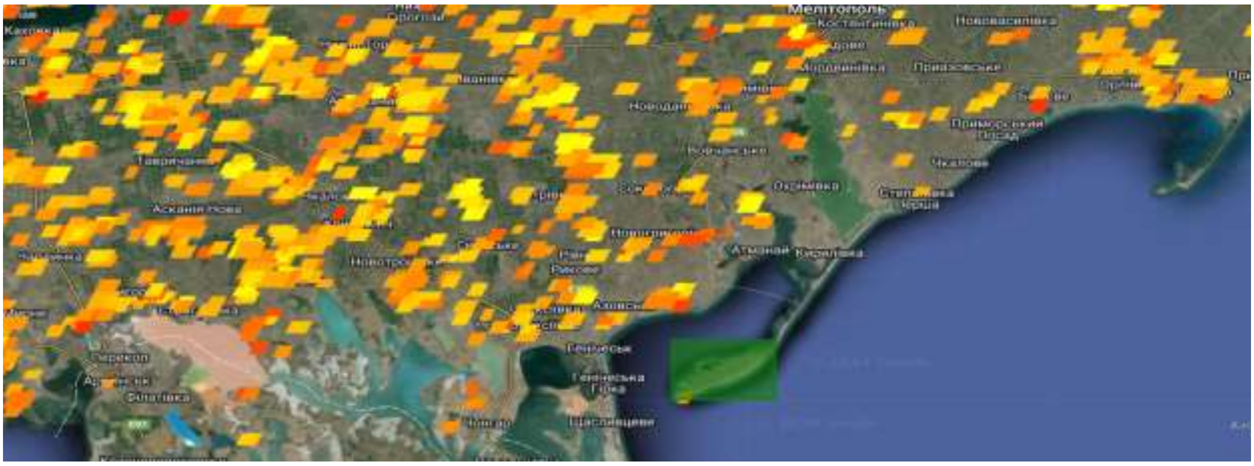

Fig. 3 – Condition of the selected area from January 2023 to December 2023
Compiled by the authors based on source [2].

Table 3

Thermal anomalies (wildfires) based on NASA FIRMS satellite monitoring in the northern Pryazovia region (Biryuchyi Island) during 2023 (Suomi NPP satellite, VIIRS instrument)

Date	Time	Coordinates	Brightness, °K	Temperature, °K	FRP, MW	Time of Day
2023 year						
06.06.2023	23:11	35.07536°, 46.1778°	302.36	288.91	0.39	night
06.06.2023	23:11	35.07462°, 46.1813°	300.33	287.91	0.39	night
08.06.2023	22:33	35.06746°, 46.19642°	290.72	310.44	1.52	night
10.09.2023	23:10	35.11687°, 46.16344°	320.04	295.22	1.91	night
11.09.2023	08:50	35.11636°, 46.17956°	340.52	312.29	12.88	day
11.09.2023	10:30	35.12804°, 46.15277°	354.85	320.19	16.43	day
11.09.2023	22:51	35.13182°, 46.14058°	294.86	305.66	1.6	night

In 2023, the first fire outbreaks were recorded from June 6 to 8, mostly at night, with low Fire Radiative Power (FRP) values ranging from 0.39 to 1.52 MW, indicating small, localized fires.

Significantly higher activity was recorded in September 2023, particularly on September 11, when a fire during the daytime reached a temperature of up to 320.19 K, brightness of 354.85 K, and an FRP of 16.43 MW, indicating intense burning. On the same morning, another powerful fire with an FRP of 12.88 MW was also detected. These events indicate a high fire hazard at the end of summer and the beginning of autumn.

Unlike June, the fires in September (September 10–11) were of a completely different nature – 17 detections were recorded, covering a broader area between 35.10–35.13°N and 46.14–46.18°E, with an estimated area of about 3 km². These fires alternated between night and day phases and showed sharp fluctuations in intensity. The daytime burning temperature reached 354.85 K, the highest value during the observed period, and the FRP peaked at 16.43 MW – a record value recorded twice on September 11.

June fires showed consistently low intensity and were detected with nominal confidence. In contrast, September fires exhibited high variability in intensity even within a single day, with a peak in activity in the morning and daytime hours of September 11. On this day, a sharp increase in fire intensity was recorded, followed by a rapid decline in the evening. Some daytime detections had mixed confidence levels due to high aerosol concentrations and possible interferences affecting the accuracy of satellite data.

Spatially, the June and September fire outbreaks did not overlap – they were located in different areas approximately 4–5 km apart. All fires had a clustered pattern, forming compact groups, which indicates local conditions for fire ignition, likely caused by human activity or uncontrolled processes on abandoned land plots.

In conclusion, NASA FIRMS data clearly captures changes in the intensity and spatial characteristics of wildfires in the second half of 2023 and demonstrates the increased risks associated with declining land management effectiveness. This further underscores the importance of satellite monitoring for detecting and assessing the dynamics of both natural and human– induced fires.

The use of the Google Earth Engine (GEE) tool made it possible to obtain information on burned areas in 2023, as recorded by MODIS and VIIRS satellites. As in the previous case, combining information from both sources allowed for an expanded understanding of the fire events (Fig. 4).


```
Burned Area per Month (km²) in 2023:
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  ▾11: Object (2 properties)
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Fig. 4 – Burned Area in 2023

In 2023, wildfire activity on Biryuchyi Island showed a clear seasonal dynamic with a sharp peak in spring. No data were available for January and February, likely due to unfavorable weather conditions and high cloud cover that prevented the acquisition of suitable satellite imagery. In March, an exceptionally large burned area was recorded – over 14.4 km², which represents the absolute maximum for the year. In April, the figure dropped sharply to 0.043 km², and in May it slightly increased to 0.10 km². June saw another significant increase in burned area to over 1.18 km², after which no burning events were recorded in July. In August, September, and October, only minor traces of fire activity were detected, with monthly burned areas less than 0.003 km². In November, the burned area was approximately 0.045 km², and in December – around 0.028 km². Overall, 2023 was characterized by abnormally high fire activity in March, less intense episodes in June, and isolated fires during other months.

An analysis of NASA FIRMS thermal anomaly (wildfire) data based on satellite monitoring of Biryuchyi Island using the Suomi NPP satellite and VIIRS instrument is presented in Table 4**.**

Table 4

Thermal anomalies (wildfires) based on NASA FIRMS satellite monitoring in the northern Pryazovia region (Biryuchyi Island) during 2024 (Suomi NPP satellite, VIIRS instrument)

Date	Time	Coordinates	Brightness, °K	Temperature, °K	FRP, MW	Time of Day
2024 year						
04.06.2024	22:44	35.10315°, 46.20099°	316.8	297.12	2.38	night
06.06.2024	22:06	35.09619°, 46.18369°	316.88	293.57	4.65	night
06.06.2024	23:46	35.09515°, 46.18308°	307.97	292.86	3.04	night
07.06.2024	09:26	35.08377°, 46.20878°	340.79	300.93	5.07	day
08.06.2024	09:07	35.07297°, 46.19811°	367.00	307.11	7.42	day
08.06.2024	10:48	35.07441°, 46.21264°	310.09	367.00	9.33	day
08.06.2024	23:09	35.06923°, 46.21117°	294.73	327.04	2.68	night
09.06.2024	08:48	35.0585°, 46.20996°	345.48	300.91	7.33	day
09.06.2024	10:29	35.057°, 46.20673°	317.82	355.77	20.17	day
09.06.2024	22:50	35.06757°, 46.11308°	268.60	312.63	1.63	night
10.06.2024	10:10	35.04699°, 46.09775°	339.59	309.68	4.09	day
10.06.2024	22:31	35.03495°, 46.08949°	291.48	317.44	1.87	night
11.06.2024	22:12	35.02854°, 46.09764°	291.70	306.25	1.79	night
12.06.2024	21:53	35.032°, 46.10518°	291.25	301.53	1.17	night
12.06.2024	09:32	35.02376°, 46.10268°	308.69	341.22	16.16	day
13.06.2024	09:13	35.0119°, 46.11203°	305.93	347.58	4.48	day
14.06.2024	10:35	35.04836°, 46.20476°	311.14	367.00	15.42	day
02.07.2024	09:57	35.19245°, 46.17499°	317.45	346.86	7.40	day
10.08.2024	09:26	35.15236°, 46.14219°	317.62	346.2	7.35	day
19.08.2024	09:58	35.19637°, 46.15812°	323.25	348.35	18.52	day
17.10.2024	22:12	35.02831°, 46.13974°	293.67	321.06	2.75	night
24.10.2024	23:22	35.21137°, 46.09368°	277.76	296.84	0.98	night

In 2024, activity began in early June. From June 4 to 7, mostly nighttime fires with moderate intensity were recorded, with FRP reaching up to 4.65 MW, concentrated geographically near 46.18–46.21°E. From June 8 to 9, the situation escalated – a series of powerful daytime fires were recorded with FRP up to 20.17 MW and temperatures above 350 K, indicating large– scale burning. The highest recorded FRP value occurred on June 9, possibly signaling the ignition of a significant area of dry vegetation. Activity continued through June 14, with a daytime fire on the 14th reaching a temperature of 367 K and FRP of 15.42 MW – one of the most intense events in the entire observation period.

In July and August 2024, intense fires with FRP exceeding 7 MW were also recorded, with a peak of 18.52 MW on August 19. Later in autumn, in October 2024, nighttime fires with moderate intensity (up to 2.75 MW) were observed, which may have been caused by both natural factors and human activity.

In summary, wildfire activity during this period demonstrates a rising trend in the spring–summer season, with peaks in June and August. This underlines the importance of continuous monitoring to prevent environmental threats, especially under conditions of arid climate and possible anthropogenic influence.

Between June 4 and June 14, 2024, the study area experienced prolonged wildfire activity characterized by a distinct phased development and spatiotemporal dynamics. The initial ignition was recorded on June 4 at 22:44 at coordinates 35.09–35.10°N and 46.19–46.20°E. In the following days, active burning zones gradually shifted toward the southwestern sector (35.00–35.08°N, 46.08–46.21°E), accompanied by increased thermal radiation intensity (FRP) and burning temperatures.

The main development phase occurred from June 8 to 10, peaking on June 10 at 10:10 at coordinates 35.04699°N, 46.09775°E, where the maximum FRP reached 35.15 MW, the burning area temperature was 309.68 K, and brightness was 339.59 K. This represents the highest energy output recorded during the entire observation period.

The daily dynamics of the fire displayed a typical natural pattern: higher FRP values were recorded during daylight hours (average ~8–12 MW), while nighttime activity decreased to around 2–3 MW. However, more detections occurred at night due to improved visibility for satellite sensors. Temperature readings ranged from 300.9 K to 367 K, with typical daytime values of 340–355 K and nighttime values of 305–320 K.

Following the peak intensity on June 10, the fire's energy gradually declined, marking the decay phase (June 11–14). During this time, the active burning zone shifted eastward (to coordinates 35.04–35.05°N, 46.20°E). A new isolated flare– up was recorded on July 2 at coordinates 35.19°N, 46.17°E, indicating a possible re– ignition or residual smoldering of organic matter.

The spatial concentration of fire activity is shown in Fig. 5.

Fig. 5 – Largest Wildfires Recorded During the Occupation on Biryuchyi Island
Compiled by the authors based on source [17].

Thus, the wildfires of June 2024 exhibited a complex development structure, with a sequential escalation of intensity, spatial expansion, a clear daily rhythm, and the conclusion of the main active phase within ten days. The highest temperatures and FRP values were recorded during daylight hours, while the nighttime phase provided detailed satellite data necessary for reconstructing the full dynamics of the wildfire.

Based on Sentinel– 2 (Copernicus) satellite imagery from August 2024, a large– scale wildfire was detected on Biryuchyi Island, covering a significant portion of its territory. The first signs of fire activity were observed on August 3, the intensity peaked on August 8, and active fire spots persisted through August 18–19. The images clearly show areas affected by thermal damage corresponding to hotspots of high temperature and burning (Fig. 6–8).

The wildfires were accompanied by thermal anomalies, with a maximum temperature reaching 348.35 K (on August 19) and fire radiative power (FRP) up to 18.52 MW. This is

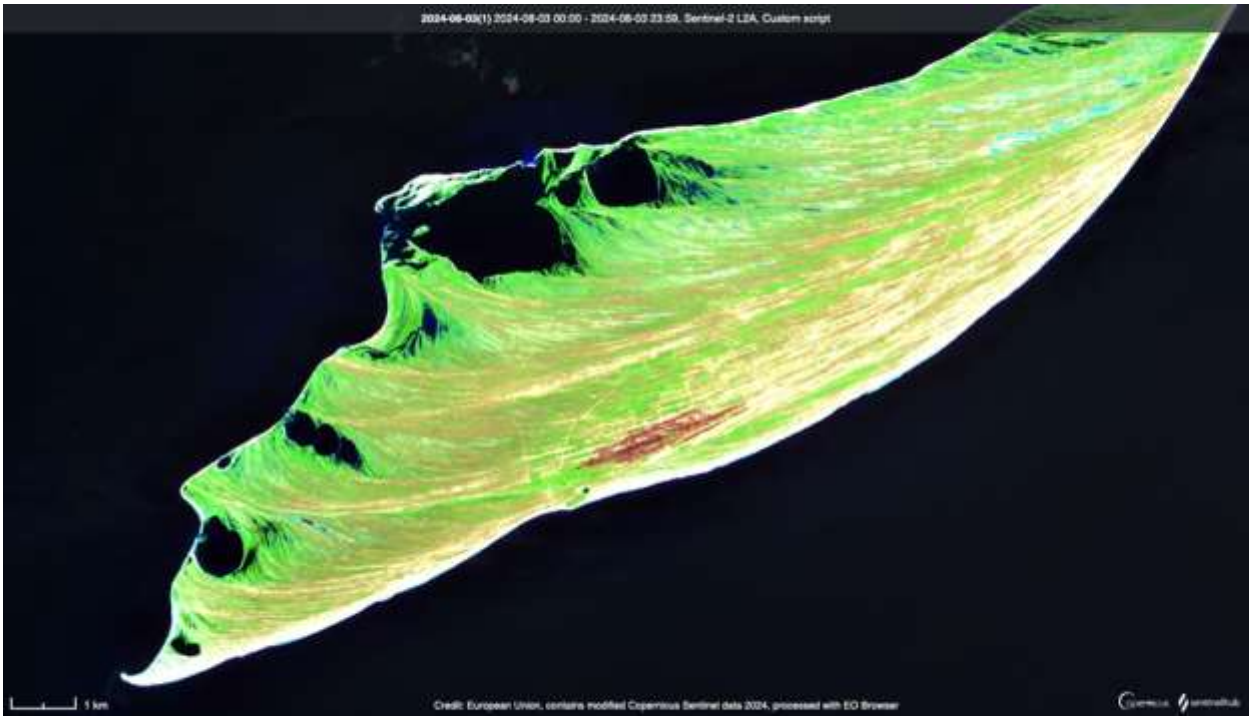

Fig. 6 – Wildfires on Biryuchyi Island, August 3, 2024
Compiled by the authors based on source [1].

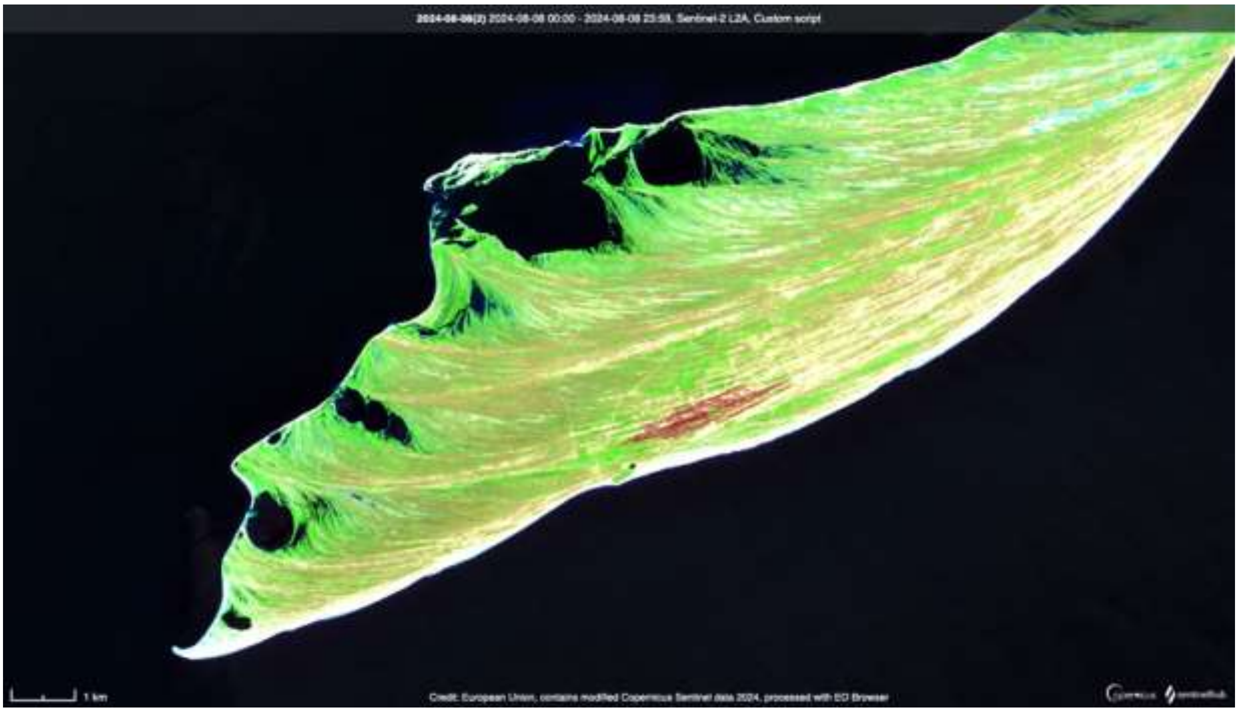

Fig. 7 – Wildfires on Biryuchyi Island, August 8, 2024
Compiled by the authors based on source [1].

confirmed by NASA FIRMS data, where these events were recorded as distinct, high–temperature daytime hotspots. In particular, the wildfire on August 10 (09:26) at coordinates 35.15236°N, 46.14219°E was accompanied by a temperature of 346.2 K and an FRP of 7.35 MW.

Throughout 2024, the overall pattern of fire load was as follows:

No fires were detected from January through May.

June accounted for the primary wave of detections, with 181 cases.

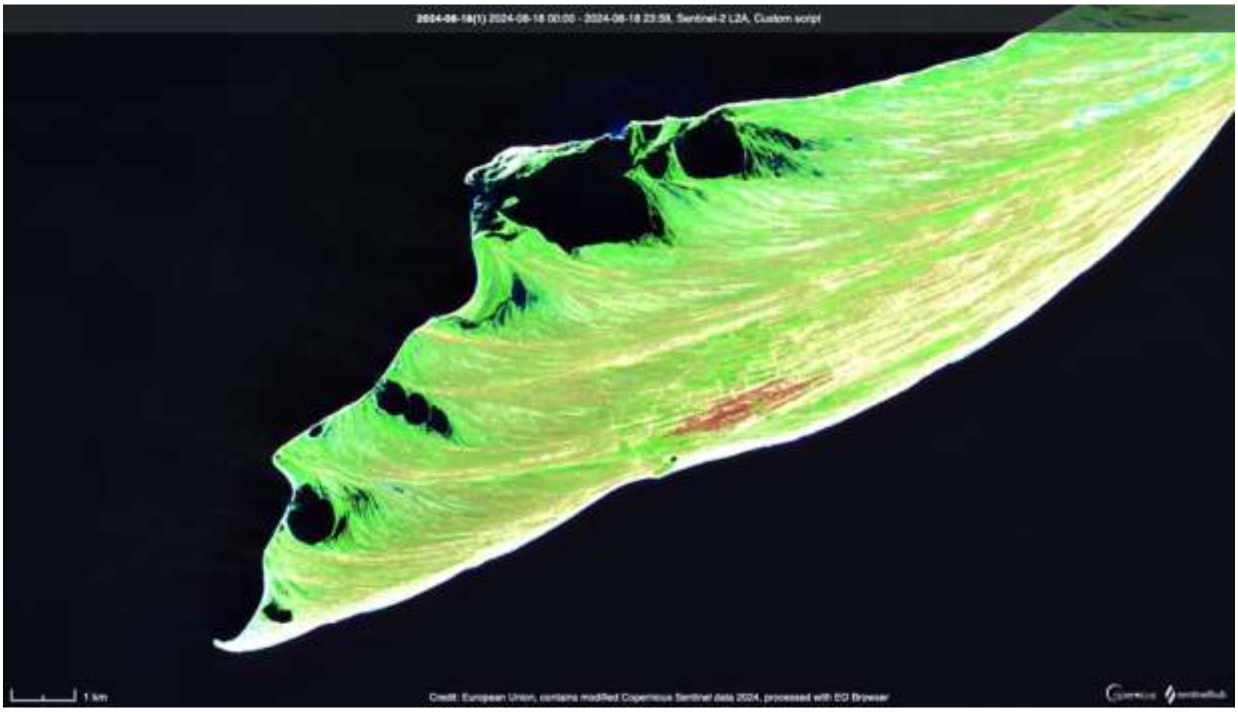

Fig. 8 – Wildfires on Biryuchyi Island, August 18, 2024
Compiled by the authors based on source [1].

July saw only 3 minor episodes.

The August outbreak was the second most intense.

October recorded 3 fire hotspots.

In autumn and early winter, fire activity gradually declined.

The temporal dynamics of the fires showed a typical diurnal pattern: intensity was higher during the day, but the total number of nighttime detections was greater due to higher contrast in the infrared spectrum. Spatially, the hotspots shifted from the eastern part of the island toward the center and then closer to the southwestern section, forming a clustered burn pattern.

The temperature range was consistent with natural burning of dry vegetation: from 300.9 K to 367 K. Daytime temperatures typically reached 340–355 K, while nighttime temperatures did not exceed 320 K. Average daytime FRP ranged from 8 to 12 MW, while nighttime values were around 2–3 MW.

Taken together, this data indicates significant wildfire activity on Biryuchyi Island in August 2024, confirmed by both remote sensing data from Sentinel– 2 and NASA FIRMS observations. The scale and duration of the fires suggest a serious ecological impact on the island's ecosystem, especially under conditions of limited fire management and restricted access for suppression efforts due to occupation.

The use of the Google Earth Engine (GEE) tool enabled the acquisition of information about burned areas in 2024, as recorded by MODIS and VIIRS satellites. As in the previous case, combining data from both sources allowed for a more comprehensive understanding of the wildfire events (Fig. 9).

In 2024, Biryuchyi Island experienced relatively moderate but traceable wildfire activity, marked by several periods of increased intensity. As early as January, a small burned area of approximately 0.004 km² was recorded. In February and March, no data were available, likely due to cloud cover or the lack of high–quality satellite images. In April and May, burned areas remained minimal– 0.013 km² and 0.0087 km², respectively. In contrast, June saw a sharp rise in activity, with over 1.63 km² burned, making it one of the two peak months of the year.

In July, the burned area dropped again to 0.0012 km², but in August it increased to over 0.2 km². September showed a more moderate figure of 0.061 km². October marked the second and most intense peak of the year, with a burned area exceeding 1.85 km²– the highest recorded monthly value. In November, wildfire activity nearly ceased (0.0006 km²), but in December, it rose again to 0.179 km².

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Fig. 9 – Burned Area in 2024

Thus, the combined use of the Google Earth Engine platform and NASA FIRMS allowed for a detailed description of the wildfire situation on Biryuchyi Island since the onset of war.

To confirm conclusions regarding the causes of fires (see Table 2), multiple sources were used– satellite data, meteorological information, and local– scale observations– which allowed for a more complete and comprehensive picture of the changes that occurred during the 2015–2024 period.

To study the influence of weather conditions on the likelihood of wildfires in the Biryuchyi Island area, a table was constructed containing data on fire detection dates and corresponding weather conditions. Fire data were obtained from the official source– NASA FIRMS (Fire Information for Resource Management System), which provides satellite monitoring of thermal anomalies.

For each recorded fire date, the average daily air temperature was calculated as the arithmetic mean between daytime and nighttime temperatures. These weather data were gathered from hydrometeorological websites that provide actual weather information in the region. The primary meteorological station used for data collection was located in the urban– type settlement of Kyrylivka, the closest to the study area [18].

In addition to temperature, the table also includes recorded weather phenomena (sunny, rain, cloudy, thunderstorm) observed on the day of the fire, as they can significantly influence ignition conditions or fire spread. This enabled a comprehensive assessment of the possible relationship between temperature conditions, atmospheric phenomena, and the risk of natural wildfires, as illustrated in Table 5.

Wildfire on 11.06.2015

The average daily temperature was 20°C, reaching 25°C during the day and dropping to 15°C at night. The weather was sunny. These temperature values do not reach critical thresholds for spontaneous ignition of vegetation. While the sunny weather could have contributed to drying the grass, the anthropogenic factor remains the most likely cause of the fire.

Wildfire on 10.06.2016

Table 5

Analysis of Meteorological Conditions on Wildfire Days Near Biryuchyi Island, 2015–2024

Date of Fire	Average Daily Temperature (°C)	Daytime Temperature (°C)	Nighttime Temperature (°C)	Weather Conditions	Date of Fire	Average Daily Temperature (°C)	Daytime Temperature (°C)	Nighttime Temperature (°C)	Weather Conditions
11.06.2015	20	25	15	Sunny	28.06.2020	22,5	26	19	Sunny
10.06.2016	15,5	18	13	Sunny	4.06.2021	15,5	18	13	Rain
13.06.2016	19,5	22	17	Sunny	5.06.2021	16	19	13	Rain
17.06.2016	22,5	25	20	Sunny	24.06.2021	23	26	20	Cloudy
18.06.2016	22,5	25	20	Sunny	25.06.2021	24,5	28	21	Cloudy
20.06.2016	26,5	32	21	Sunny	26.06.2021	24	27	21	Cloudy
23.06.2016	27	30	24	Sunny	21.07.2021	27	31	23	Sunny
1.07.2017	27,5	32	23	Sunny	22.07.2021	21,5	22	21	Thunderstorm
9.07.2017	21,5	24	19	Thunderstorm	18.07.2022	21	26	16	Sunny
10.07.2017	19,5	24	15	Sunny	19.07.2022	20,5	25	16	Cloudy
11.07.2017	23	26	20	Sunny	20.07.2022	22	26	18	Cloudy
12.07.2017	23	25	21	Sunny	21.07.2022	21,5	26	17	Cloudy
13.07.2017	24	26	22	Sunny	22.07.2022	23,5	27	20	Cloudy
30.08.2017	16	18	14	Sunny	23.07.2022	21,5	27	16	Cloudy
20.06.2018	22,5	25	20	Sunny	24.07.2022	23	28	18	Cloudy
3.07.2018	20,5	23	18	Sunny	6.06.2023	16	20	12	Sunny
7.07.2018	25	30	20	Sunny	8.06.2023	17	20	14	Sunny
12.07.2018	27,5	34	21	Sunny	4.06.2024	22	26	18	Cloudy
3.08.2018	24	27	21	Sunny	6.06.2024	22,5	26	19	Cloudy
8.08.2018	24	31	17	Sunny	7.06.2024	23	27	19	Cloudy
2.06.2019	21,5	25	18	Rain	8.06.2024	23	27	19	Cloudy
14.06.2019	22,5	25	20	Sunny	9.06.2024	23	27	19	Cloudy
15.06.2019	22	26	18	Sunny	10.06.2024	24,5	28	21	Cloudy
16.06.2019	23	27	19	Sunny	11.06.2024	24,5	27	22	Cloudy
19.06.2019	23,5	27	20	Sunny	12.06.2024	25	28	22	Rain
17.07.2019	21,5	25	18	Sunny	13.06.2024	22	27	17	Cloudy
4.08.2019	22	24	20	Thunderstorm	14.06.2024	22,5	26	19	Cloudy
14.08.2019	24,5	27	22	Sunny	2.07.2024	25,5	29	22	Sunny
26.06.2020	21	24	18	Sunny	10.08.2024	25	28	22	Cloudy
27.06.2020	22	25	19	Sunny	19.08.2024	24	28	20	Cloudy

Compiled by the authors based on sources [1, 2, 18].

The average temperature was 15.5°C, with a daytime high of 18°C and a nighttime low of 13°C. Although the weather was sunny, the temperature was too low for natural ignition. The fire was most likely caused by human activity.

Wildfire on 13.06.2016

Average temperature: 19.5°C (22°C day, 17°C night). Sunny weather, but moderate temperatures make spontaneous ignition unlikely. Again, the anthropogenic factor is the main hypothesis.

Wildfire on 17.06.2016

Average daily temperature: 22.5°C (25°C day, 20°C night). Sunny conditions could dry out vegetation, but temperatures are still below levels typical for spontaneous ignition. Most likely human– caused.

Wildfire on 18.06.2016

Average temperature: 22.5°C (25°C day, 20°C night). Conditions similar to 17.06 – conducive to burning, but not spontaneous ignition. Anthropogenic cause remains most probable.

Wildfire on 20.06.2016

Higher average temperature: 26.5°C (32°C day, 21°C night). Sunny weather and high daytime temperature may have created conditions for natural ignition, but definitive conclusions require more data.

Wildfire on 23.06.2016

Average temperature: 27°C (30°C day, 24°C night). Temperatures were high and sunny weather promoted drying. Natural ignition is possible, though human involvement cannot be ruled out.

Wildfire on 1.07.2017

Average temperature: 27.5°C (32°C day, 23°C night). High temperatures and sunny weather provided favorable conditions for ignition, though human factors remain possible.

Wildfire on 9.07.2017

Average temperature: 21.5°C (24°C day, 19°C night). Thunderstorms were reported, suggesting possible lightning ignition.

Wildfire on 10.07.2017

Average temperature: 19.5°C (24°C day, 15°C night). Sunny with moderate temperatures. Most likely anthropogenic.

Wildfire on 11.07.2017

Average temperature: 23°C (26°C day, 20°C night). Sunny weather and moderate temperatures do not exclude human influence.

Wildfire on 12.07.2017

Average temperature: 23°C (25°C day, 21°C night). Anthropogenic factor remains the leading cause, as temperatures are not critical.

Wildfire on 13.07.2017

Average temperature: 24°C (26°C day, 22°C night). Conditions similar to previous days. Most likely human– caused.

Wildfire on 30.08.2017

Average temperature: 16°C (18°C day, 14°C night). Low temperatures rule out natural ignition. Human activity is the main suspected cause.

Wildfire on 20.06.2018

Average temperature: 22.5°C (25°C day, 20°C night). Sunny weather supports burning, but not natural ignition. Human activity is the likely cause.

Wildfire on 3.07.2018

Average temperature: 20.5°C (23°C day, 18°C night). Moderate temperatures again point to anthropogenic origin.

Wildfire on 7.07.2018

Average temperature: 25°C (30°C day, 20°C night). High but not extreme temperatures. Both natural and human causes are possible.

Wildfire on 12.07.2018

Average temperature: 27.5°C (34°C day, 21°C night). High daytime temperature increases likelihood of natural ignition.

Wildfire on 3.08.2018

Average temperature: 24°C (27°C day, 21°C night). Conditions support burning, but spontaneous ignition is unlikely.

Wildfire on 8.08.2018

Average temperature: 24°C (31°C day, 17°C night). Sunny weather and high daytime temperature could facilitate ignition, though a human cause is still possible.

Fires on 30.08.2017, 20.06.2018, and others up to August 2019. These dates reflect similar average temperatures (16°C–27.5°C) with sunny weather. Temperatures do not exceed thresholds for natural ignition, suggesting human activity as the probable cause.

Fires during 06–07 months of 2020–2022

Temperatures ranged between 15.5°C and 27°C under varied weather conditions (sunny, cloudy, rainy). The lack of extreme heat suggests low probability of spontaneous ignition. Fires during cloudy days further support the anthropogenic origin theory.

Fires in 2023–2024

Data shows a temperature increase up to 25.5°C (with daytime highs of 29°C). At such temperatures, natural ignition is unlikely, especially since vegetation might be more humid during this period. Cloudy weather conditions in 2024 once again highlight the role of human activity.

The results of this comprehensive analysis confirm the main conclusion about the predominant causes of wildfires – anthropogenic pressure resulting from the occupation of the territory, rather than climatic anomalies, throughout the studied period.

Conclusions

During the study of the chronological dynamics of thermal anomalies on the territory of the Biryuchyi Peninsula for the period 2014–2024, a full– scale spatiotemporal analysis of fire activity was carried out based on satellite data from NASA FIRMS and Google Earth Engine. Two stable periods of increased intensity were identified – the spring– summer season (especially June–July) and, in some years, September. Fires during these periods were characterized by significant thermal loads, confirmed by high fire radiative power (FRP) values exceeding 20 MW, indicating extremely intense burning. The spatial distribution of thermal anomalies showed a clustered pattern: ignition zones concentrated in compact areas of 3–5 km² with a tendency for repeated ignition in the same locations. The movement of fire hotspots from the northeastern to the southwestern part of the peninsula indicates the formation of localized fire– prone zones, likely linked to landscape morphology, vegetation type, and the presence of abandoned infrastructure.

The daily distribution of fire activity revealed a clear pattern: the highest FRP values were recorded during the daytime (from 08:00 to 12:00), associated with peak air temperatures, while the number of detections increased at night (22:00–02:00) due to optimal conditions for infrared signal reading. June and August 2024 were particularly active in terms of thermal dynamics due to a combination of high air temperatures, low precipitation levels, and increased dryness of soil and vegetation. A retrospective analysis of burned areas conducted via GEE revealed significant annual variability: over 2.1 km² in 2022, over 16.5 km² in 2023 (with a peak in March – 14.4 km²), and about 3.9 km² in 2024, with pronounced peaks in June and October.

The ecological situation in the region has significantly deteriorated since 2022 due to military occupation. There has been a decline in environmental monitoring, loss of operational control over protected areas, and reduced effectiveness of fire suppression. As a result, uncontrolled wildfires have spread on a large scale, leading to the degradation of biotopes, loss of floristic and faunal diversity, and the activation of secondary destructive natural processes such as erosion and changes in microclimatic conditions.

Meteorological context accompanying the thermal anomalies, determined by comparing weather conditions (based on data from the Kyrylivka meteorological station) with fire detection dates, showed that most fires occurred under average daily temperatures of 18–26°C – values not critical for spontaneous vegetation ignition. Moreover, some thermal anomalies occurred under cloudy skies or following rainfall, which significantly reduces the probability of natural causes and points to an anthropogenic origin.

The integration of multi– source satellite analysis – particularly NASA FIRMS (VIIRS), Google Earth Engine (MODIS/VIIRS), and Sentinel– 2 (Copernicus) imagery – enabled high– precision reconstruction of the real fire dynamics. The use of NDVI for assessing post–fire vegetation condition helped to detect the degree of vegetation degradation and objectively assess the scale of environmental damage.

The overall assessment of fire hazard in the study area indicates a high level of ecosystem vulnerability on the Biryuchyi Peninsula and adjacent areas of the Henichesk coastline. This hazard is caused by a combination of natural factors (arid climate, open landscapes, rapid biomass drying) and anthropogenic impact (military presence, neglect, abandoned land plots). Therefore, there is an urgent need to create an adaptive fire risk management system based on satellite monitoring, meteorological modeling, and the development of fire danger forecast maps.

Conflict of Interest

This work was supported by a grant from the Simons Foundation, Award ID: 1030285 (2023) Award ID: 1290592 (2024).

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ДОСЛІДЖЕННЯ ВПЛИВУ ВІЙНИ НА ЗАПОВІДНІ ТЕРИТОРІЇ ПІВДНЯ УКРАЇНИ

Мета. Провести комплексний аналіз динаміки та екологічних наслідків лісових пожеж на території Бірючого півострова (Азово-Сиваський національний природний парк) за період з 2014 по 2024 роки з використанням інструментів супутникового моніторингу. Дослідження спрямоване на виявлення просторово-часових закономірностей виникнення пожеж, оцінку їхнього впливу на рослинність і тваринний світ, а також виявлення екологічних загроз, що посилюються окупацією та відсутністю протипожежного менеджменту.

Методи. Для виявлення та картографування пожежних аномалій були використані дані супутників NASA FIRMS (датчики MODIS та VIIRS), Sentinel-2, Google Earth Engine та погодні архіви (RP5). Просторово-часовий аналіз проводився на основі радіаційної потужності пожежі (FRP), теплової яскравості, координат пожежі та погодних параметрів. Дані з різних джерел були інтегровані для підтвердження пожежних подій, а зміни NDVI на основі Sentinel були проаналізовані для оцінки пошкодження рослинності.

Результати: Встановлено, що пожежі на Бірючому півострові мали кластерний характер і демонстрували чітку добову та сезонну динаміку. **В**иявлено два основні піки пожеж: Червень і серпень 2024 року. Найвищі значення ПРП (35,15 МВт) і температури (367 K) були зафіксовані 10 червня. Пожежі мали чіткі добові закономірності - вища інтенсивність вдень і більша кількість загорянь вночі. Втрата рослинності та пожежні шрами були підтверджені за допомогою знімків Sentinel. Географічний аналіз показав зміщення осередків горіння з північного сходу на південь півострова. Метеоаналіз підтвердив, що більшість пожеж виникали в умовах помірної або високої температури при відсутності опадів, що свідчить про вірогідну участь антропогенного чинника у виникненні загорянь. Фактори, пов'язані з окупацією (недостатнє гасіння, військові дії), були пов'язані зі збільшенням поширення пожеж. Супутникові дані після пожежі показали значну деградацію природної рослинності та фрагментацію середовищ існування оленів, земноводних і перелітних птахів**,** що виявляється за зниженими значеннями NDVI після пожеж

Висновки. Пожежі на Бірючому півострові в умовах окупації стали частішими, масштабнішими та менш контрольованими. Втрата природоохоронного режиму, припинення пожежогасіння та зменшення антропогенного догляду за територією стали критичними чинниками загострення екологічної ситуації. Наслідки включають серйозні порушення екосистем через ерозію ґрунту, втрату рослинності та трофічний дисбаланс. Відновлення вимагає невідкладних заходів: моніторингу популяцій диких тварин, відновлення лісів місцевими видами, боротьби з ерозією та регулювання чисельності копитних. Використання супутникових інструментів виявилося дуже важливим для виявлення невеликих пожеж та моніторингу екологічної динаміки на важкодоступних територіях. Без активного втручання можлива каскадна деградація, включаючи мікрокліматичні зміни та вторгнення чужорідних видів. Для відновлення та захисту цієї унікальної екологічної території необхідний довгостроковий план управління.

КЛЮЧОВІ СЛОВА: *Бірючий півострів, моніторинг лісових пожеж, супутникове дистанційне зондування, FRP, NDVI, деградація екосистем, копитні, втрата рослинності, динаміка пожеж, зайнятість, Google Earth Engine*

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