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ASSESSMENT OF VEGETATION IN THE RAVINES OF KHORTYTSIA ISLAND (ZAPORIZHZHYA) USING LANDSAT SATELLITE DATA

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This work highlights the issues of prompt detection of changes in vegetation density of small forests in steppe ravines, which belong to the recreational zone of Zaporizhzhya city, using Landsat 8 satellite multispectral images in the time range. The results of changes in the density of woody and herbaceous plants using the normalized difference vegetation index (NDVI) are presented. The main advantage of NDVI is the reliability and ease of data acquisition, as well as a wide range of tasks that can be solved using it. A series of thematic maps was obtained for the years 2000, 2010, 2020, 2024. Based on the values of the NDVI index, several classes of dense, moderate and sparse vegetation were distinguished within each ravine forest. Forest ravines also feature some areas with exposed soil. The dynamics of vegetation changes over the years of research have been examined. Temporal changes of the relative area occupied by woody vegetation and the state of this type of vegetation were also assessed. The multidirectional nature of their changes has been established both within a particular ravine and when compared to the parameters of various other ravines over the course of our research. This is due to the influence of many exo- and endodynamic environmental factors. The coastal part of Khortytsia Island has undergone drainage due to the destruction of the dam of the Kakhovka HPP, which led to an increase in the length of the coastline and the area of the mouth of the ravines under study. As was established via the satellite images in 2024 that, compared to 2020, the area of the coastal zone of the analyzed ravines increased by at least a factor of 1.75 (Heneralka) and at most 3.4 (Shyroka) respectively. The magnitude of this indicator for the remaining ravines falls within the aforementioned range of values.
It is recommended to continuously monitor changes in the coast of Khortytsia Island in terms of its succession processes and the state of hydrobionts.

Key words: *ravine forests, satellite images, NDVI, density and the state of woody vegetation, coastal area*[4].

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ОЦІНКА РОСЛИННОСТІ БАЛОК О. ХОРТИЦЯ (М. ЗАПОРІЖЖЯ) З ВИКОРИСТАННЯМ ДАНИХ СУПУТНИКА LANDSAT

А. В. Денисенко, В. П. Бессонова, С. О. Яковлєва-Носарь

У роботі висвітлено питання оперативного виявлення змін густоти рослинності байрачних лісів, що входять до рекреаційної зони м. Запоріжжя, за допомогою багатоспектральних знімків супутників Landsat 8 у часовому діапазоні. Наведено результати змін густоти деревних і трав'яних рослин із використанням нормалізованого відносного індексу рослинності (NDVI). Головною перевагою NDVI є надійність і легкість отримання даних, а також широкий діапазон задач, що вирішуються за їх використання. Було отримано серію тематичних карт за 2000, 2010, 2020, 2024 роки. На основі величин індексу NDVI виділено по декілька класів густої, помірної та розрідженої рослинності в межах кожного байраку. На території балок також є відкритий ґрунт. Розглянуто динаміку змін рослинності за роками досліджень. Також оцінювалися зміни в часі відносної площі, що зайнята деревною рослинністю, та стану цього типу рослинності. Встановлено різноспрямований характер їх змін як у межах певної балки, так і за порівняння показників різних балок за роками досліджень. Це пов'язано із впливом багатьох екзо- й ендодинамічних екологічних факторів. Стан деревної рослинності визначається у всі роки дослідження як добрий та задовільний. Узбережна частина острова Хортиця зазнала осушення внаслідок руйнування греблі Каховської ГЕС, що призвело до збільшення протяжності берегової лінії та площі гирла досліджених балок. Як було встановлено на космічних знімках 2024 р., порівняно з 2020 р., площа узбережної зони проаналізованих балок збільшилася від 1,75 (Генералка) до 3,4 (Широка) раза. Величина даного показника решти балок потрапляє в цей діапазон значень. Рекомендовано здійснювати постійний моніторинг змін узбережжя острова Хортиця щодо його сукцесійних процесів та стану гідробіонтів.

Ключові слова: *байрачні ліси, космічні знімки, індекс NDVI, густота і стан деревної рослинності, прибережна зона.*

Introduction

Under the conditions of the treeless steppe, pockets of natural woody phytocenoses are formed in river valleys, in the foothills, in the gullies and watershed ravines. Ravine forests being one such example is confined to the gully biocenoses and with regard to the steppe zone of Ukraine they are considered an atypical, unique phenomenon. The importance of ravine forests within the ecosystem is multifaceted: they protect the soil, fulfill various sanitary and hygienic functions and act as a shelter for many species of flora and fauna, among which there are a number of endangered ones. At the same time, ravine forests are influenced by both endogenous and exogenous factors. Among the latter, global environmental changes and the anthropogenic factor play a particularly significant role. In particular, human activity often takes place in the ravines at the island of Khortytsia, which is part of the recreational area of the city of Zaporizhzhya and is a favorite location for recreation for both locals and tourists alike. In this regard, it is important to regularly monitor the state of the vegetation and regularly update data in order to preserve biodiversity.

As for the changes of climate indicators in Ukraine, the Intergovernmental Panel on Climate Change (IPCC), analyzing the A1B scenario (moderate expected temperature increase with decreasing precipitation), predicts significant warming and aridification, as well as a shift in the boundaries of moisture and heat supply zones in the north-west direction. I.F. Buksha et al. (2017) believe that even in the case when a moderate version of this rather harsh scenario unfolds, there is a high probability of species impoverishment, degradation and death of entire ecosystems over a significant area with regard to forest plantations in the steppe and southern forest-steppe zones (Букша та ін., 2017).

Given the above challenges, the use of monitoring systems and the introduction of modern information technologies for the purposes of collecting and analyzing information, especially remote sensing techniques, are of particular relevance. This is emphasized by many scientists, in particular P. Liu et al. (2023) who published a review that includes a literary analysis of eight different articles, the results of which demonstrate the latest research regarding the state of forests, surface waters, air pollution, soil degradation etc. The authors emphasize the importance of such data in making informed decisions to ensure sustainable environmental management (Liu et al., 2023).

Remote sensing data and geographic information systems have been successfully used to assess magnitudes of forest fires and their consequences. For example, S. Liu et al. (2020) note the need to use the capabilities of satellite imagery in order to determine the scale of burnt out areas. The researchers propose a new approach to detect fire-affected areas based on the fire index using Landsat-8 OLI data. Compared to eight index-based detection methods described in the literature (NDVI, GEMI, NBR, BAI, NDSWIR, MIRBI, NBRT, NSTV2), the proposed approach (NBRSWIR CD method) has the best performance in terms of class separation and accuracy (Liu et al., 2020).

O. Soydan (2024), using Landsat-8 OLI satellite images of the study area before and after the forest fire that broke out on Mount Yamanlar in Karşıyaka district on August 15, 2024, established its level of propagation over a significant area, including residential areas. To estimate the area of burned sites, the author used several spectral indices, including NDVI (Normalized Difference Vegetation Index), NBR (Normalized Burn Ratio), dNBR (Differenced Normalized Burn Ratio). According to the results of the comparative analysis, among the selected indices, it was determined that dNDVI is the index with which the area of burned forest can be determined with the highest accuracy. In this case, the resolution of the satellite image used is of grave importance (Soydan, 2024).

It is also advisable to use satellite images when assessing anthropogenic impact on artificial and natural plant communities and while studying biodiversity of vegetation as well as its biomass.

P. Mallegowda et al. (2015) aimed to create detailed time-dependent maps of the Western Ghats Mountain Landscape Reserve using the NDVI index. The reserve is surrounded by other protected areas and forms forest corridors within the biosphere reserve. Over the past four decades, the area has experienced increased anthropogenic impacts (human settlement, mining, livestock grazing and forest fires) combined with drought and the invasion of *Lantana camara*. The researchers concluded that since vegetation structure is very important for the formation of animal communities, NDVI-based models can play an important role in the conservation of natural forests, especially in the case of the introduction of alien plant species (Mallegowda et al., 2015).

N. Pettorelli et al. (2014) in their review article emphasize the importance of synergistic interaction between remote sensing specialists and ecologists in solving biodiversity conservation problems (Pettorelli et al., 2014).

Therefore, a long-term remote sensing approach based on NDVI index time series serves as an effective tool for detecting landscape changes.

Material and methods

The dynamics of changes in the density of vegetation of the ravines under study were assessed using remote sensing (RS) methods. A series of Landsat 8 satellite images were collected in the time range for the years 2000–2024, namely: 09.14.2000; 09.26.2010; 09.23.2020; 09.22.2024. The selection of images was carried out according to the criteria of minimal cloudiness and absence of smoke. All scenes that were taken for analysis characterized the state of vegetation in the second and third 10-day intervals of September for each of the years that were examined.

Since we have used images of medium spatial resolution, the area of one scene can significantly exceed the region of interest, i.e. the area of the ravine. Therefore, for the purposes of further study, all the images were “cropped” to the desired area polygon by polygon.

In this way, a series of thematic maps for the years 2000, 2010, 2020, 2024 were obtained based on the values of the normalized difference vegetation index (NDVI). For each of them, based on the frequency histograms of the distribution of NDVI values, the areas of green plantations within the city of Zaporizhzhya were determined, as well as the percentage of areas of plots that differ in plant density in each territory under study.

The NDVI index of the vegetation of the ravine forests in the vicinity of the city of Zaporizhzhya was calculated using the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED},$$

where NIR is the reflectance in the near infrared region of the spectrum, RED is the reflectance in the red region of the spectrum. Due to the peculiarities of reflection in the NIR-RED regions of the spectrum, natural objects have fixed NDVI values, which allows using this parameter for their identification and assessment of their condition.

V.I. Lyalko et al. (2008) created a scale of NDVI index values for land cover identification, in which 0.2–0.3 correspond to grassy vegetation, and values of 0.4–0.6 correspond to deciduous tree stands (Лялько та ін., 2008).

I.G. Semenova (2014) proposed using the following scale to assess the state of vegetation (Table 1) (Семенова, 2014):

Table 1
Criteria for classifying vegetation status using NDVI values

NDVI values	State of vegetation
0,71–1,00	Very good
0,56–0,70	Good
0,41–0,55	Satisfactory
0,31–0,40	Bad
0,21–0,30	Stunted

The recommendations of the above-mentioned authors were used by us to identify the types of vegetation and assess their condition in the territory of the ravine forests under study.

Results

The distribution of vegetation in the Heneralka gully according to a corresponding year (2000, 2010, 2020 and 2024) is presented in Fig. 1. In the year 2000, more than half of it was covered by moderate vegetation – 57.28%. After 10 years, in 2020, a decrease down to 52.43% was observed. With regard to the NDVI values, this occurs in the range of 0.5-0.6, which is classified as dense vegetation (Table 2). In 2020, the size of the territory occupied by moderate vegetation changes little (54.97%), but after 4 years (2024) there was a significant reduction down to 43.98% in the range of values from 0.4 to 0.5. The area with sparse vegetation, on the contrary, increased by 4.85% in 2010 compared to 2000 and, subsequently (in 2020), an expansion of the area with this type of vegetation was observed (up to 43.46%), reaching 47.12% in 2024. Moreover, the increase in areas of sparse vegetation was due to changes in the range of values from 0.3 to 0.4. In general, the difference between the indicators of 2000 and 2024 is 10.23%.

Dense vegetation in 2000 and 2010 was absent and during 2020 only a very a small part of it was present (0.04 ha), which in 2024 increased up to 0.35 ha (5.24%). The figures characterizing the size of open soil areas in 2010, compared to 2000, did not change (5.82%). In 2020, they decreased to 1.05%, which indicates some activation of overgrowth processes. However, in 2024, the area without plants increased again and amounted to 3.66%.

Therefore, moderate vegetation prevailed in the Heneralka gully during the years of our research.

In 2000, the main portion of the vegetation cover of the Khortyts'ka ravine (Fig. 2, Table 3) belonged to the class of sparse vegetation – 76.47%. In 2010, the size of its area practically did not change and reached 77.77%. However, according to 2020 data, the share of vegetation of this category decreased compared to 2010 by 24.87%. Subsequently, a significant decrease in the area with sparse vegetation occurred in 2024 compared to 2020 – from 52.90 to 43.00%, i.e. by 9.9%.

The areas of moderate vegetation, as well as sparse vegetation, were almost the same in 2010 compared to 2000. However, in 2020, a significant expansion of the area with this

Table 2
NDVI values for the Heneralka gully

Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0.9 – 1	0							
2	Dense vegetation	0.8 – 0.9	0							
3	Dense vegetation	0.7 – 0.8	0							
4	Dense vegetation	0.6 – 0,7	0				0,04	0,52	0,35	5,24
5	Moderate vegetation	0,5 – 0,6	1,70	25,24	1,25	18,45	1,38	20,42	1,27	18,85
6	Moderate vegetation	0,4 – 0,5	2,16	32,04	2,29	33,98	2,33	34,55	1,70	25,13
7	Sparse vegetation	0,3 – 0,4	1,70	25,24	1,70	25,24	1,98	29,32	2,58	38,22
8	Sparse vegetation	0,2 – 0,3	0,79	11,65	1,11	16,50	0,95	14,14	0,60	8,90
9	Bare soil	0,1 – 0,2	0,07	0,97	0,13	1,94	0,07	1,05	0,21	3,14
10	No vegetation	0,0 – 0,1	0,13	1,94	0,07	0,97	0	0	0,04	0,52
11	No vegetation	-1 – 0,0	0,20	2,91	0,20	2,91	0	0	0	0

Source: developed by the authors

Table 3

NDVI values for the Khortyts'ka ravine

Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0,9 – 1								
2	Dense vegetation	0,8 – 0,9								
3	Dense vegetation	0,7 – 0,8								
4	Dense vegetation	0,6 – 0,7							0,69	6,48
5	Moderate vegetation	0,5 – 0,6	0		0,07	0,65	1,52	14,33	2,46	23,21
6	Moderate vegetation	0,4 – 0,5	1,39	13,07	1,39	13,07	3,00	28,33	2,75	25,94
7	Sparse vegetation	0,3 – 0,4	5,34	50,33	4,51	42,48	2,37	31,74	3,15	29,69
8	Sparse vegetation	0,2 – 0,3	2,77	26,14	3,74	35,29	2,24	21,16	1,41	13,31
9	Bare soil	0,1 – 0,2	0,55	5,23	0,49	4,58	0,22	2,05	0,14	1,37
10	No vegetation	0,0 – 0,1	0,14	1,31	0,14	1,31	0,11	1,02	0	
11	No vegetation	-1 – 0,0	0,42	3,92	0,28	2,61	0,14	1,37	0	

Source: developed by the authors

Table 4

NDVI values for the Shyroka gully

Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0,9 – 1								
2	Dense vegetation	0,8 – 0,9								
3	Dense vegetation	0,7 – 0,8								
4	Dense vegetation	0,6 – 0,7	0,26	1,69	0,13	0,84	0	0	0,71	4,56
5	Moderate vegetation	0,5 – 0,6	3,87	24,89	3,34	21,52	2,69	17,31	3,75	24,15
6	Moderate vegetation	0,4 – 0,5	5,97	38,40	5,64	36,29	7,05	45,33	3,54	22,78
7	Sparse vegetation	0,3 – 0,4	3,93	25,32	4,53	29,11	4,39	28,25	3,97	25,51
8	Sparse vegetation	0,2 – 0,3	1,31	8,44	1,44	9,28	1,38	8,88	3,22	20,73
9	Bare soil	0,1 – 0,2	0,20	1,27	0,46	2,95	0,04	0,23	0,35	2,28
10	No vegetation	0,0 – 0,1								
11	No vegetation	-1 – 0,0								

Source: developed by the authors

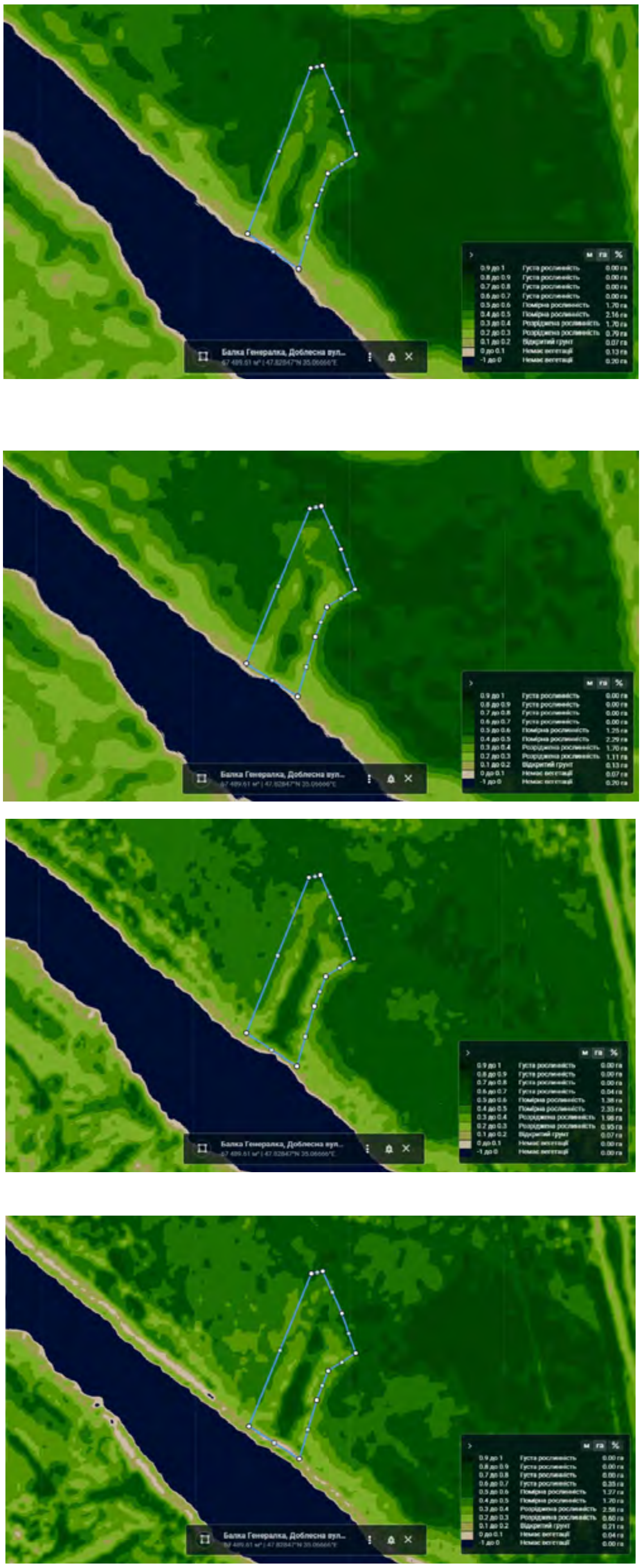
type of vegetation was recorded (42.66%, i.e. 3.11-fold).

In 2024, the area occupied by moderate vegetation increased even further and amounted to 49.15% against the background of the recorded decrease in the area occupied by sparse vegetation. It should be noted that dense vegetation appeared during this period, the share of which was 6.48%.

Thus, there is an apparent absence of changes in the proportions of moderate and sparse vegetation in 2010 compared to 2000. During other years of study, satellite imagery data indicates a densification of the vegetation cover of the Khortyts'ka ravine.

Changes in vegetation density in the Shyroka gully are presented in Table 4 and Fig. 3.

In 2000, the area of moderate vegetation occupied 63.29%, which indicates its major role in the overall relative density of vegetation cover. In 2010, it was 57.81%, i.e. there was a reduction of 5.48%. According to the indicators of 2020, the share of vegetation of this category increased again back to 62.64%, which indicates its return to the indicators of the year 2000. However, during the period until 2024, the area of moderate vegetation decreased down to 49.93%.



14.09.2000

26.09.2010

23.09.2020

22.09.2024

Fig. 1. Vegetation density of the Heneralka gully, determined using the NDVI vegetation index

The area occupied by sparse vegetation of the Shyroka gully in 2000 was 33.76%, which is significantly less compared to the moderate vegetation at this time. According to 2010 data, the area of sparse vegetation increased by 4.63% and reached 38.39%. In 2020, it barely changed (37.13%). However, according to 2024, the share of vegetation of this category

14.09.2000

26.09.2010

23.09.2020

22.09.2024

Fig. 2. Vegetation density of the Khortyts'ka ravine, determined using the NDVI vegetation index

has increased significantly – up to 46.24%, equaling the values recorded for moderate vegetation during the same period. As for the dense vegetation, its share in the cover of the Shyroka gully was determined to be small. In the images pertaining to the year 2020, dense vegetation is completely absent, and its largest share was established in 2024 – 4.56%.

14.09.2000

26.09.2010

23.09.2020

22.09.2024

Fig. 3. Vegetation density of the Shyroka gully, determined using the NDVI vegetation index

Open ground areas are small. In 2000, their area was 1.27%, increasing to 2.95% in 2010, with a subsequent decline to 0.23% in 2020 and a new increase to 2.28% in 2024. This points to undulating patterns in the changes of their area.

Moderate vegetation prevails in the Shyroka gully. Over the years of study, the nature of changes in the size of the territories occupied by this category of vegetation can be described as multidirectional. Among the living cover in this gully, the share of dense vegetation is the smallest, while its largest indicators were determined in 2024.

At the beginning of the study (2000), the predominant share of the cover of the Hannivka gully was moderate vegetation (77.97%) (Table 5, Fig. 4). According to 2010 data, it changed very little – up to 79.66%. 10 years later, in 2020, the area of moderate vegetation decreased by 6.16%, and after another 4 years it increased again to the values of 2010 and amounted to 77.78%. Thus, during the years of our study, moderate vegetation was dominant in the territory of this gully, which indicates the predominance of vegetation of medium density. The predominance of values in the ranges of 0.5–0.6 was observed, with the exception of 2020 (Table 4). No cardinal changes in the size of the area occupied by this category of vegetation over the years of observation were recorded.

The area of sparse vegetation was much smaller compared to the moderate category. Thus, in 2000 it was only 8.47%, and in 2010 the share of vegetation of this category decreased to 5.08% (by 3.39%). This was due to an increase in the area of moderate (by 1.69%) and dense (by 1.69%) vegetation. In 2020, the size of sparse vegetation areas increased significantly compared to 2010 data – up to 16.24%, and after 4 years (in 2024) they decreased slightly and reached 11.11%. Thus, there is a fluctuation in the size of areas occupied by sparse vegetation over the years of research.

In 2000, dense cover occupied 3.39% of the territory of the Hannivka gully, and in 2010 – 5.08%. According to 2020 data, this category of vegetation has completely disappeared. After another 4 years (2024), its share has recovered almost to the values of 2010 and amounted to 5.98%. This indicates the limited number of areas with dense vegetation cover and their instability over time whch results in their disappearance with subsequent restoration. The size of the area without plants did not change over the years of research, and equalled 10.16% in the years 2000, 2010 and 10.26% in 2020. But in 2024, the area of open soil decreased to 5.12%.

Thus, in the Hannivka gully moderate vegetation prevailed during the period from 2000 to 2024. Along with this, certain fluctuations in its area occurred during various years of study, which is why unidirectional changes were not observed. Fluctuating waves in terms of area also affected sparse vegetation category. Dense vegetation cover increased only in small areas of the ravine.

In the Ushvyva gully, according to 2000 data, moderate vegetation occupied 26.02% of the area, while in 2010 its increase to 34.96% was observed (Table 6, Fig. 5). In 2020, the share of vegetation of this category increased to 40.17%. The expansion of its territory compared to 2000 was 14.15%, and compared to 2010 – 5.21%. In 2024, there were no changes in values compared to 2020. In general, from 2000 to 2020, a trend of growth in the area of vegetation of this category was observed.

The predominant part of the cover of the Ushvyva gully in 2000 was sparse vegetation – 45.53%. In 2010, its area decreased and amounted to 39.02%. However, during the next measurement period (2020), its share increased by 8.75% and reached 47.77%, increasing to 50.0% in 2024.

The presence of dense vegetation in this gully was determined based on the 2020 sat-

Table 5

NDVI values for the Hannivka gully

Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0,9 – 1								
2	Dense vegetation	0,8 – 0,9								
3	Dense vegetation	0,7 – 0,8								
4	Dense vegetation	0,6 – 0,7	0,13	3,39	0,20	5,08			0,24	5,98
5	Moderate vegetation	0,5 – 0,6	2,00	50,85	2,07	52,54	1,01	25,64	2,02	51,28
6	Moderate vegetation	0,4 – 0,5	1,07	27,12	1,07	27,12	1,88	47,86	1,04	26,50
7	Sparse vegetation	0,3 – 0,4	0,27	6,78	0,13	3,39	0,50	12,82	0,34	8,55
8	Sparse vegetation	0,2 – 0,3	0,07	1,69	0,07	1,69	0,13	3,42	0,10	2,56
9	Bare soil	0,1 – 0,2	0,07	1,69	0,07	1,69	0	0	0,17	4,27
10	No vegetation	0,0 – 0,1	0,13	3,39	0,13	3,39	0,07	1,71	0,03	0,85
11	No vegetation	-1 – 0,0	0,20	5,08	0,20	5,08	0,34	8,55	0	0

Source: developed by the authors

Table 6

NDVI values for the Ushvyva gully

Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0,9 – 1								
2	Dense vegetation	0,8 – 0,9								
3	Dense vegetation	0,7 – 0,8								
4	Dense vegetation	0,6 – 0,7			0,13	1,63				
5	Moderate vegetation	0,5 – 0,6	0,46	5,69	0,98	12,20	0,36	4,46	0,25	3,12
6	Moderate vegetation	0,4 – 0,5	1,63	20,33	1,82	22,76	2,86	35,71	2,97	37,05
7	Sparse vegetation	0,3 – 0,4	1,76	21,95	1,76	21,95	2,72	33,93	2,89	36,16
8	Sparse vegetation	0,2 – 0,3	1,89	23,58	1,37	17,07	1,11	13,84	1,11	13,84
9	Bare soil	0,1 – 0,2	0,78	9,76	0,59	7,32	0,18	2,23	0,54	6,70
10	No vegetation	0,0 – 0,1	0,26	3,25	0,39	4,88	0,32	4,02	0,18	2,23
11	No vegetation	-1 – 0,0	1,24	15,45	0,98	12,20	0,46	5,80	0,07	0,89

Source: developed by the authors

Table 7

NDVI values for the Velyka Molodnyaga gully

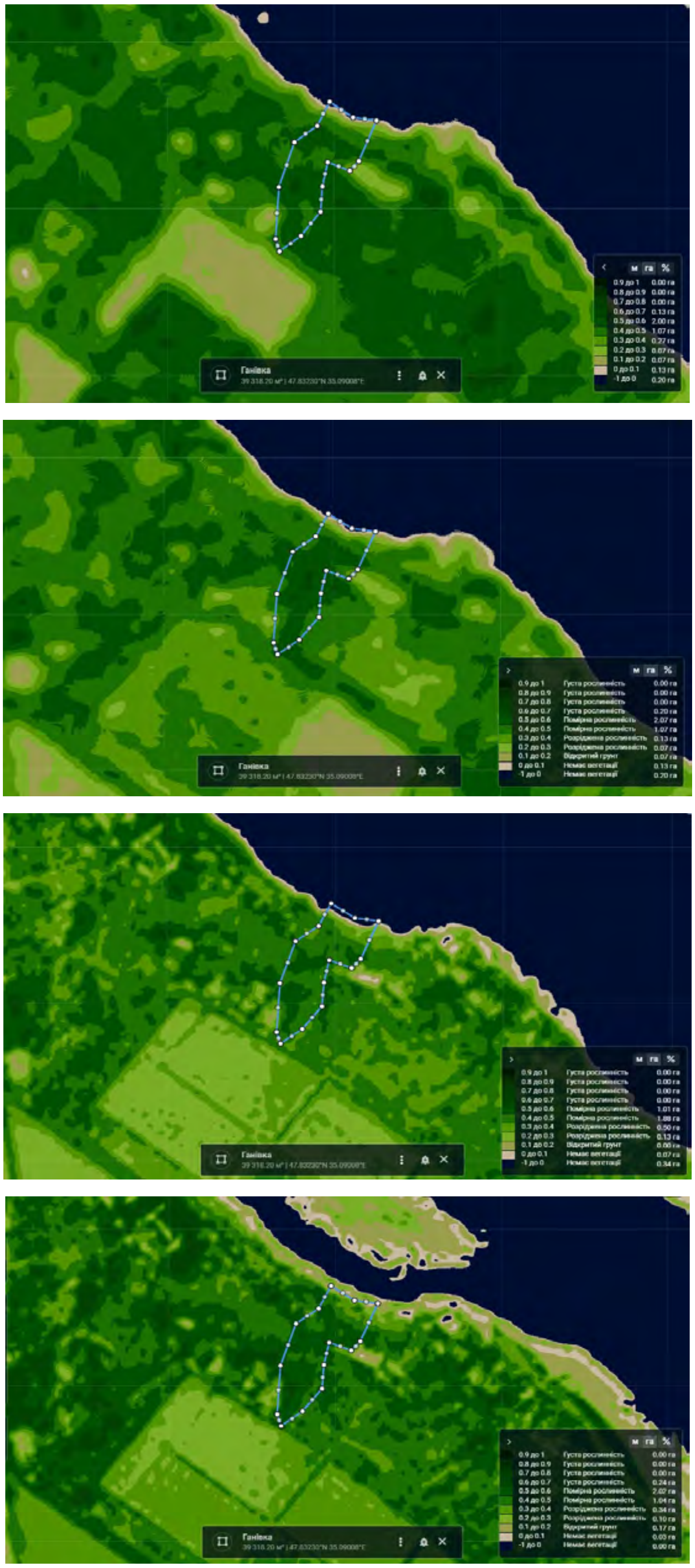
Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0,9 – 1								
2	Dense vegetation	0,8 – 0,9								
3	Dense vegetation	0,7 – 0,8					0,03	0,97		
4	Dense vegetation	0,6 – 0,7	0,12	3,51	0,41	12,28	1,77	52,43	0,03	0,97
5	Moderate vegetation	0,5 – 0,6	1,36	40,35	1,66	49,12	1,18	34,95	1,01	30,10
6	Moderate vegetation	0,4 – 0,5	1,01	29,82	0,59	17,54	0,29	8,74	1,67	49,51
7	Sparse vegetation	0,3 – 0,4	0,53	15,79	0,35	10,53	0,03	0,97	0,36	10,68
8	Sparse vegetation	0,2 – 0,3	0,06	1,75	0,12	3,51	0,03	0,97	0,13	3,88
9	Bare soil	0,1 – 0,2	0,18	5,26	0,12	3,51	0,03	0,97	0,16	4,85
10	No vegetation	0,0 – 0,1	0	0	0	0	0,03	0,97	0	0
11	No vegetation	-1 – 0,0	0,12	3,51	0,12	3,51	0	0	0	0

Source: developed by the authors

ellite images and amounted to only 1.63%, but in 2024 it wholly disappeared. The area of open soil in 2000 was quite large – 28.46%, while in 2020 – 24.40%. Over the following period, areas of soil without vegetation decreased to 12.05% in 2020, and in 2024 – to 9.82%. Thus, compared to 2000, their area decreased by 2.9 times, which indicates the gradual overgrowth of the Ushvyva gully.

As can be seen from Fig. 6 and the data in Table 7, in 2000, the main part of the cover of the Velyka Molodnyaga gully was moderate vegetation – 70.17%. According to the indicators of 2010, its share decreased to 66.66%, but it continued to remain the predominant category of vegetation cover. By 2020, there was a further more significant reduction in its area to 43.69%.

However, as of 2024, moderate vegetation occupied an even larger area compared to the year 2000. That is, the trend towards a decrease in this type of vegetation in the Velyka Molodnyaga gully changed to an increase in this indicator of up to 79.61%. But, if according to the data of 2000, 2010 and 2020, there was more moderate vegetation in the range of NDVI values from 0.5 to 0.6, then in 2024 its share prevailed in the range of values from 0.4 to 0.5, which is closer to being classified as sparse vegetation.



14.09.2000

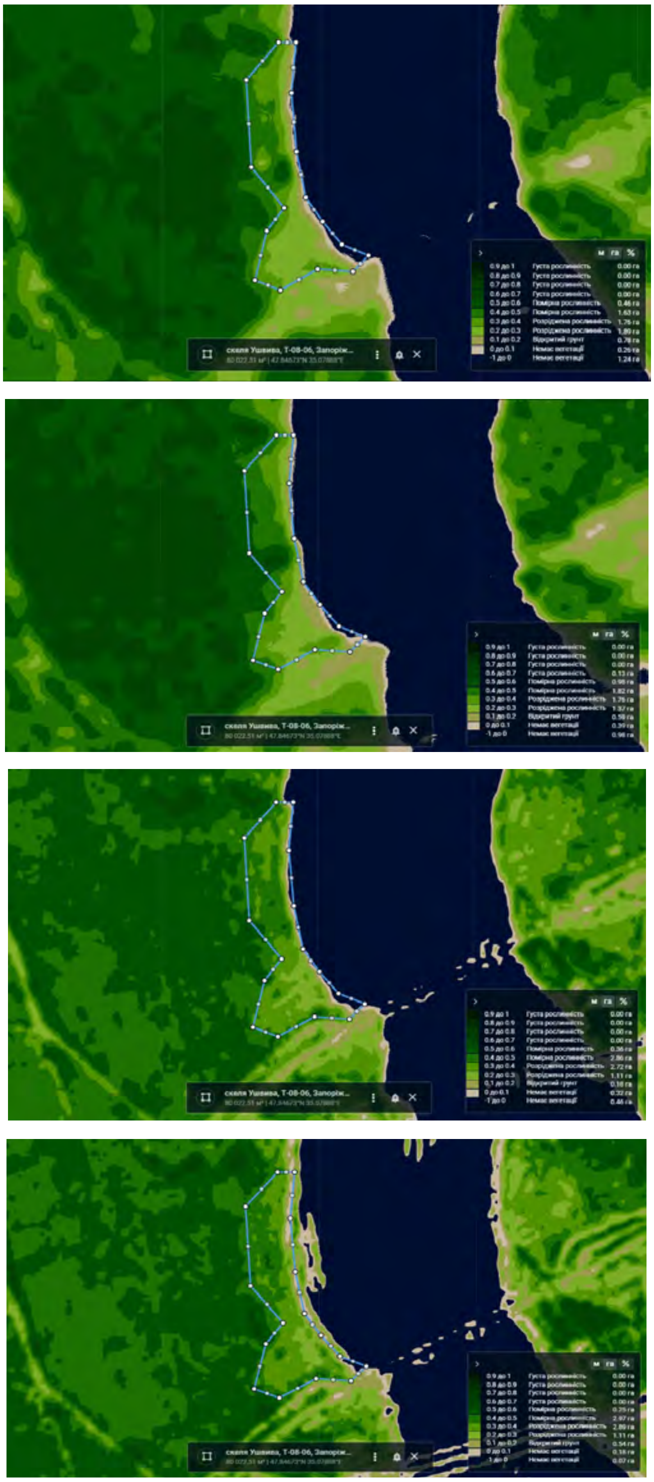
26.09.2010

23.09.2020

22.09.2024

Fig. 4. Vegetation density of the Hannivka gully, determined using the NDVI vegetation index

The area of sparse vegetation cover of this gully was 17.54% at the time of the beginning of the research (2000). At the same time, it was 4 times smaller compared to the area with moderate vegetation. By 2010, the share of sparse vegetation cover had slightly decreased (to 14.04%). In 2020, more significant changes occurred, which led to it occupying only 1.94%



14.09.2000

26.09.2010

23.09.2020

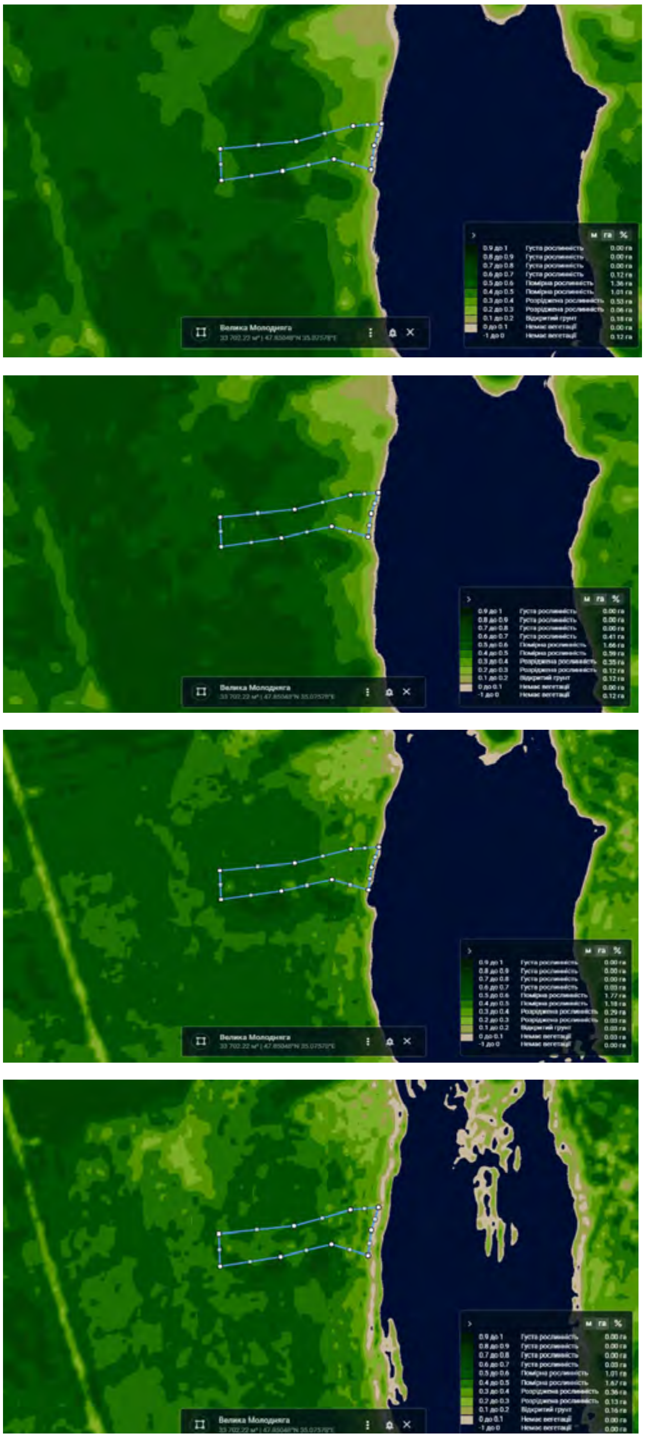
22.09.2024

Fig. 5. Vegetation density of the Ushvyva gully, determined using the NDVI vegetation index

of the area. However, in 2024, a sharp increase of this indicator of up to 14.56% was recorded (to the level of 2010, in fact), mainly in the 0.3–0.4 range of values, which borders on the values of moderate vegetation category.

In 2000, dense vegetation accounted for the smallest share compared to other vegetation categories in this gully. However, in 2010, a significant increase to 12.28% was recorded, which was even greater in the year 2020 – 54.40%.

But later this type of vegetation practically disappears: in 2024 it was only 0.97%, which indicates a rapid reduction in the area occupied by vegetation of this category. This is consistent with the expansion of areas with moderate and sparse vegetation.



14.09.2000

26.09.2010

23.09.2020

22.09.2024

Fig. 6. Vegetation density of the Velyka Molodnyaga gully, determined using the NDVI vegetation index

The area of open soil in 2000 was 8.77%. According to NDVI indicators, the share of soil without plants in 2010 decreased to 7.02%, and in 2020 – to 1.94%, although as of 2024 it rebounced to 4.85%.

Thus, in the Velyka Molodnyaga gully, over the years of our research, a reduction in the area of both dominant moderate and sparse vegetation has been observed. The share of dense cover, on the contrary, is increasing.

According to the data of 2000, the cover of the Sovutina gully was dominated by moderate vegetation, the area of which was 47.89%. In 2010, this type of vegetation continued to dominate, and its share increased to 53.52% of the total surface area of the gully. From this point on, the process of expansion by this category of vegetation has continued (Table 8, Fig. 7).

According to the indicators of 2020, vegetation density was 69.05%, which indicates an increase in the dominance of medium-density cover. In 2024, the indicator decreased to 41.24%, which is even less than in the year 2000, when it was minimal over the course of our research.

In 2000, sparse vegetation also made up a significant portion of vegetation cover – 40.85%. However, this trend became opposite in the following years. According to the indicators of 2010, it decreased by 4.23% – to 36.62%, and in 2020 – by another 10.43%, down to 26.19%. Its participation in the formation of the vegetation cover of the Sovutina gully during this period was much less pronounced than that of moderate vegetation (2.6 times). This trend continued and in 2024, sparse vegetation amounted to only 10.68%.

If the sizes of areas of dense vegetation during the years of data analysis (2000, 2010 and 2020) were close in values, then in 2024 this indicator increased significantly – to 46.58%. The share of open soil in 2010 did not change compared to 2000 (5.64%), but in 2020 and 2024 its surface was almost completely overgrown with vegetation.

Thus, during the years of research, the cover of the Sovutina gully was dominated by moderate vegetation. The area occupied by the sparse vegetation category, on the contrary, was decreasing. In general, there is a tendency of the increased density of vegetation in the territory of this gully.

For the purposes of identification and stratification of the ground cover of the ravines under study, we relied on the recommendations of V.I. Lyalko *et al.* (2008). The results of dynamic changes in the relative area of deciduous stands (trees and shrubs) by the years of research are shown in Fig. 8. The same figure also presents data on the variability of the condition of woody plants. According to the scale of I.G. Semenova (2014), the condition of the stands in the analyzed gullies was assessed as good and/or satisfactory throughout the entire research period.

The curve describing the fluctuations of the relative area of woody vegetation in the Heneralka gully has a rather smooth behavior (Fig. 8). At the same time, the value of this indicator acquired values within the range from 57.3% (2000) to 52.4% (2010), and in the year 2020 it equaled 55.5%. In 2024, there is some reduction to 49.2%, which coincides, as already noted, with the expansion of areas with sparse vegetation.

The share of woody plants that had a good condition changed very little (18.5–25.2%). Only in 2010, compared to 2000, it decreased by 6.8%. Woodlands that received a satisfactory assessment were distributed over the territory of 32.0–34.5% during the period 2000–2020. But in 2024, their share decreased to 25.1% and practically equaled the relative area of woody plants in good condition (24.1%).

A completely different situation is observed in the case of the Khortyts'ka ravine. The trend characterizing changes in the area with woody vegetation tends to constantly grow, starting from 13.7% in 2010 and up to 55.6% in 2024. This can be explained by objective reasons: a decrease in recreational load and the accompanying soil compaction and trampling

Table 8

NDVI values for the Sovutina gully

Class	Class name	Range of values	Relative area							
			2000		2010		2020		2024	
			ha	%	ha	%	ha	%	ha	%
1	Dense vegetation	0,9 – 1								
2	Dense vegetation	0,8 – 0,9								
3	Dense vegetation	0,7 – 0,8							0,60	12,82
4	Dense vegetation	0,6 – 0,7	0,25	5,63	0,19	4,23	0,21	4,76	1,58	33,76
5	Moderate vegetation	0,5 – 0,6	1,24	28,17	1,62	36,62	1,79	40,48	1,26	26,92
6	Moderate vegetation	0,4 – 0,5	0,87	19,72	0,75	16,90	1,26	28,57	0,67	14,32
7	Sparse vegetation	0,3 – 0,4	0,87	19,72	0,99	22,54	0,91	20,63	0,25	5,34
8	Sparse vegetation	0,2 – 0,3	0,93	21,13	0,62	14,08	0,25	5,56	0,25	5,34
9	Bare soil	0,1 – 0,2	0,06	1,41	0,12	2,82	0	0	0,07	1,49
10	No vegetation	0,0 – 0,1	0,06	1,41	0	0	0	0	0	0
11	No vegetation	-1 – 0,0	0,12	2,82	0,12	2,82	0	0	0	0

Source: developed by the authors

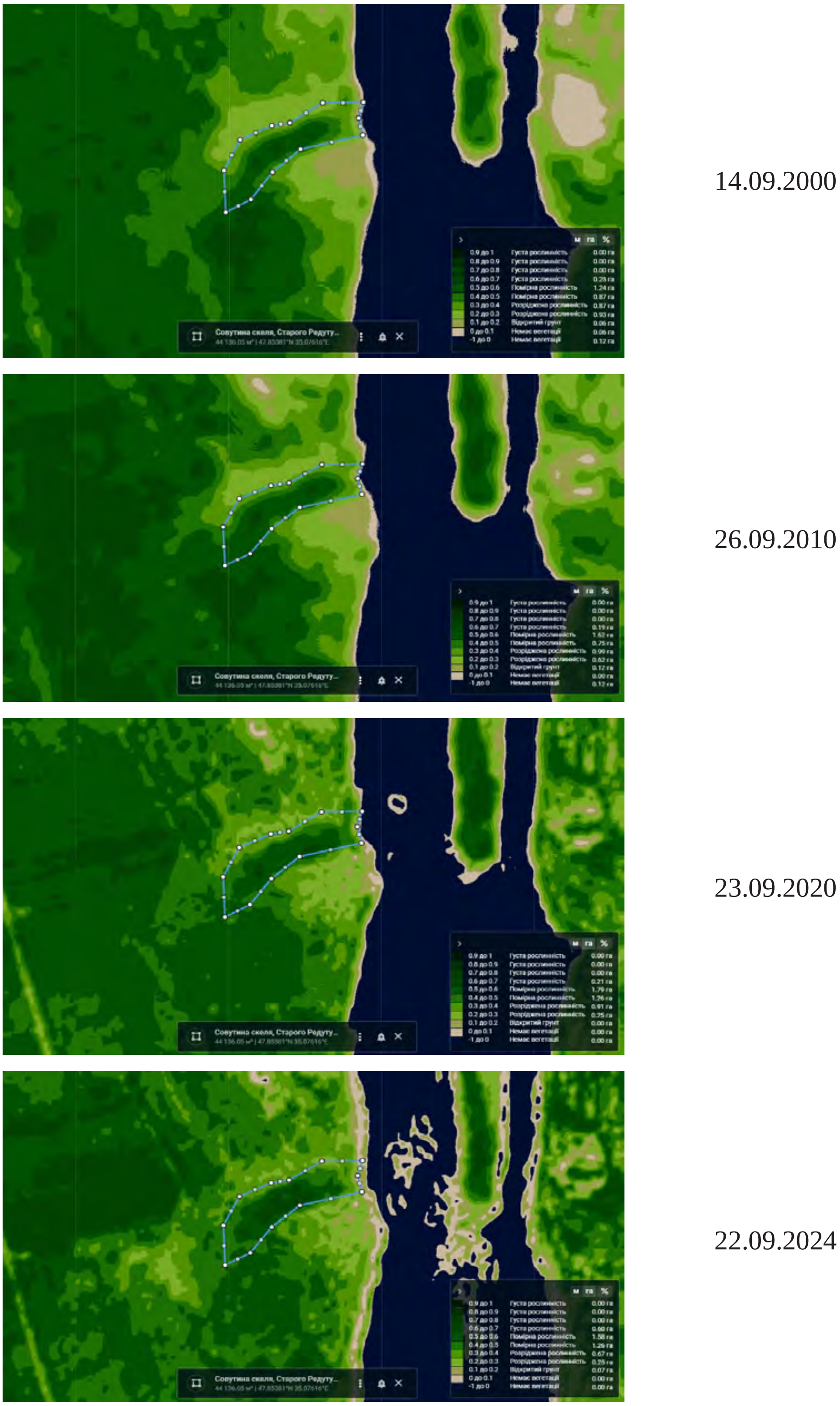


Fig. 7. Vegetation density of the Sovutina gully, determined using the NDVI vegetation index

of self-seeding tree species. The improvement in the state of the ravine forest dendroflora is also evidenced by the histograms that contain this indicator.

The direction of changes that occurred during the years of research in the territory of the Shyroka gulley is similar to those in the Heneralka gulley (Fig. 8). In this gulley, the rec-

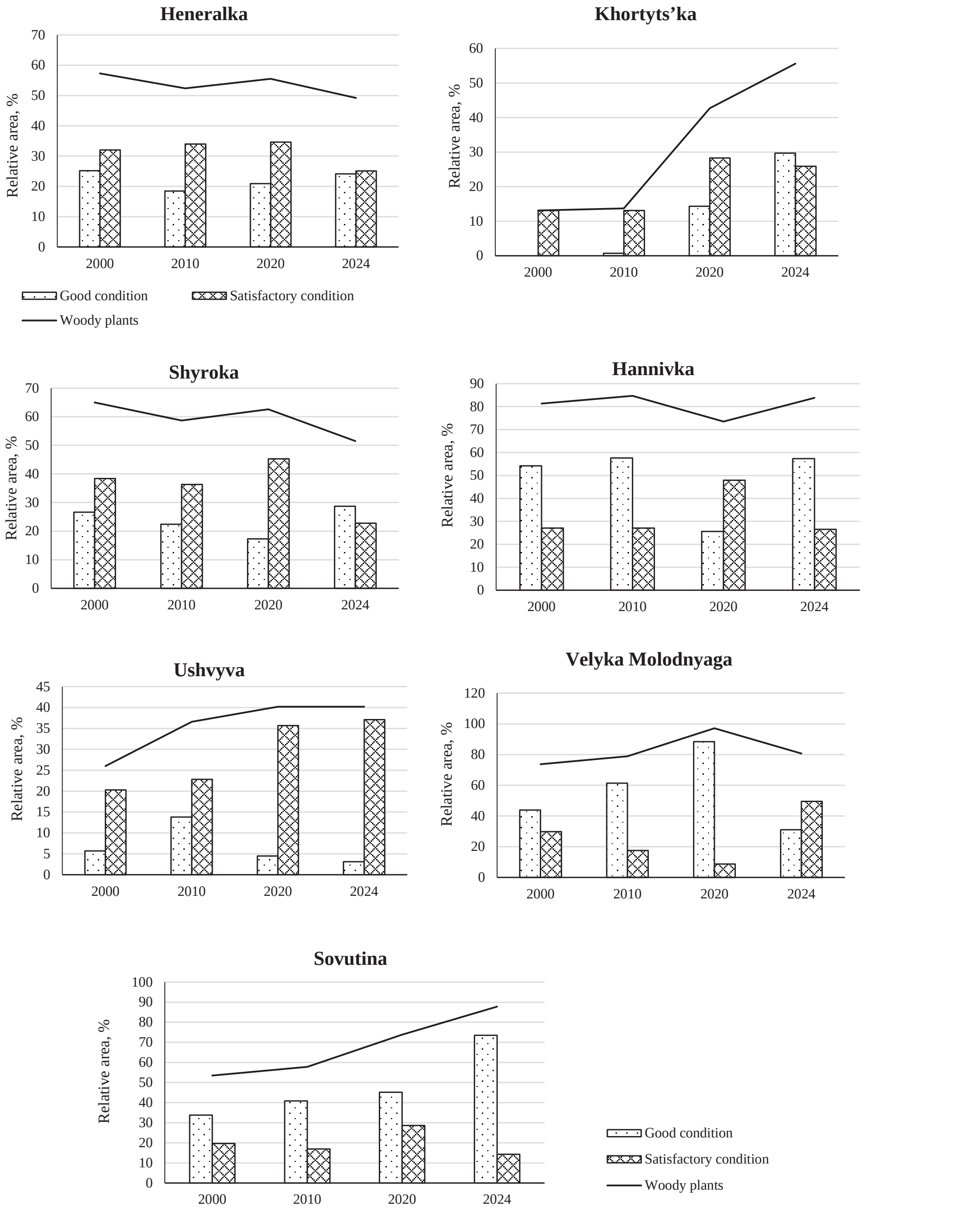


Fig. 8. Changes in the area occupied by woody vegetation in ravine forests and the qualitative condition of trees and shrubs during the years of research

reational load has also decreased in the recent years, primarily by the vacationers of the sanatorium-dispensary of the Zaporizhzhya Titanium-Magnesium Combine (ZTMK PJSC). However, the sandy beach (named "Titan") at the mouth of the gulley is characterized by a rather high degree of attractiveness for visitors, which may be one of the factors in the decrease in the area occupied by woody and shrub vegetation, especially as pertains to its natural renewal. At the same time, from 2000 to 2020, there is a tendency of the reduction in the share of woody plants in good condition and the increase of the ones whose condition is rated as satisfactory. And in 2024, the areas occupied by plants in both good and satisfactory condition amounted to 28.7 and 22.8%, respectively.

The Hannivka gully has one of the highest indicators of the relative area of woody vegetation among the analyzed gullies (Fig. 8), which fluctuates throughout the study period within the limits of 73.5–84.7%. In 2000, 2010 and 2024, the share of woody plants in a good condition reached 54.2; 57.6 and 57.3%, respectively. The values of the areas with vegetation cover in a satisfactory condition were also very close to each other. However, in 2020, there was a sharp decrease in the share of woody vegetation, the condition of which is assessed as good, and, conversely, an increase in the relative area of plants with a satisfactory condition.

In the Ushvyva gully, there is an expansion of the area occupied by woody plants over the study period. The curve describing this process is smooth. It should be noted that this occurs mainly due to vegetation, the condition of which is assessed as satisfactory. Thus, whereas in 2000 the area of this category of woody plants is 20.3%, in 2024 it reaches 37.1%.

The territory of the Velyka Molodnyaga gully is also characterized by a high indicator of the relative area occupied by woody plants, similar the Hannivka gully. In 2000, it was 73.7%, while in 2010 – 78.9%. In 2020, it increased sharply to 97.1%, and in 2024 it decreased to 80.6%, as has already been noted, due to an increase in the share of sparse vegetation cover.

In the territory of the Sovutyna gully, there is a steady trend towards an expansion of the area under woody vegetation: in 2000 it was 53.5%, while in 2024 it was 87.8% (Fig. 8). This is mainly due to an increase in the share of woody vegetation, the condition of which is assessed as "good".

Thus, in the studied gullies, multidirectional changes in the relative area occupied by woody vegetation (trees and shrubs) are observed. This indicator is influenced by various factors, among which the recreational activities inside the gullies, their location relative to highways and public transport stops, accessibility and attractiveness of individual areas.

As you probably know, on June 6, 2023, the Russian troops blew up the dam of the Kakhovka hydroelectric power plant, which had huge negative consequences for Ukraine, primarily in the case of the territories located in and around the Dnieper River basin. The satellite images of the gullies that we analyzed, which were obtained in September 2024, show not only changes in vegetation density, but also in the length of the coastline and the area of their mouths.

In 2020, the area of the mouth of the Heneralka gully was 3,500 m^2 (sandy/muddy shores), and in 2024 it increased almost 1.75-fold.

Before the water receded, the coastal part of the Khortyts'ka ravine was a relatively narrow strip, mainly rocky and muddy in nature, with an area of about 250 m^2; in 2024, it increased threefold.

The coast of Shyroka gully in 2020 was composed of the estuary, where a sandy beach was arranged for visitors to the sanatorium-dispensary owned by the titanium-magnesium plant. The area of the coastal part was 250 m^2 (excluding the beach). Satellite imagery of 2024 show that its size increased almost 3.4-fold.

The mouth of the Hannivka gully has undergone strong anthropogenic impact, mainly due to the fact that the Scientific Town Str. passes through it. The coastal zone is sandy, overgrown with trees and their descendants of vegetative origin. In 2020, it had an area of about 3750 m^2, and in 2024 it increased 3.3-fold.

The Ushvyva gully stretches along the Dnieper River, its mouth is raised, as if hanging over the river. In addition to the main one, there are two smaller outlets with small sandy beaches. There are many boulders on the territory of the main mouth, among which there are many large ones. In the 2020 photos, the length of its coastline, interrupted in several places, was over 400 m, and the area was about 5,000 m^2, while in 2024 the latter increased 2.2-fold.

The area of the coastal part of the Velyka Molodnyaga gully (sandy in nature) in the 2020 images was slightly more than 250 m^2 but it increased 3.2-fold in 2024.

The mouth of the Sovutyna gully is sandy and rocky. Nearby is the Sovutyna cliff, which was destroyed in the first half of the 20th century due to granite mining. In 2020, the coastal part had an area of about 2000 m^2, and in 2024 it expanded almost 2.3-fold.

Thus, the area of the coastal zone in the analyzed gullies increased by at least a factor of 1.75 in the case of the Heneralka gully and up to 3.4 times in the case of the Shyroka gully.

Discussion

Assessment of changes in various vegetation classes of the ravine forests under study according to the magnitude of the NDVI index allowed us to establish the absence of a single pattern in the dynamics of vegetation density, relative area and the condition of woody plants. The direction and intensity of these changes are influenced by a number of factors (location and attractiveness for vacationers, recreational activities, fluctuations in climatic indicators and the success of natural renewal of woody plants). However, the assessment of vegetation dynamics with the help of a series of thematic images using the values of the normalized difference vegetation index (NDVI) proved to be a promising express method, with which it was possible to cover significant areas during monitoring studies.

It should be noted that the works regarding determination of density and vital state of woody plants was also carried out by other authors.

Sh.-T. Wu & Y.-Sh. Chen (2016), who investigated the issue of integrating remote sensing data and vegetation indices, in particular NDVI, concluded that such a combination is appropriate when studying dynamic changes in the ecological environment of recreational areas within national nature parks (Wu & Chen, 2016).

A.V. Sklyarenko & V.P. Bessonova (2020) assessed the density and condition of green plantations in sanitary protection zones of seven industrial enterprises in the city of Zaporizhzhya with the help of Landsat satellite data using the NDVI index. The density of tree plantations varied depending on the intensity of self-reproduction and the degree of human oversight: when filling the territory with self-seeding species as well as planting seedlings manually, an increase in vegetation density was observed, in part due to natural renewal. The act of planting new species had a negligible effect on this indicator. The authors also assessed the condition of vegetation in various green areas of sanitary protection zones, and it was found that only 10% of them can be given a "good" rating (Скляренко і Бессонова, 2020).

O.Y. Ivanchenko et al. (2022) studied density dynamics and the condition of vegetation on the territory of major recreational facilities of the right-bank part of the Dnipro city – five parks in total as well as the Tunel'na gully – over a 20-year period with five year long intervals. Landsat satellite data were used. The authors concluded that by the year 2010, the decrease in the density of the tree stands and the deterioration of their condition were associated with the decline of the aforementioned parks and the lack of care with regard to plants against the background of a critical state of the country's economy. After 2010, the density of woody vegetation increased due to the planting of new seedlings and the growth of their crowns, the spread of self-seeding species as well as undergrowth, all despite a lack of full-fledged agrotechnical oversight on the territory of certain parks (Іванченко та ін., 2022).

As can be seen from Figures 1–7, presented above, the outline and area of the banks of the gullies have significantly changed, which was noted during the analysis of satellite images in 2024. This can be explained by the decrease in the water level of the Dnieper river.

According to the classification given in (Знищення ..., 2025), the coastal zone of the island is classified as the water area of the former Kakhovka reservoir and is considered a drainage zone (Знищення ..., 2025). M.A. Mulenko (2025), studying the consequences of the destruction of the Kakhovka HPP for the island of Khortytsia, indicates a decrease in the water level of the Dnieper River. At the same time, its absolute values vary from -4.64 m to -1.92 m from the normal support level. The territory of the island increased due to the newly created coasts with an unstable coastal strip (Муленко, 2025).

The process of drainage and increase in the area of the mouth, as already noted above, was observed in the case of all of the gullies under study. At the same time, the area of the coastal zone expanded the least in the case of Heneralka (1.75 times compared to the previous value recorded in 2020) and the most – 3.4 times at the mouth of the Shyroka gully. The changes that affected the remaining gullies and led to an increase in the length of the coastline and the area of their mouths are somewhat smaller and fall within the specified range of values.

Currently, as reported by researchers, in particular S. Kobets & V. Shelegeda (2024), who studied the state of the coast of the right bank of the Dnieper River in the area of the "Vyrva" protected zone, which is a part of the "Khortytsia" national reserve, it is possible to state the course of successional changes in the territories exposed to the outflow of water (Кобець і Шелегеда, 2024).

Therefore, constant monitoring of changes in the coast of the Khortytsia Island regarding its successional processes and the state of hydrobionts is necessary. This issue is of grave environmental importance, since Khortytsia Island (with the exception for gardens and arable land) is part of the general geological reserve of national importance called "Dnieper Rapids", which in 2016 was included in the list of objects of the Emerald Network of Ukraine (Охріменко і Ткач, 2019).

Conclusions

Analysis of changes in the density of woody vegetation within seven ravine forests included in the recreational area of the city of Zaporizhzhya over the course of the study period (2000, 2010, 2020, 2024) and their condition using data from the Landsat 8 satellite showed that these indicators are constantly changing. Usually, these changes occur simultaneously with the ones regarding the area of grass vegetation and bare areas.

The assessment of trends in the relative area occupied by woody vegetation indicates their different orientation in the gullies under study. The condition of this type of vegetation is determined as good and satisfactory throughout the entire research period. The correlation of these condition categories differed even within a particular gully but also when compared with one another according to a corresponding year of the study.

The direction and intensity of changes in the density, relative area and condition of woody plants are determined by exogenous and endogenous environmental factors, among which the accessibility and attractiveness of forest areas for recreation, the intensity of recreational activities, fluctuations in climatic indicators over the years and the success of natural renewal of woody plants.

As a result of the collapse of the Kakhovka HPP dam, as was determined with the help of satellite imagery in 2024, compared to the year 2020, the area of the coastal zone of the gullies under study increased by at least a factor of 1.75 (Heneralka) and 3.4 (Shyroka) at the most.

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