Spatiotemporal analysis of the changes of the main habitats of the Kozachelaherska arena (Nyzhniodniprovsky sands, Kherson region, Ukraine) in the period of 1990–2020

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ABSTRACT
Landsat satellite images (Landsat-5 for the period of 1990–2010 and Landsat-8 for the year of 2020) were used for the spatio-temporal analysis of the dynamics of the main habitats of the Kozachelaherska arena (Nyzhniodniprovsky sands, Kherson region, Ukraine). The algorithm of minimum distance of automatic k-mean clustering was used for the classification of the satellite images. Habitats were classified according to EUNIS classification principles. The analysis revealed a considerable decrease in a summary area of coniferous plantations in the period of 2000–2010. During the last two decades, the area of losses significantly exceeded the renewal area of coniferous plantations. The area of large permanent aquatic habitats in the north-east part of the arena decreased by 2.5 times in the last thirty years. The water supply of the territory is constantly decreasing, probably due to the reduction in precipitation and in the ground water level. At the same time, the area of territories under open sand doubled, the process of sand overgrowth with vegetation has slowed down, and its losses have increased. All these changes are most likely caused by the increasingly arid climate in southern Ukraine, which may, over time, lead to the replacement of habitats characteristic of sandy steppes with habitats of open sands.

KEYWORDS
GIS; remote sensing; land cover changes; habitats; Kozachelaherska arena

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1. Introduction

Nyzhniodniprovsky (Low-Dnipro) sands is an unique ecosystem which has been under a significant anthropogenic load for a long time. Excessive intervention of human into this ecosystem caused serious damage to the ecological balance. There appeared the necessity to do research on some ecological peculiarities of these territories and to work out the trends of the preservation of sand arenas, which are unique for Ukraine (Hranovska 2019). In 2010 a national natural park (NNP) "Oleshky sands" was created in the territory of two historically significant nyzhniodniprovsky arenas (Kozachelaherska and Chalbaska). However, in October of 2015, after the war in the East of Ukraine had broken out, a military training ground resumed its functioning in the territory of Kozachelaherska arena, which limited the access of the researchers to this place to a great extent. In February, 2022 the territory of NNP Oleshky sands was occupied by russian troops. Under these conditions, it became possible to monitor the condition of these valuable ecosystems only with the remote sensing techniques.

During the last decades, the Earth remote sensing techniques (ERS) have been widely used to monitor the changes of the land cover, including the areas under natural reserves (Alves et al. 2022; Zou et al. 2022; Melnyk and Yachniuk 2022; Myroniuk 2020; Sorokina and Petrov 2020). This can be explained by several advantages of the remote sensing techniques as compared with the traditional expedition methods: they cover large territories, they are informative, operative and objective, their use is quite frequently cheaper than the arrangement of research expeditions and chamber processing, they provide a precise topographic base to make the maps of the transformation of the territory structure, a digital format of the ERS materials and the use of special programs (software) for their processing and analysis guarantee fast results (García-Alvarez et al. 2022).

As far as the use of the data of ERS to monitor the condition of the ecosystem of Oleshky sands is concerned, a proper attention was not paid to it. We are aware of one research aimed at the identification of the dynamics of the land cover of the Kozachelaherska arena with the use of a 30-year (the years of 1987–2017) temporal series of Landsat images (Bogdanets 2017). It is to be stated that the method of visual decryption of satellite images, which allowed to identify only the largest noticeable changes of the land cover, was used in this research. Other than that, the author does not mention any numerical characteristics of the discovered changes of the land cover which makes an objective evaluation more complicated.

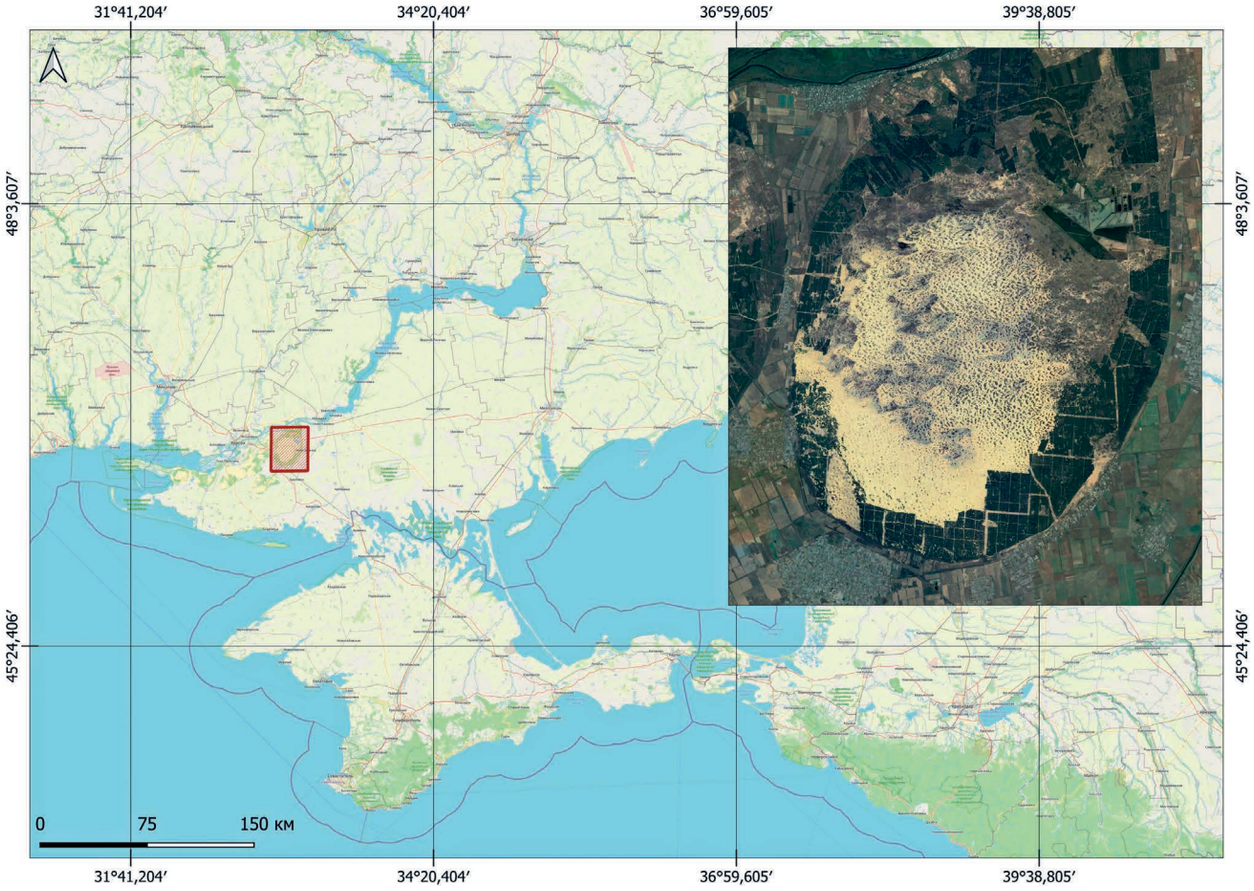

Fig. 1 Geographical location of Kozachelaherna arena of Low-Dnipro sands (Open Street Map, Google Satellite).

The purpose of this work is, based on the analysis of a temporal series of satellite images, to single out the main habitats of Kozachelaherska arena of Nyzhniodniprovsky sands, to establish the peculiar features of their spatial-temporal dynamics for the last thirty years. It may be useful for the management of the area and for conservation of endangered species. Also, it is important that this territory is currently in the area of military operations and is likely to be significantly affected. Therefore, this study provides valuable information on the initial state and habitat areas of this territory at the beginning of the full-scale invasion of Ukraine by the russian federation.

2. Characteristics of the territory under study

Nyzhniodniprovsky sands stretch for 150 km from Nova Kakhovka to Kinburnska foreland in the form of seven sand arenas. Five arenas are adjacent to Dnipro flood: Kakhovska, Kozachelaherska (Fig. 1), Oleshkivska, Zburiivska and Ivanivska (Oleshkivsky massif). Chalbaska arena is situated to the south-east of this massif and the last massif is located on Kinburnskyi peninsula. The total area of these arenas is 161 thousand hectares. Lowlands are situated among some massifs, salty lakes occur there (Hordiienko 1969).

Although the territory belongs to the basin of Dnipro, there are no permanent natural watercourses in it (National Atlas of Ukraine 2008). Only the lakes of anthropogenic and natural origin are available. Such water reservoirs have atmosphere and underground nutrition; in addition, adsorption and condensation of water vapor from the atmosphere due to the daily temperature gradient are available (Marynych 1989–1993).

According to botanical-geographical zoning, the territory of Nyzhniodniprovsky sands is part of Chornomorska (Black Sea, Pontic) steppe province, European-Asian steppe region and it belongs to the sub-zone of feather-fescue-grass steppes (Moisiienko 2012).

3. Materials and methodology

The data of spacecrafts (SC) of Landsat (Landsat-5 for the period of 1990–2010 and Landsat-8 for the year of 2020) was used for the spatiotemporal analysis of the land cover dynamics of the region under study. Free products of satellite images, used in this research, were received from geo-site of the geological survey of the USA (United States Geological Survey) (Earth Explorer 2022) with the module for downloading satellite images of Semi-Automatic Classification Plugin for QGIS (Congedo 2021). The images downloading was carried out in the mode of automatic prior processing.

The images taken on 06.06.1990, 26.06.2000, 06.06.2010 and on 08.06.2020 were used as they were characterized with the lack of cloudiness of the region under study.

The algorithm of minimum distance of automatic k-mean clustering, implemented in Semi-Automatic Classification Plugin for QGIS, was used for the classification of the satellite images (Congedo 2021). The optimal differentiation of the earth cover was reached when its 15 classes were singled out.

As a redundant quantity of the land cover classes is formed as a result of such classification, then at the next stage the reclassification of the results with the singling out of six main habitats was done: aquatic habitats, grassland habitats, psammophyte habitats, coniferous plantations, deciduous forests and open sands. Habitats were classified according to EUNIS classification principles. For terrestrial, the 2021 version of the classification was used (EUNIS habitat type hierarchical view … 2023). Since there is no classification of water and swamp habitats is not available in this version, we used an earlier version. Today, we are able to analyse with the help of satellite images mainly the habitats of the second level of the EUNIS classification (Willner et al. 2017). In some cases, we combine several units of this level together. Otherwise, we have to divide them into several smaller units.

To interpret and to make more accurate the results of the classification, satellite images of high resolution Google maps (Fig. 1) and photo materials Google Earth Pro were used.

The evaluation of the classification accuracy was carried out based on the matrix of mistakes. To calculate the latter, 5–6 training grounds were built for each habitat on the basis of visualization of a corresponding space picture in a natural color. Cross-validation of the classification results was done by pixel samples from these training grounds (García-Alvarez et al. 2022). The received Kappa-coefficient shows the correspondence/identity between the classification image and the standard (Foody 1992). It can take the values from 0 to 1. If the Kappa-coefficient is equal to zero, then there is no correspondence/identity between the classification image and the standard. If the Kappa-coefficient is equal to 1, then the classification image and the standard are totally identical. To interpret the values of the Kappa-coefficient, they are classified into 3 groups: over 0.80 (80%) – high classification accuracy, from 0.40 to 0.80 (40–80%) – average classification accuracy, lower than 0.40 (40%) – low classification accuracy (Congalton 1991).

To discover the temporal changes of the land cover, the algorithm “Land cover change”, implemented in the plagin menu of post-processing of the classification results for QGIS, was used (Congedo 2021). The received maps of spatial-temporal changes were reclassified to single out the changes of coniferous plantations, water habitats and sands. The graphs were created with the table processor Microsoft Excel

based on the digital characteristics of the land cover changes, received in QGIS.

4. Results

4.1 Main habitats in the territory under study and the peculiarities of their identification on satellite images

Aquatic habitats, grassland habitats, psamophyte habitats, deciduous forests, coniferous plantations, and open sands are important for identification on satellite images and for nature conservation practice.

Aquatic habitats are small bodies of water that mostly dry up in the summer. According to the EUNIS classification, these habitats belong to RLC – Freshwater habitat and RLD – Mires and bogs. Some of them were formed by the craters from powerful aerial bombs, formed when the national park was a military training ground (Moysiyenko et al. 2019). Only a few reservoirs remain permanently irrigated due to constant groundwater recharge. The reservoirs have a small open floodplain covered with sparse macrophytes. Coastal aquatic habitats are most often located in a narrow strip around such reservoirs. Halophilic vegetation develops on the banks of salty lakes. Since these habitats cover small areas, their correct identification on the used space images is somewhat difficult, and they are not always distinguished separately. This aspect also applies to coastal aquatic habitats, which are found sporadically in the studied area. In addition, coastal aquatic habitats are located in narrow strips around water bodies, which makes it difficult to identify and estimate areas.

Psammophyte habitats occupy the largest areas of the studied territory. These are mainly R1 – Dry grasslands, which are several types of sandy steppes (Shapoval and Kuzemko 2021). Among them, R1Q – Inland sanddrift and dune with siliceous grassland

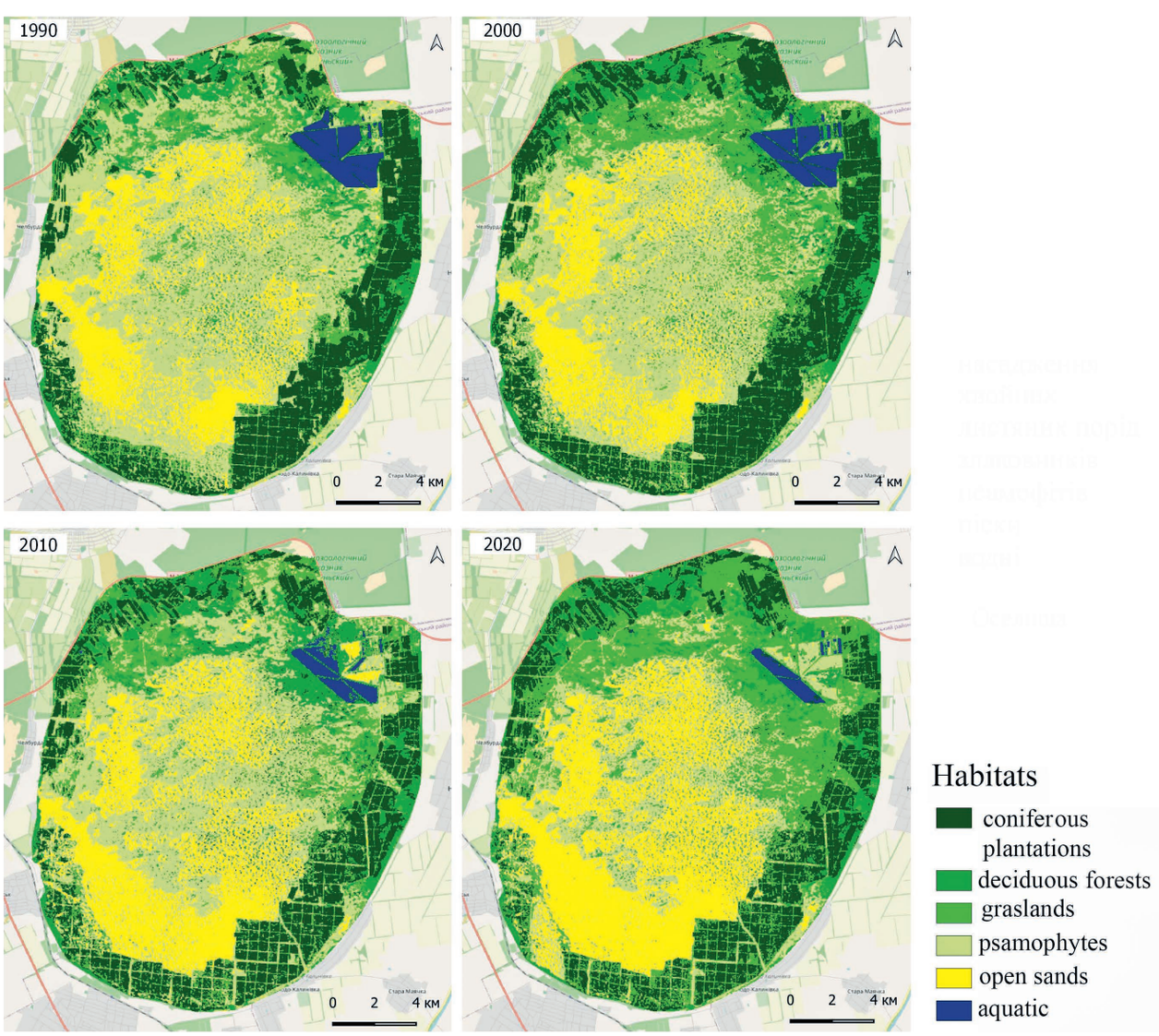

Fig. 2 Distribution of the main habitats in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990, 2000, 2010 and 2020.

and R11 – Pannonian and Pontic sandy steppe are most common. Other types of grassland are also found here. Small areas of wet meadows (R3 – Seasonally wet and wet grasslands according to the EUNIS classification) and mesophytic meadows (R2 – Mesic grasslands according to the EUNIS classification) occur around freshwater bodies.

Natural habitats formed by phanerophytes occur mainly in narrow strips around water bodies. By EUNIS classification, they belong to T4: Lines of trees, small anthropogenic forests, recently felled forest, early-stage forest, and coppice.

Artificial plantations are another type of phanerophyte habitats. Here, Pinus pallasiana, Pinus sylvestris and Robinia pseudoacacia were used for artificial plantations. The last species often penetrates into small deciduous natural forests. The coniferous plantation is somewhat different from the rest of the forest habitats. They have ecotonic areas with psammophytic vegetation of sandy steppes. Therefore, in this study we divided phanerophyte habitats into deciduous forests and coniferous plantation.

A large part of the studied area is represented by sand dunes practically devoid of vegetation. This habitat corresponds to U5 – Miscellaneous inland habitats usually with very sparse or no vegetation according to the EUNIS classification. After rains, temporary algae crusts (Hantzschia amphioxys, Klebsormidium flaccidum, K. mucosum Pinnularia borealis) form on the surface. The formation of vegetation is hindered by the constant movement of sand.

Under a visual analysis of the satellite images one can pay attention to the fact that during the period of 30 years, the arena area has not changed at all. This made it possible, based on a polygonal mask, to single out identical fragments from the satellite images, the ones which correspond to the arena territory with a stable number of image pixels. In turn, it became possible to monitor the transformation of each pixel during the period of the research, as well as to make the evaluation of the dynamics of the main habitats. Thus, as a result of the classification of the satellite images of the studied territory, six main habitats were classified (Fig. 2). The satellite images were analyzed over an interval of ten years, beginning from the year of 1990.

4.2 Evaluation of the classification accuracy.

The evaluation of the accuracy is an important step in the process of the classification of a satellite image. For instance, the classification accuracy defines the quality of a thematic map, prepared on the basis of a satellite image. We made the evaluation of the classification accuracy of four Landsat images used for the research (Tab. 1).

According to the results of the research it has been found out that the total classification accuracy ranges from 87.02% to 91.15%. The Kappa-coefficient varies from 0.83 to 0.89. It is a known fact that its value over 0.8 confirms high classification accuracy.

If to consider the classification accuracy of some habitats, it is to be stated that aquatic habitats and open sands are classified most reliably (Kappa coefficient = 1.0), which is natural as these classes are characterized with definite spectral peculiarities. The lowest classification accuracy is typical for the habitats of grasslands and psammophytes, but even in their cases the classification accuracy is sufficient. This makes it possible to use the received thematic maps for the analysis of spatiotemporal changes of the singled out habitats in the territory under study.

Tab. 1 Evaluation of the classification accuracy of the habitats in the territory of Oleshky sands.

Image	Parameters	Habitats						Overall accuracy (%)	Kappa (overall)
		Aquatic	Grasslands	Psamophytes	Coniferous plantations	Deciduous forests	Open sands		
1990	PA (%)	94.77	62.60	96.97	98.88	96.73	95.49	90.00	0.87
	UA (%)	100.00	91.81	80.33	96.55	99.01	99.84		
	Kappa	1.00	0.90	0.70	0.96	0.99	1.00		
2000	PA (%)	94.70	98.00	90.39	97.88	98.96	75.26	91.15	0.89
	UA (%)	100.00	82.37	85.45	98.38	99.08	99.94		
	Kappa	1.00	0.79	0.79	0.98	0.99	1.00		
2010	PA (%)	92.20	78.34	99.62	85.37	92.38	79.19	87.02	0.83
	UA (%)	100.00	80.47	72.54	99.53	98.15	99.89		
	Kappa	1.00	0.77	0.63	0.99	0.98	1.00		
2020	PA (%)	64.09	97.47	94.12	79.41	94.28	89.60	90.24	0.88
	UA (%)	100.00	78.53	85.32	96.49	98.53	99.84		
	Kappa	1.00	0.73	0.81	0.96	0.98	1.00		

5. Discussion

Three classes of the habitats were chosen for a further analysis: coniferous plantations (which are most clearly identified in the vegetation cover, and accordingly, their changes are clearly observed in the satellite images), open sands (as an indicator of aridization) and aquatic habitats (as an indicator of the water supply for the territory) (Didukh et al. 2020). As a result of the use of the identification procedure of the land cover change to the classified images, implemented in a Semi-automatic classification plagin for QGIS (SCP), a series of maps of the changes of the coniferous plantations with a ten-year interval (1990–2000, 2000–2010, 2010–2020) was created. Besides, the map of the changes of the coniferous plantations during the whole period under study was developed (1990–2020) (Fig. 3). Similar maps concerning the changes of the aquatic habitats (Fig. 4) and open sands (Fig. 5) were made.

The maps confirm that on the one hand, some plots of the coniferous plantations are lost, on the other hand, the renewal of this habitats take place. The nature of the location of the new plots of this habitats proves that the natural reproduction plays a very important role in this process. It concerns specifically the northern part of the arena.

The total area of the coniferous plantations decreased considerably in the years of 2000–2010 (Fig. 6), and in the following periods it remained relatively stable.

Accordingly, in the period of 2000–2010, the maximal losses of the coniferous plantations (21.07 km^2) were observed. In the last decade (2010–2020) this indicator decreased significantly (9.09 km^2), but the increase of the coniferous plantation losses doubled as compared with the period of 1990–2000. Along with this, in the first decade the losses were well compensated due to the renewal, however in

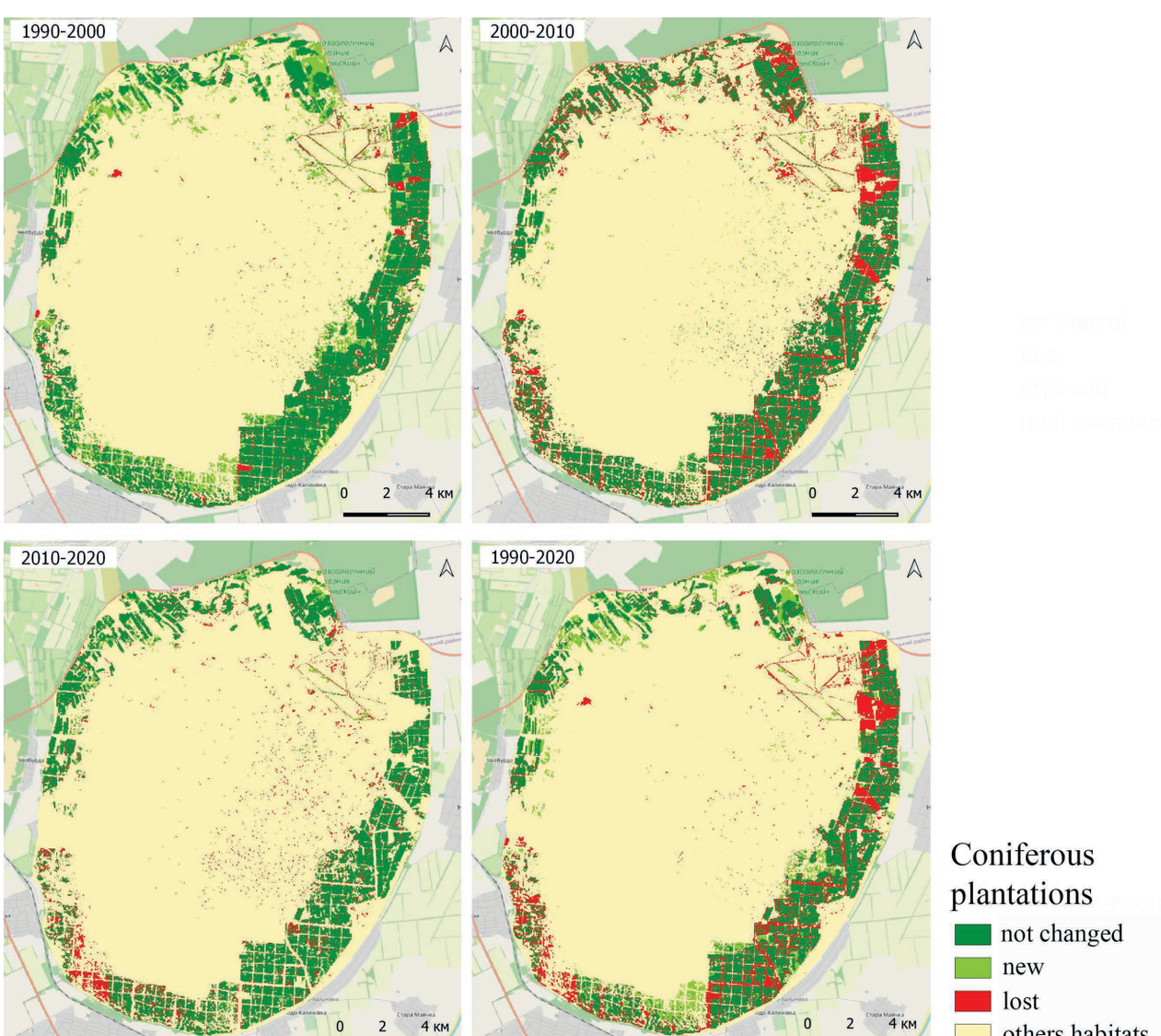

Fig. 3 Changes of the area under the coniferous plantations in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990–2020.

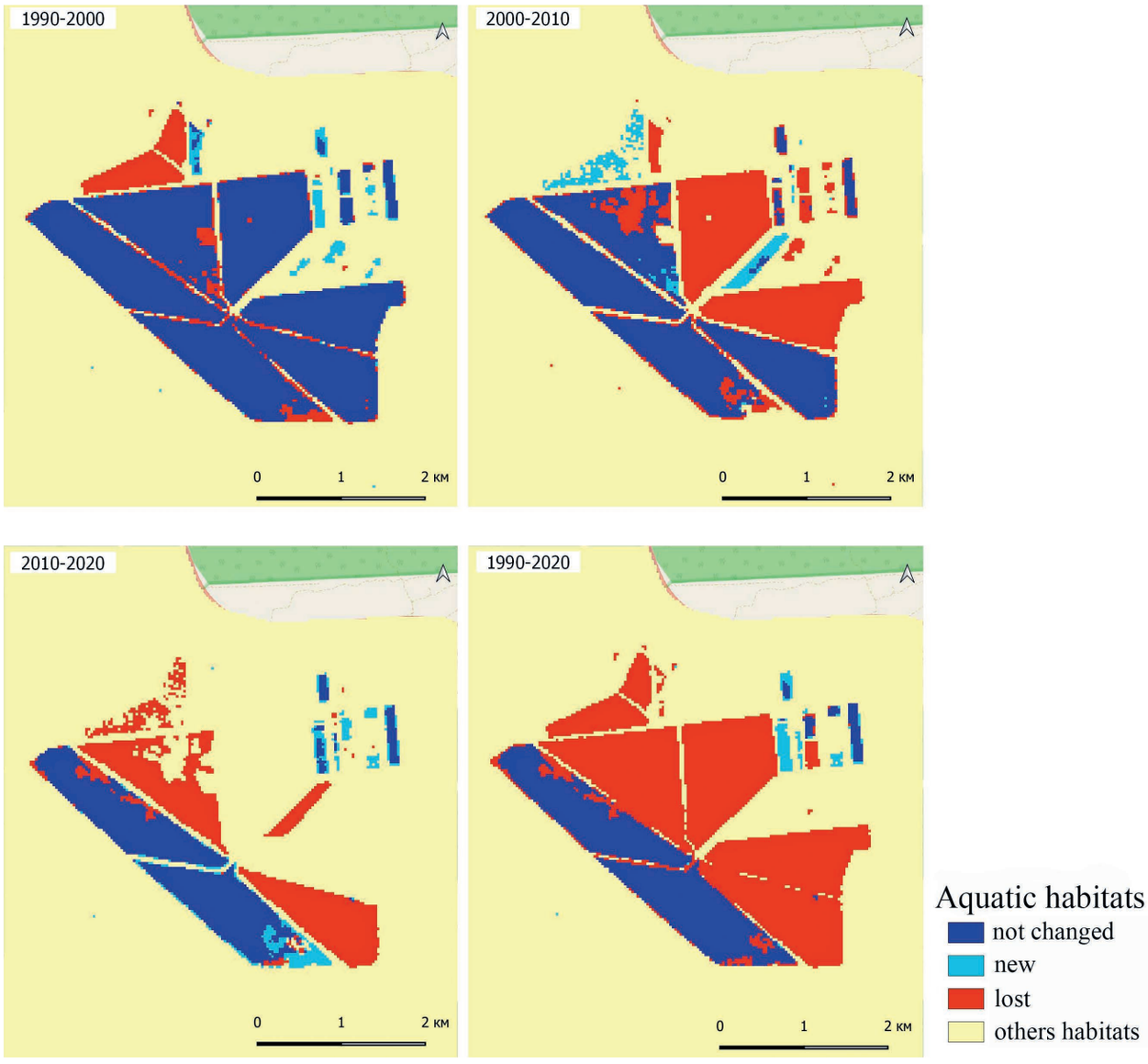

Fig. 4 Area changes of the aquatic habitats in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990–2020.

the latest decades the loss area exceeded, to a great extent, the area of the renewal of the coniferous plantations.

In fact, all permanent large aquatic habitats are concentrated in the north-east part of the arena. The results of the analysis made prove the progressive losses of the water surface. Within the period of thirty years, its area decreased by 2.5 times (from 7.1 km^2 to 2.57 km^2) (Fig. 4, Fig. 7). At the same time, the renewal of the aquatic habitats almost does not take place. Similar to the situation with the coniferous plantations, the maximal losses of the aquatic habitats were recorded in 2000–2010, which told about the unfavorable climatic conditions in this period. In general, it can be stated that the water supply of the territory decreases constantly, most likely it occurs due to the reduction of the precipitation amount and the level of the ground waters.

The results of the analysis of the open sand area changes (Fig. 4) show the progressive increase of the territories occupied by these habitats. Within the period of 30 years of the research, the area of the open sands increased from 46.86 km^2 to 84.21 km^2 (Fig. 8).

However, in case of the territory of Kozachelaherska arena, a clear pattern is recorded: the process of sand overgrowing with vegetation slows down gradually, and the losses of vegetation increases constantly (Fig. 8). This means that vegetation in these territories degrades gradually, and the territories with open sands increase. It is most likely connected with the general tendency towards the aridization of the climate of the south of Ukraine resulted from the global climate changes (Vozhehova et al. 2021). Over time, this may lead to the replacement of habitats characteristic of sandy steppes with habitats of open sands.

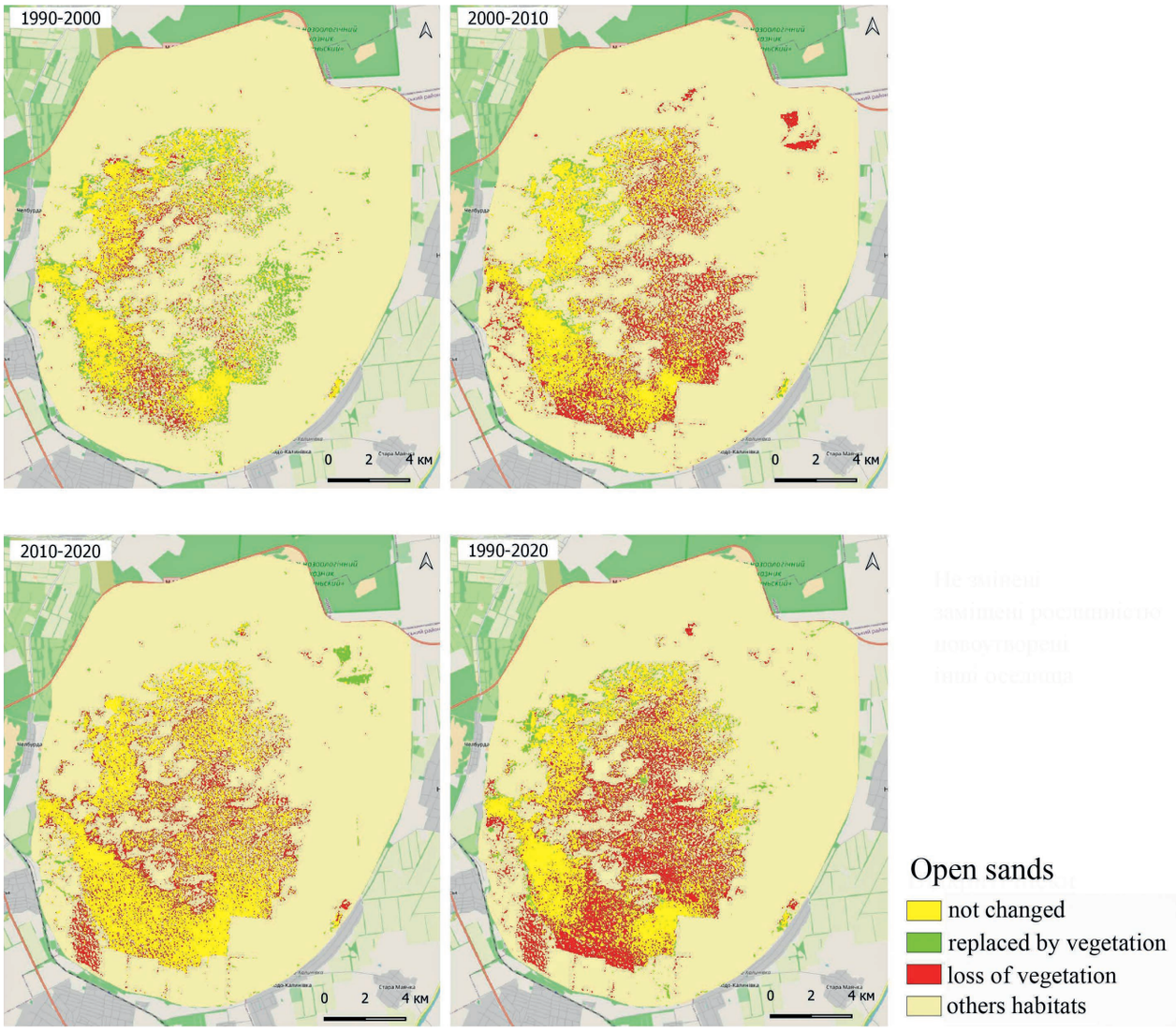

Fig. 5 Area changes of the open sands in the territory of Kozachelaherna arena of Low-Dnipro sands in 1990–2020.

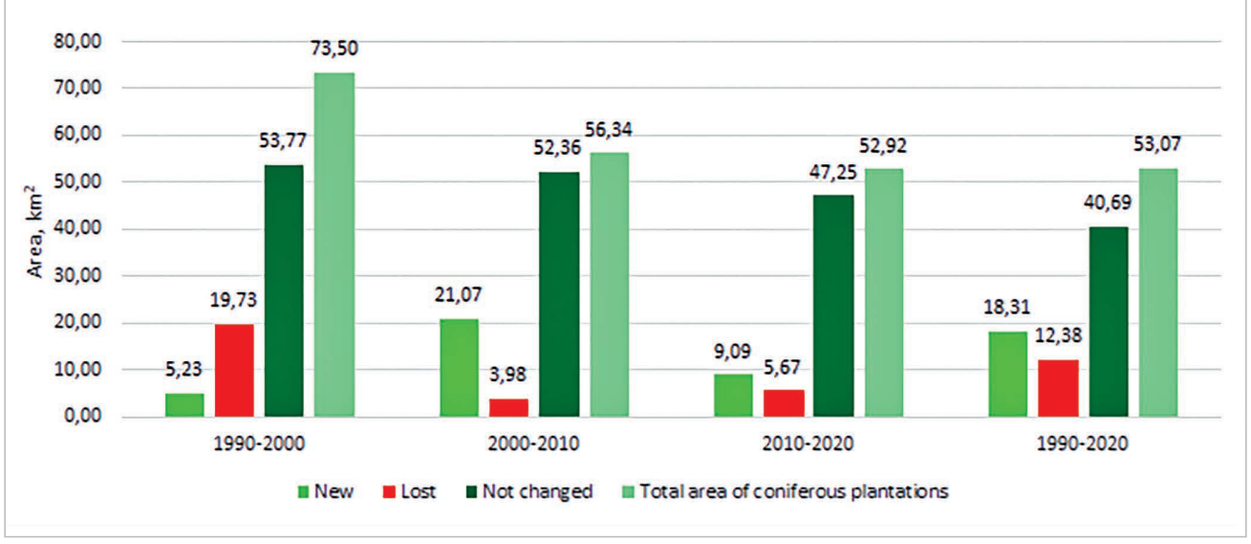

Fig. 6 Area dynamics of the coniferous plantations in the territory of Kozachelaherna arena of Low-Dnipro sands.

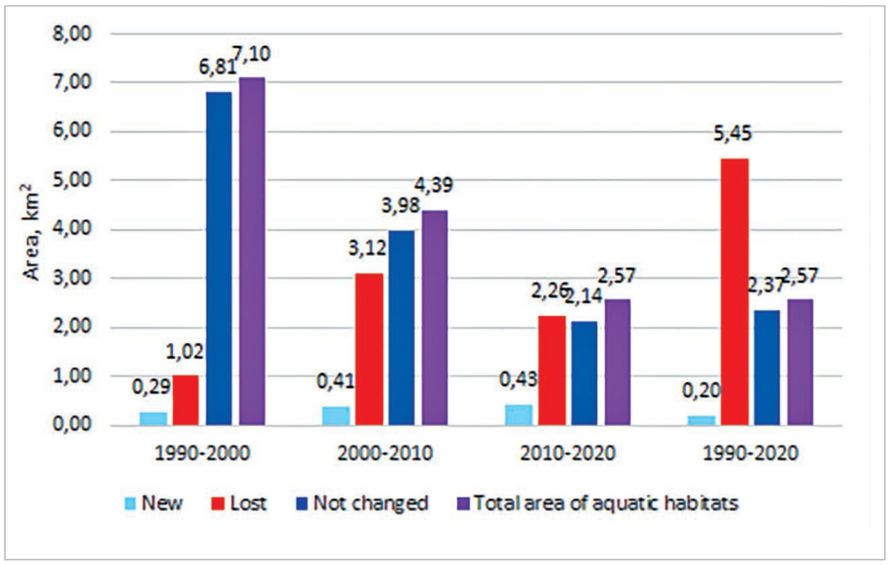

Fig. 7 Area dynamics of the aquatic habitats in the territory of Kozachelaherna arena of Low-Dnipro sands.

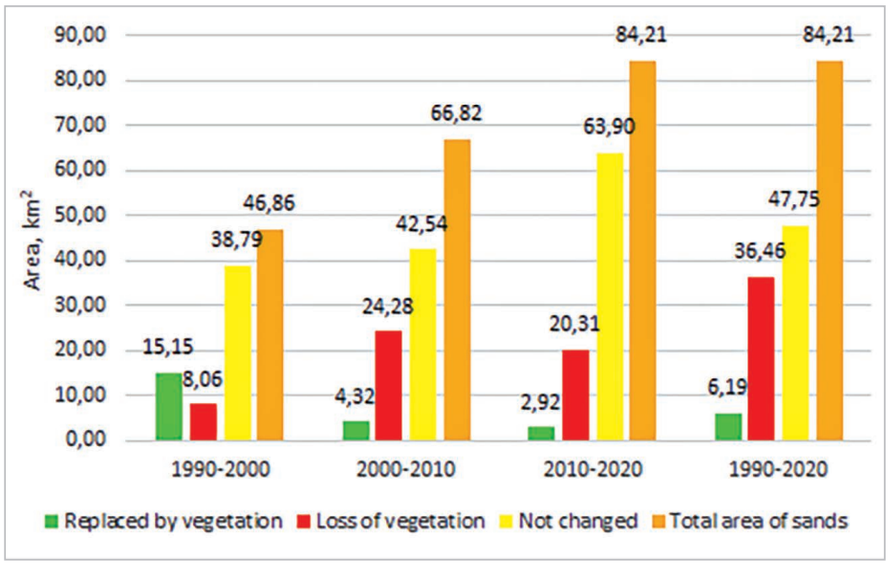

Fig. 8 Area dynamics of the open sands in the territory of Kozachelaherna arena of Low-Dnipro sands.

6. Conclusions

It was established that during thirty years of the research the total area of the coniferous plantations decreased considerably in the period of 2000–2010, and in the following period it remained relatively stable. Along with this, in the first decade the losses were well compensated due to the renewal, however in the latest decades the loss area exceeded significantly the area of the renewal of the coniferous plantations.

During thirty years the area of the large permanent aquatic habitats, located in the north-east part of the arena, decreased by 2.5 times (from 7.1 km^2 to 2.57 km^2). And in fact, their renewal does not take place. One can state that the water supply of these territories decreases constantly, probably because of the reduction of the precipitation amount and the level of the ground water.

There was a progress in the increase of the territories under open sands. During thirty years of the research the area of the open sands increased from 46.86 km^2 to 84.21 km^2. At the same time, the process of the overgrowing of the sands with vegetation slows down gradually, and the vegetation losses increase constantly. Most likely it is connected with the tendency towards aridization of the climate in the south of Ukraine. Over time, this may lead to the replacement of habitats characteristic of sandy steppes with habitats of open sands.

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