Assessment of the saline biotope state of the North-Western Pryazovia as breeding sites of *Glareola pratincola* with the help of remote sensing data

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Abstract. Given the biology features of the pratincole (*Glareola pratincola*), the possibilities of using remote sensing data were studied for the assessment of the species breeding habitats. Sentinel-2 images allowed analyzing a number of vegetation indexes reflecting such specific habitat characteristics as humidity and vegetation cover. The surface temperature is also was investigated. Moreover, the GIS analysis revealed spatial distribution of the collared pratincole breeding colonies, primarily in relation to water sources, settlements and roads. *Glareola pratincola* chooses saline areas as breeding habitats, which are characterized by a wide range of values of vegetation indices: NDVI is from 0.143246 to 0.365503, MSI is from 0.987138 to 1.3531. All saline areas suitable for breeding were located in close proximity to the water body (not more than 300 m). The possible impact of the proximity of settlements and roads on the location of breeding colonies was not found. The salt marshes used by pratincoles for breeding were situated at an average distance of 1405 ± 386 m from settlements and 1714 ± 274 m from roads. The main disturbance factor is potentially cattle grazing. According to results the North-Western Pryazovia is a significant breeding place for *Glareola pratincola* on the Azov-Black Sea coast of Ukraine. The obtained data can be used to determine an ecological niche of the collared pratincole and to develop its conservation strategy in North-Western Pryazovia.

1. Introduction

*Glareola pratincola* is a rare species listed in the Red Data Book of Ukraine, protected by a number of international conventions (the Birds Directive, the Bern Convention, the Bonn Convention, AEWA). It chooses mainly saline biotopes (salt marshes, solonetzes, salt meadows) for breeding. But these biotopes are very vulnerable to abiotic, biotic, and especially anthropogenic factors [1, 2]. In addition, even in the south of Ukraine, the distribution of salt marshes is very limited and segmented.

The availability of remote sensing data (RS) opens up new opportunities for assessing the state and monitoring of biotopes, including the saline ones. In particular, they are used to map saline biotopes [3, 4], vegetation status [5, 6], analysis of their spatiotemporal changes [7, 8].
The state assessment of the biotopes allows to identify some factors that affect the distribution of birds that inhabit them. Understanding the requirements of the species to the biotope, determining the quantitative characteristics of such requirements is the basis for management decisions on the protection of the species, and therefore, for the sustainable existence of the ecosystem.

The purpose of this paper is to assess the quantitative indicators of abiotic and individual biotic factors that affect the distribution of *Glareola pratincola*; to determine the possibilities of using remote sensing data to assess the state of saline biotopes as breeding sites of *Glareola pratincola*. Given the latter, of the full range of characteristics that can be determined by remote sensing, we consider only those that may be important for the formation of the ecological niche of the species.

2. Methods

The location and state of saline biotopes were determined on the basis of remote sensing data, namely satellite images of the European Space Agency Sentinel-2 Level-1C processing for the period from April 1 to June 30, 2020 (cloud cover is not more than 10%). In addition to the cases specified separately, the median image for each month was taken for analysis. Access to satellite data and related calculations were performed using the Google Earth Engine Cloud Computing Platform.

The location of saline biotopes in the North-Western Pryazovia was determined using a supervised classification, the Random Forest method. The data were verified during field expeditions to the research area.

In the spring and summer of 2020, field surveys were carried out at 44 control sites to assess the state of biotopes and determine the breeding sites of *Glareola pratincola*. In total 2325 ha of saline biotopes were surveyed. Within each salt marsh, surveys were carried out along the transect routes with 20-fold binoculars. Gatherings of birds and finds of nests were recorded by GPS.

In order to assess the state of saline areas, vegetation indices were calculated on the basis of reflectance values in different spectral channels of remote sensing data. To assess the suitability of individual indicators for the purpose of the study, 14 indices were calculated, the calculation formulas of which are shown in table 1.

Soil samples were taken at 10 sites where *Glareola pratincola* nesting was determined to assess its field moisture. The hydrostatic weighing method was used for the analysis. Field soil moisture $W$ (in %) is calculated by the formula: $W = 100 \times \frac{a}{b}$, where $a$ is the mass of evaporated water, g; $b$ is the mass of dry soil, g [23].

DJI Mavic Pro shooting was performed at 9 control sites. The obtained images were digitized and divided into 2 classes: vegetation is present / vegetation is absent. The vegetation cover based on these images was calculated as the ratio of the area occupied by vegetation to the total area.

The distance to roads and settlements, which was considered a sign of a possible factor in disturbance of birds, was also assessed as an “indirect” factor. In addition, during the field research there were recorded places of grazing sheep, as well as the number of heads, places of amateur fishing and beach recreation using GPS. Distance analysed were performed using the ArcGis 10.5 software package. Statistical analysis was carried out in the R programming environment.
Table 1. Indices that were used to assess the state of saline biotopes.

| №   | Index                                           | Formula                                      | Link |
|-----|------------------------------------------------|----------------------------------------------|------|
| 1   | Normalized Difference Water Index               | \( NDWI = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}} \) | [9]  |
| 2   | Modified Normalized Difference Water Index      | \( mNDWI = \frac{\text{Green} - \text{SWIR1}}{\text{Green} + \text{SWIR1}} \) | [10] |
| 3   | Land Surface Water Index                        | \( LSWI = \frac{\text{NIR} - \text{SWIR2}}{\text{NIR} + \text{SWIR2}} \) | [11] |
| 4   | Normalized Multi-band Drought Index             | \( NMDI = \frac{\text{NIR} - (\text{SWIR1} - \text{SWIR2})}{\text{NIR} + (\text{SWIR1} - \text{SWIR2})} \) | [12] |
| 5   | Normalized Difference Moisture Index            | \( NDMI = \frac{\text{NIR} - \text{SWIR1}}{\text{NIR} + \text{SWIR1}} \) | [13] |
| 6   | Moisture Stress Index                           | \( MSI = \frac{\text{SWIR1}}{\text{NIR}} \) | [14] |
| 7   | Surface Water Capacity Index                    | \( SWCI = \frac{\text{SWIR1} - \text{SWIR2}}{\text{SWIR1} + \text{SWIR2}} \) | [15] |
| 8   | Shortwave Infrared Soil Moisture Index          | \( SIMI = \sqrt{\frac{\text{SWIR1}^2 + \text{SWIR2}^2}{2}} \) | [16] |
| 9   | Visible and Shortwave infrared Drought Index    | \( VSDI = 1 - \frac{\text{SWIR1} \cdot \text{Blue}}{\text{Red} \cdot \text{Blue}} \) | [17] |
| 10  | Normalized Difference Vegetation Index          | \( NDVI = \frac{\text{NIR} \cdot \text{Red}}{\text{NIR} + \text{Red}} \) | [18] |
| 11  | Soil Adjusted Vegetation Index                  | \( SAVI = \frac{\text{NIR} \cdot \text{Red}}{\text{NIR} + \text{Red} + L} \) | [19] |
| 12  | Green normalized difference vegetation index    | \( GNDVI = \frac{\text{NIR} \cdot \text{Green}}{\text{NIR} + \text{Green}} \) | [20] |
| 13  | Infrared Percentage Vegetation Index            | \( IPVI = \frac{\text{NIR}}{\text{NIR} + \text{Red}} \) | [21] |
| 14  | Enhanced vegetation index                      | \( EVI = 2.5 \cdot \frac{\text{NIR} \cdot \text{Red}}{\text{NIR} + 6 \cdot \text{Red} - 7.5 \cdot \text{Blue} + 1} \) | [22] |

Notes: Blue – reflectence value in blue band, Green – reflectence value in green band, Red – reflectence value in red band, NIR – reflectence value in near infra-red band, SWIR1 – reflectence value in the first short wave infra-red band, SWIR2 – reflectence value in the second short wave infra-red, L is the correction coefficient for reducing soil noise (taking into account the vegetation sparsity, it was taken as 0.8).
3. Study area
In North-Western Pryazovia salt marshes are distributed along the banks of all estuaries located here: the Bolhradskyi Syvashyk, Utliutskyi, Molochnyi and Tubalskyi, in the lower reaches of some rivers, on some plains along the Sea of Azov, as well as on the Obytichna and Berdianska Spits. As mentioned in Methods section 44 sites of saline biotopes were selected for study (figure 1).

According to [24] there are: damp and wet, periodically flooded salt marshes dominated by \textit{Salicornia perennans} (B: 4.111), salt marshes with an annual plant \textit{Salicornion prostratae} and short-term flooding (B: 4.112), salt marshes with prolonged or periodic flooding dominated by \textit{Halocnemum strobilaceum} (B: 4.121), loose salt marshes with short-term flooding dominated by \textit{Halimione verrucifera} (B: 4.122).

4. Species characteristics
\textit{Glareola pratincola}, like the vast majority of sandpiper species, is ground-breeding, but it nests in colonies. The species is characterized by its attachment to breeding sites under stable conditions there. The colonies can be located in almost the same places with minor differences for several years [25].

\textit{Glareola pratincola} occupies nesting areas in April, and starts breeding in the third decade of May - early June. Repeated breeding is possible until mid-July because of the death of egg clutches.

According to the literature data [26, 27], breeding sites generally meet the following requirements:

(i) lowlands with solid ground, free from various kinds of barriers (ravines, trees, shrubs, high grass stand);
(ii) vegetation height is $6 - 20\, \text{cm}$, projective cover area is $9 - 35\%$;
(iii) certain proximity of water sources;
(iv) optimal climatic and microclimatic conditions (average temperature and low humidity);

At the same time, \textit{Glareola pratincola} is a labile species and quickly respond to the disturbance factor, changes in the state of biotopes, and other factors [25, 26].
5. Results
There were identified 93 sites of saline biotopes due to additional classification of satellite images. The sites differed significantly in area (from 0.4 to 310 ha). Their total area was 2864 ha. The largest sites were situated on the banks of the Bolhradskyi Syvashyk, Tubalskyi and Molochnyi Estuaries. Colonies of *Glareola pratincola* were recorded only on 12 sites (figure 2). Single birds of this species were recorded on 6 more sites. In most cases colonies were located on salt marsh sites with an area of 10 to 50 ha (median is 34.4 ha). However, some colonies were recorded both on sites of less than 10 ha and more than 100 ha.

![Figure 2. Distribution of the Glareola pratincola colonies in the study area.](image-url)
6. Moisture dynamics of saline biotopes

To assess the moisture content of saline biotopes, 10 soil samples were taken, for which the percentage of moisture content was determined. For sampling sites, based on remote sensing data for the same dates (3 days), water content coefficients (NDWI, mNDWI, NDMI, NDDI, NMDI, MSI, LSWI, SWCI, SIMI, VSDI) were calculated. The most effective were indices based on the values of near (NIR) and middle (SWIR1) infrared spectral bands (MSI, NDMI). The MSI is characterized by a positive correlation (Pearson’s correlation is 0.8148574, \( p = 0.04824 \)), while the NDMI is characterized by a negative one (Pearson’s correlation is \(-0.8287782, p = 0.04147 \)).

Based on the median images for each month of the breeding period (April-June), the water content index MSI was calculated for all salt marsh sites, as well as mNDWI, as more frequently used in studies, which in the future may allow to compare our data with other regions. The obtained data are shown in table 2. For the sites that were used by *Glareola pratincola* as breeding ones, the MSI value in April was in the range from 0.8411 to 1.2132 (average 1.067 ± 0.036), in June from 0.9943 to 1.3289 (average 1.1701 ± 0.0264). The value of the index mNDWI fluctuated in April from −0.4576 to −0.1493 (average −0.3057 ± 0.03); in June from −0.4423 to −0.2424 (average −0.3694 ± 0.02).

According to the results of the analysis of soil samples, the moisture content of salt marshes during the breeding period of *Glareola pratincola* fluctuated in the range from 13.3 to 33.1%.

Thus, *Glareola pratincola* used salt marshes with a fairly wide range of moisture for breeding.

7. State of vegetation

In addition to estimating the vegetation cover (see “Methods”) in the breeding sites of *Glareola pratincola* using a drone, the following vegetation indices for the same sites were estimated based on satellite data for the same dates (±3 days): NDVI, SAVI, GreenNDVI, IPVI, EVI. All calculated indices showed a statistically accurate correlation with the value of the actual projective cover. The lowest correlation coefficient was found for EVI (Pearson’s correlation is \(-0.6867503, p = 0.04101 \)), the highest one for SAVI, an index that takes into account the influence of soil in its value (Pearson’s correlation is 0.8575388, \( p = 0.003117 \)). But given that the most common index is NDVI, which in our studies also found a high correlation (Pearson’s correlation is 0.8575214, \( p = 0.003118 \)), we used it for further analysis. The value of NDVI in June, the period of maximum vegetation, for breeding sites of *Glareola pratincola* averaged 0.2544 ± 0.0160. According to our data, the vegetation cover of breeding saline biotopes, in some cases, was 24 – 66%, which is significantly higher than it is given in the literature [27].

The obtained values of all indices for breeding biotopes of *Glareola pratincola* are presented in table 2.

Table 2. Indices that were used to assess the state of saline biotopes.

|       | MSI      | mNDWI    | NDVI     | SAVI     |
|-------|----------|----------|----------|----------|
| April | 1.067 ± 0.036 | −0.310 ± 0.032 | 0.231 ± 0.0195 | 0.416 ± 0.035 |
| May   | 1.144 ± 0.022  | −0.359 ± 0.023  | 0.247 ± 0.015  | 0.445 ± 0.027  |
| June  | 1.17 ± 0.026   | −0.373 ± 0.019 | 0.254 ± 0.016 | 0.458 ± 0.029 |
8. Soil surface temperature
Among the microclimatic parameters, the soil surface temperature during the egg-laying period is considered, which may be important for ground-breeding species. Since all the nests were found in June, the median value of the ground surface temperature was analyzed exactly for June using data from a satellite survey of the Landsat Missions, the sensors of which have a thermal band. For the sites used by *Glareola pratincola*, the soil surface temperature averaged $34.7 \pm 0.2 \, ^\circ C$. For comparison, the average soil surface temperature for land areas within the basins of the Azov estuaries was $32.68 \pm 0.32 \, ^\circ C$. Presumably, *Glareola pratincola* chooses warmer parts of the soil as a breeding habitat.

9. Distance to water
All considered saline areas suitable for nesting were located in close proximity to the water area. The average distance from the found colonial settlements of *Glareola pratincola* to the water body was $130.1 \pm 19.7m$ (minimum $19.9m$ in the Syvashyk Estuary, maximum $274m$ in the Molochnyi Estuary, the mouth of the Tashchenak River).

In relation to freshwater sources (a river, a canal or a well), the colonial settlements of *Glareola pratincola* were mostly located right next to the source, at the same time 3 colonies were at a distance of $720 – 1100m$, and 2 colonies in the Syvashyk Estuary were at a distance of about $10km$.

10. Disturbance factor
As mentioned above, the disturbance factor was assessed both through indirect data - the distance to potential sources of such a factor, and through the fixation of the direct facts of grazing, recreational activities, etc.

10.1. Indirect disturbance factors
On average, colonies of *Glareola pratincola* were located at a distance of $1919 \pm 342m$ from the settlements. One of the colonies was located at a distance of $400m$ from the edge of the village (the mouth of the Tashchenak River, and another 5 colonies at a distance of less than $1km$). It should be noted that the place of the colony, which turned out to be the closest to the settlement, in the past was a stable breeding place for *Glareola pratincola*. Its colonies have been recorded here from 2000 to 2013 mostly annually [28]. The colony of *Glareola pratincola* on the salt marshes of the Tubal Estuary, which according to research is also quite stable, was located less than $1km$ from the resort (the village of Prymorskyi Posad) and $444m$ from the sea shore, where there are places of unorganized beach recreation.

The average distance from the colonial settlements to the roads was $1714 \pm 274m$ (minimum $429m$ in the area of the Tubal Estuary).

10.2. Direct disturbance factors
In total, during the period of expeditionary research, there were recorded 9 facts that were assessed as a possible impact on the *Glareola pratincola* colonies. In 7 cases these were the facts of sheep grazing (meeting flocks of sheep or fresh traces of manure near the colony), in two other cases it was recreation (beach recreation on the shores of the Molochnyi Estuary and a place of amateur fishing on the shores of the Utiutskyi Estuary). We did not record such factors near the salt marshes of the Bolhrad Syvashyk Estuary or the Tubal Estuary. In the only colony, which was located less than $1km$ from the place of grazing sheep ($708m$), no birds or nests were found when re-visiting (but we did not establish the exact reasons for the disappearance of the colony). But it should be noted that a successful colony of *Glareola pratincola* was recorded $84m$ from the place of amateur fishing.
11. Discussion of results
Thus, the ranges of all indices and parameters of interest to us were estimated: water content (soil moisture), projective vegetation cover, soil temperature, distance to water, settlements, roads and other anthropogenic disturbance factors for birds. In most cases, a wide range has been identified within which Glareola pratincola chooses breeding habitats. For all analyzed salt marshes, no significant differences in the analyzed parameters for the sites used for breeding and not used were found.

Based on the 95% confidence interval of each of the analyzed parameters, 67% of the saline biotopes in the region meet the eligibility criteria.

It can be assumed that unoccupied areas include both sites that meet the needs of the species, but not occupied due to the small number of breeding pairs, and sites not suitable for breeding. But this assumption needs further verification.

It should be noted that not only estimation of projective cover is important, but also the structure of vegetation, plant height, which contributes to the protection of chicks, that also requires additional research. Further research is also needed to clarify the impact of disturbance factors, including non-anthropogenic factors.

12. Conclusions
Remote sensing data objectively reflect the current state of the saline biotopes, namely the state of soil moisture, vegetation and surface temperature. The obtained results can be a starting point for further monitoring of breeding sites of a very vulnerable rare species of Glareola pratincola, as well as for further assessment of its ecological niche.

Glareola pratincola chooses saline areas as breeding habitats, which are characterized by a wide range of values of vegetation indices: NDVI is from 0.143246 to 0.365503, MSI is from 0.987138 to 1.3531. All saline areas suitable for breeding were located in close proximity to the water body (not more than 300 m). The possible impact of the proximity of settlements and roads on the location of breeding colonies was not found. The main disturbance factor is potentially cattle grazing, which is confirmed by other researchers [29].

Based on the total area of salt marshes suitable for breeding, the North-Western Pryazovia is a significant breeding place for Glareola pratincola on the Azov-Black Sea coast of Ukraine.

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