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Using biodiversity indices to assess the current state of tugai vegetation of the Amu Darya River, Uzbekistan

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Abstract. *Rakhimova NK, Shomurodov KF, Sharipova VK, Saitjanova USH, Sadinov JS. 2023. Using biodiversity indices to assess the current state of tugai vegetation of the Amu Darya River, Uzbekistan. Biodiversitas 24: 467-472.* Changes in plant associations of the tugai reserve of Uzbekistan (Amu Darya coast) due to climate change were considered. The state of associations represented by the xeromesophilic-mesothermal group of plants of the tugai (POTAMODENDRA), shrub (POTAMOTHAMNA) and herbaceous (POTAMOPOIA) vegetation types of the Amudarya tugai was analyzed. At the same time, ten associations were evaluated in a comparative aspect. An analysis of biodiversity within and between associations were carried out, various biodiversity indices (Shannon, Simpson, Margalef) were compared, and the sensitivity of the indices to various factors was assessed. In the tree layer, there was a significant decrease in the abundance of *Populus euphratica, P. pruinosa*, as well as the number of shrubs and perennial grasses. Alarming indicators of vegetation transformation have been identified using the α- and β-biodiversity indices. The evaluation results of vegetation in terms of biodiversity indices showed that due to the violation of the structural and functional organization, general degradation, simplification and impoverishment of the floristic composition, change of plant communities and xerophytization, significant changes occurred in the studied associations, as reflected in biodiversity indices. The results obtained will make it possible to understand the ways of formation and development of tugai vegetation, to identify the mechanisms of transformation of tugai forests on different ecological gradients (bioclimatic, hydrological, edaphic and anthropogenic), to assess the current state of tugai forests, to identify rare plant communities that need protection and to develop recommendations for their protection.

Keywords: Association, biodiversity, climate change, degradation, tugai, vegetation cover

INTRODUCTION

Biodiversity in the last decade has become one of the most common concepts in scientific literature, the environmental movement, and international relations. Scientific research has proven that a sufficient level of natural diversity on our planet is necessary for the normal functioning of ecosystems and the biosphere. Biological diversity is considered the main parameter characterizing the state of superorganism systems. In several countries, the characteristics of biological diversity act as the basis for the environmental policy of the state, which seeks to preserve its biological resources to ensure sustainable economic development (Lebedeva et al. 2002).

Tugai is desert floodplain forests common in Central and Central Asia. They are found in river valleys - along the banks, islands, on low-lying terraces. Typical riparian trees grow in a narrow band interspersed with meadows and thickets. Their main edificators are *Populus euphratica*, *P. pruinosa*, *Elaeagnus angustifolia*, *Salix songarica*, *Tamarix ramosissima*, *T. hispida*, *Halimodendron halodendron*, *Phragmites australis*, *Calamagrostis dubia*, *Elytrigia repens*. According to Kuzmina and Treshkin (2012), tugai forests are everywhere in very poor condition, as they are subject to constant anthropogenic impacts of regional and local nature. The main reason for the degradation of tugai ecosystems at present should be considered soil salinization, caused by the regulation of river flow. The main part (up to 95% of the area) of modern tugai belongs to degraded ecosystems, characterized by a simplified community structure, reduced species diversity, weak year-to-year changes in the composition of communities, and reduced productivity.

Uncharacteristic processes develop in tugai ecosystems: the widespread halophytization of tugai leads to the formation of various serial stages, which contributes to the disappearance of the characteristic floristic and structural features of tugai communities in different regions that previously had zonal and subzonal differences; there is a disappearance of typical tugai tree and shrub communities; various variants of herbal tugai, which were not previously widespread, are replacing tree and shrub communities; there is an accelerated irreversible transformation of typical tugai into saline vegetation; there is a significant loss of species diversity in the communities of modern grass and tree-shrub tugai compared to typical tugai of the recent past (Kuzmina and Treshkin 2012). In order to preserve biological diversity, human habitats, as well as valuable commercial and relict species of animals and plants, it is necessary to develop artificial halophyte tugai reforestation throughout Central Asia.

The phreatophytic tree species *P. euphratica* Oliv forms riparian (*tugai*) forests along the Tarim River at the northern and eastern fringe of the hyper-arid Taklamakan

Desert (Xinjiang Province, NW China). These forests are threatened by decreasing groundwater levels due to excessive withdrawal of water for agricultural irrigation (Zhang et al. 2005; Hao et al. 2010; Wu et al. 2010; Liu et al. 2011; Cao et al. 2012; Ling et al. 2015; Aishan et al. 2015; Deng et al. 2015; Lang et al. 2016; Zeng et al. 2016; Aishan et al. 2016; Wang et al. 2018; Keyimu et al. 2018; Zeng et al. 2020; Keram et al. 2021).

According to Treshkin (2011), climate change, along with anthropogenic flow regulation, is also the main cause of the widespread degradation of relict tugai ecosystems in Central Asia since the main trends in climate change (arid warming, i.e. increase in temperature and reduction in precipitation in the warm half of the year, summer and autumn, as well as the lengthening of the warm period) contribute to an increase in the drying of floodplain and delta territories during the growing season. The natural dynamics of tugai ecosystems has been disturbed as a result of anthropogenic transformations of a direct (clearing, grass, fires) and indirect (regulation of river flow) character; the general direction of the dynamic process is sharply shifted to the side - halophytization and desiccation; everywhere there is a loss of typical (conditionally native) tugai tree and shrub communities, not only groups of associations disappear, but also completely separate formations of tugai vegetation; there is a replacement of tree-shrub tugai with various variants of grass and halophyte communities, which previously did not have a large distribution. Anthropogenic impacts in tugai forests associated with the regulation of river flow, deforestation, or overgrazing lead to the degradation of alluvial tugai soils and, as a rule, to the formation of meadow salt marshes in their place, typical or residual medium and strong salinity.

This study aimed to evaluate representative associations of tugai of the Amudarya (Uzbekistan) using biodiversity indices. The assessment of the state of ecosystems using biodiversity indices can be seen in highly rated international journals (Sidabukke et al. 2021; Murdjoko et al. 2021; Sahputra et al. 2022; Taguiam et al. 2022; Ekawaty et al. 2022).

MATERIALS AND METHODS

Study area

The research was carried out at the *"Badai-Tugai"* nature reserve (Figure 1). *The "Badai-Tugai" nature reserve* is located on the banks of the Amu Darya River in Uzbekistan, established in 1971 on an area of 6462 hectares. It is the only nature reserve in the Republic of Karakalpakstan. A special animal among the protected ones is the Bukhara deer. The climate is sharply continental and dry, as the territory is far from the ocean. Winter is harsh. The absolute minimum temperature reaches -33-34 degrees, and the summer is hot and dry. The warmest month is July, with an average temperature of +27+28 degrees Celsius. The absolute maximum is +40+41 degrees Celsius. The northeast wind prevails. During the year, 70-90 mm of precipitation falls (www.orexca.com/rus/uzbekistan/nature/badai tugai.htm).

The "Badai-Tugai" reserve is one of the last oases of hydromorphic areas with tree and shrub vegetation among the desert plains. The time of the formation of the reserve coincided with the construction of the Tuyamuyun (1980) and Takhiatash (1974) hydroelectric facilities. Because of this, the water level in the river has decreased by 4.0-4.5 m over the past 25 years (Kuzmina and Treshkin 2012). Since the formation of the reserve in 1976 and until 1998, its territories were not flooded at all. Partial flooding was only in 1998 and 2002. Today, the necessary ecological conditions for the sustainable existence of tugai ecosystems are not maintained in reserve.

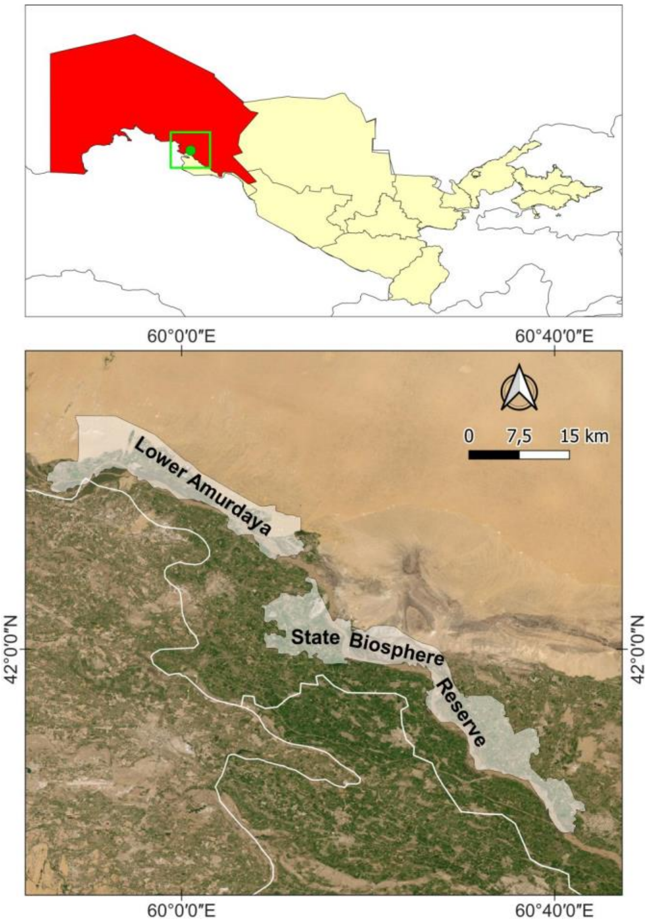

Figure 1. Map of Uzbekistan with the location of the state reserve "Badai-Tugai" marked with a green dot

In the course of the study, two periods of time were studied: historical (H-historical) and current (C-current). Diversity indices (α- and ß-diversity) were analyzed to assess representative associations, including species composition, total projective cover, projective cover of individual species, life forms, and ecological groups of species. ¥ diversity will be studied in the following research. The material for the analysis was geobotanical descriptions of the historical ("Vegetation cover of Uzbekistan", 1973) and current (2022) periods to assess ten plant associations: *Populus euphratica* + *P. pruinosa* (1); *Tamarix hispida* - *Populus euphratica* + *P. pruinosa* (2); *Glycyrrhiza glabra* - *Populus euphratica* + *P. pruinosa* (3); *Erianthus ravennae* - *Populus euphratica* + *P. pruinosa* (4); *Phragmites australis* - *Glycyrrhiza glabra* - *Zygophyllum oxianum* - *Elymus repens* - *Populus euphratica* + *P. pruinosa* + *Elaeagnus angustifolia* (5); *Phragmites australis* + *Elaeagnus angustifolia* + *Salix songarica* (6); *Tamarix hispida* (7); *Karelinia caspia* + *Halostachys belangeriana* - *Tamarix hispida* (8); *Alhagi pseudalhagi* - *Karelinia caspia* - *Aeluropus littoralis* - *Limonium otolepis* - *Zygophyllum oxianum* - *Tamarix hispida* (9); *Tamarix ramosissima* - *Glycyrrhiza glabra* (10) tugai of the Amudarya.

The following methods were used in the study: geobotanical descriptions were made in all associations where the landscape-ecological approaches of species were studied, according to the generally accepted methodology (Guidelines 1980). The life form of plants is determined based on the "Conspectus Florae Asiae Mediae" (2015). Latin names of plant species are given from Plants of the World Online (https://powo.science.kew.org/).

Based on the indices of α-diversity (Simpson - *1-D*, Shannon - *H'*, Margalef - D_{Mg}, as well as β-diversity (Whittaker - β_W), representative associations of the Amudarya tugai were estimated in connection with climate change in the region according to the generally accepted methodology (Franklin et al. 2016; Aleksanov 2017; Adilov et al. 2021). Indices of biodiversity were calculated using the program PAST version 3.2 (Hammer et al. 2001), and the equations are as follows:

Simpson index : $I - D = 1 - \sum_{i=1}^{s} \frac{N_i(N_i - 1)}{N(N-1)}$,

Where: N_i is the number of individuals of the *i*-th species, *N* is the total number of individuals;

Shannon index : $H = -\sum_{i=1}^{s} \left(p_i \ln p_i \right)$,

Where: the value p_i is the proportion of individuals of the *i*-th species;

Margalef index : $D_{Mg} = \frac{S-1}{\ln N}$,

Where: the ratio of the number of identified species (*S*) and the total number of individuals of all species (*N*).

$$\beta w = \frac{S}{\alpha} - 1$$

Where: *S* is the total number of species registered in the system and *α* is the average species diversity of communities, measured as the species richness of standard sized samples.

Biodiversity indices were calculated for xeromesophilic-mesothermal trees (*Populus euphratica*, *P. pruinosa*), (*Elaeagnus angustifolia*), (*Salix songarica*), as well as large shrubs and tall grasses: (*Tamarix ramosissima, T. hispida*), *(Halimodendron halodendron)*, *(Phragmites australis)*, *(Calamagrostis dubia)*, *(Elytrigia repens)* etc.

RESULTS AND DISCUSSION

The state of associations represented by the xeromesophilic-mesothermal group of plants of the tugai (POTAMODENDRA), shrub (POTAMOTHAMNA) and herbaceous (POTAMOPOIA) vegetation types of the Amudarya tugai was analyzed. At the same time, ten associations were the abundance of dominant species in the studied associations shown in Table 1. The analysis of species diversity showed the following results (Table 2).

For the first association (*Populus euphratica* + *P. pruinosa*), the current Shannon index (H') was 0.99, higher than the historical H', i.e. 0.28. The current Margalef index (D_{Mg}), 3.71, was also higher than the historical value, 2.99. Meanwhile, the current Simpson index (1-D), 0.47, was lower than its historical value, 0.91). The increase of *H'* and D_{Mg} was probably due to an increase in the total number of species, mainly perennial grasses, due to the addition of new species, such as *Glycyrrhiza glabra*, *Asparagus brachyphyllus*, *Erianthus ravennae*, and in the upper layer - *Elaeagnus angustifolia*. However, the evenness in species abundance declined, as indicated by the decrease of the Simpson diversity index (1-D), due to the dominance of some species.

Table 1. The abundance of the historical and current dominant species of 10 associations studied

	1		**2**		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**	
Dominant species	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C
Populus euphratica	75	20	38	25	30	20	35	35	25	15	0	5	0	7	0	0	0	0	0	1
Populus pruinosa	1	30	3	23	2	28	7	10	0	0	0	0	0	5	0	0	0	0	0	0
Elaeagnus angustifolia	0	4	0	0	4	6	0	4	30	30	0	20	0	0	0	0	0	0	0	1
Tamarix ramosissima	1	0	25	12	25	2	4	0	5	0	0	0	75	30	25	0	50	0	15	0
Halimodendron halodendron	0	2	0	2	2	2	0	1	5	0	0	2	0	1	1	0	10	0	0	1
Salix songarica	0	0	0	0	0	0	1	0	0	0	50	40	0	0	0	0	0	0	0	0
Glycyrrhiza glabra	0	1	0	1	8	15	1	1	10	10	0	0	0	0	0	0	3	0	50	60

Table 2. The species richness and diversity indexes of the ten associations studied

Association	Shannon index (H’)		Simpson index (1-D)		Margalef index (D_{Mg})		Whittaker
	H	C	H	C	H	C	(β_W)
1	0.28	0.99	0.91	0.47	2.99	3.71	0.79
2	2.05	1.37	0.20	0.31	6.07	4.01	0.71
3	1.54	1.43	0.34	0.30	4.65	3.81	0.65
4	1.66	1.08	0.24	0.50	2.62	2.85	0.73
5	1.91	1.68	0.18	0.21	2.24	1.57	0.68
6	0.85	1.40	0.48	0.32	0.72	2.04	0.70
7	1.32	1.30	0.29	0.41	1.07	5.70	0.93
8	1.49	1.17	0.29	0.33	3.74	1.34	0.71
9	1.46	1.14	0.39	0.43	3.30	1.94	0.74
10	1.79	0.68	0.22	0.72	3.17	2.58	0.87

For the second association (*Tamarix hispida* - *Populus euphratica* + *P. pruinosa*), the current Shannon index *(H’)* was 1.37, lower than the historical H’, 2.05. The current Simpson index *(1-D)* was 0.31, higher than the historical value, 0.20. The current Margalef index (D_{Mg}) was 4.01, lower than the historical value, 6.07. The decreased current Margalef index showed that species richness decreased, which also caused the decrease of Shannon index. However, the increased Simpson index *(1-D)* indicated that the species evenness increased or the dominance of certain species decreased.

The current Shannon index *(H)* for the third association (*Glycyrrhiza glabra* - *Populus euphratica* + *P. pruinosa*) was 1.08, lower than the historical value, 1.54. The current Margalef index (D_{Mg}) for the third association was 3.81, lower than the historical value, 4.65. The decrease in Shannon index (H’) and Margalef index (D_{Mg}) in association 3 was an indication of the decrease in species richness of this community. It might also be caused by the decreased abundance of shrubs such as *Halimodendron halodendron* and perennial grasses. Dried specimens of those shrubs and grasses were often found. Meanwhile, the current Simpson index (1-*D*) for the third association was 0.30, almost the same as the historical value, 0.34, indicating that the evenness of species abundance did not change much.

The current Shannon index (H’) in the fourth association (*Erianthus ravennae* - *Populus euphratica* + *P. pruinosa*) was 1.43, slightly lower than the historical value, i.e., 1.66, while the current Simpson index was 0.50, much higher than the historical value, 0.24. The current Margalef index was 2.83, slightly higher than the historical value, 2.62. The values of the three indexes were not consistent. The increase in Margalef index means an increase in species richness, while the increase in Simpson (1-D) index means an increase in species evenness or a decrease in the dominance of certain species. So, the Shannon index should have increased too.

In the four associations (1, 2, 3, 4), the historical values of the Shannon index *(H’)* ranged from 0.28 to 2.05, the Simpson index (1-*D*), from 0.20 to 0.91, and the Margalef index (D_{Mg}) from 2.62 to 6.07. The large differences in values are associated with large differences in the number of species and their abundance. The current values of Shannon index *(H’)* ranged from 0.99 to 1.43, the Simpson (1-*D*) from 0.30 to 0.50, and the Margalef (D_{Mg}) from 2.85 to 4.01. The ranges were smaller than the historical ones.

The current Shannon index (H’) for the fifth association (*Phragmites australis* - *Glycyrrhiza glabra* - *Zygophyllum oxianum*, *Elymus repens* - *Populus euphratica* + *P. pruinosa* + *Elaeagnus angustifolia*) was 1.68, lower than the historical value, 1.91. Likewise, the current Margalef index (D_{Mg}) was 1.57, lower than the historical value, 2.24. The decrease of Shannon and Margalef indexes indicates that the species richness in this association deceased due to the disappearance of shrubs such as *Tamarix pentandra, T. elongata*, *Halimodendron halodendron*. On the other hand, the current Simpson index (1-*D*) was 0.21, almost the same as the historical value 0.18.

For association 6 (*Phragmites australis* + *Elaeagnus angustifolia* + *Salix songarica*), the current Shannon index (H) was 1.40, higher than the historical value, 0.85. Likewise, the current Margalef index (D_{Mg}), 2.04 was higher than the historical value, 0.72. The increase in both indexes might be due to the increase of tree and grass species richness on the upper tier of trees and the addition of perennial grasses (*Trachomitum lancifolium, Cynanchum sibiricum, Aeluropus littoralis*). The increased abundance of common species decreases the evenness and reduces the H’.

In associations, 7 (*Tamarix hispida*), 8 (*Karelinia caspia* + *Halostachys belangeriana* - *Tamarix hispida*) and 9 (*Alhagi pseudalhagi* - *Karelinia caspia* - *Aeluropus littoralis* - *Limonium otolepis* - *Zygophyllum oxianum* - *Tamarix hispida*) the historical indices of Shannon and Simpson had significant differences, ranging from 1.32 to 1.49 *(H)*, from 0.29 to 0.39 *(1-D)*. The current H’ values ranged from 1.14 to 1.30, and 1-D from 0.33 to 0.43*;* so, the indices did not change widely, which indicates the uniformity of the distribution of species since the oppressed associations had a smaller number of species in their composition. However, the current Margalef index had high values, greater than 5.70, which may be due to a decrease in the level of groundwater and relative atmospheric moisture, an increase in the salinity of the substrate, etc.

The current Shannon index for association 10 (*Tamarix ramosissima* - *Glycyrrhiza glabra*) was 0.68, lower than the historical value, 1.79. Likewise, the current Margalef index (2.58) was lower than the historical value (3.17). On the contrary, the current Simpson index (1-*D*), 0.72 was higher than the historical value, 0.22. The changes in the three indexes indicated that the evenness increased, but the species richness decreased.

The analysis of β-diversity characterizes the degree of difference or similarity of habitats in terms of their species composition and the quantitative representation of species. One way to determine β-diversity is to compare the species composition of cenofloras. The less their similarity, the higher the β-diversity. The data of the β-diversity analysis give an idea of the general diversity of the habitat conditions of the association (Lebedeva et al. 2002).

The β-diversity index (Whittaker - β_W) for (7) association has a high value of 0.93, close to this index has (10) association 0.87. This suggests that the species composition of these associations bears little resemblance to other associations. More similar in species composition are (2) association (0.71), (4) association (0.73), (8) association (0.71), and (9) association (0.74).

Thus, due to the violation of the structural and functional organization, general degradation, simplification and impoverishment of the floristic composition, the change of plant communities and xerophytization, significant changes occurred in the studied associations, which are reflected in biodiversity indices. The use of biodiversity indices makes it possible to assess the degree of interaction within phytocenoses and compare them with each other, highlighting the most significant factors of influence.

The main reason for the anthropogenic degradation of tugai is the regulation of river runoff, which leads to a change in the flooding regime, a change in the nature and intensity of soil formation, and the loss of the possibility of natural renewal of tugai trees, shrubs and grass associations. Climate change is also one of the main reasons for the widespread degradation of tugai ecosystems. In the research region, climate change is manifested: an increase in temperatures and a decrease in precipitation in the warm half of the year, summer and autumn. In order not to completely lose the tugai type of vegetation under the conditions of climate change, it is necessary to develop new approaches to the conservation and stabilization of these ecosystems in the absence of floods.

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