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Impact of High Water Levels in Lake Baikal on Rare Plant Species in the Coastal Zone

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Abstract: This paper presents an assessment of potential losses and damage costs to rare coastal plant species of Lake Baikal (UNESCO World Heritage Site) as a result of inundation at high water levels. The lake's ecosystem is characterized by an exceptional diversity of rare and endemic animal and plant species. The construction of a hydroelectric power plant caused an increase in the water level of Lake Baikal, resulting in the inundation of low-lying coastal areas, the destruction of the coastline, alterations to the hydrological regime, etc. However, there are practically no works devoted to water-level modeling and the assessment of its impact on riparian vegetation, including rare species. We conducted fieldwork to determine the abundance of four vulnerable species and identified inundation zones at different high water levels on the basis of digital elevation models based on aerial photography data. The analysis revealed that at the maximum level of inundation, the number of plant species affected would total 5164, amounting to a financial loss of biodiversity estimated at 3098.4 thousand rubles. To mitigate the projected losses, it is imperative to implement measures that restrict water-level fluctuations above the 457.00 m threshold. The absence of flora as an object of state environmental monitoring, which is not specified in the regulatory legal document, must be rectified in a timely manner.

Keywords: Russia; reservoir; hydropower plant; endemics; inundation; damage cost

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1. Introduction

Studies on water-level fluctuations in aquatic systems are currently becoming increasingly important, especially in the context of global climate change. Water-level monitoring has been identified as one of the key objectives of both the World Meteorological Organization (WMO) and the Global Climate Observing System (GCOS) [1,2]. The focus of relevant scientific research is on the study of the ecological response of ecosystems to water-level fluctuations [3,4]. It has been repeatedly noted that changes in the hydrological regime lead to large-scale losses and degradation of coastal ecosystems [5–7]. The vegetation that grows on the banks of water bodies may be vulnerable to inundation due to water-level fluctuations [8,9]. Among the hydrological and climatic factors that influence riparian zone vegetation conditions, the duration of inundation and water depth have the greatest effect [10,11]. Studies have shown that the shoreline zone of reservoirs experiences a decline in the species diversity of plant communities [12,13], a decrease in plant reproductive function [14], and the invasion of non-native species [15].

The most significant impact on vegetation is seen as a result of reservoir construction [16]. During the process of reservoir filling, significant areas are inundated, leading to the irreversible loss of plant habitats [17]. Following the rise in water level, former valley slopes transition into the zone of reservoir banks transformation. During the initial years of reservoir operation, the shore may widen by several tens or even hundreds of meters. This abrasion process also leads to the degradation and loss of vegetation cover. Subsequently, a new shoreline ecosystem adapted to the reservoir-level regime is formed [18]. Undoubtedly, studies of the impacts of water-level fluctuations on rare species are of great importance. They are among the most vulnerable components of ecosystems, as they have a limited number of populations and are localized within a narrow range. Thus, the conservation of rare plant species and endemics is crucial for maintaining biodiversity and ecosystem resilience [19].

The paper considers threats to rare coastal plant species of a lake of international ecosystem importance. In 1996, Lake Baikal was designated a UNESCO World Heritage Site, thereby underscoring its distinctive attributes and global significance. Its territory also encompasses the Selenga River delta, which is classified as a wetland under the Ramsar Convention [20]. The lake's ecosystem is characterized by an exceptional diversity of rare and endemic animal and plant species.

Lake Baikal has been functioning as a water reservoir since the late 1950s, following the regulation of the Angara River [21,22]. The construction of the Irkutsk HPP dam resulted in a 0.8 m increase in the lake level [23]. This led to a number of negative consequences: changes in the hydrochemical and hydrobiological regime, the flooding of residential houses and infrastructure facilities, the activation of abrasion processes, impacts on flora and fauna, etc. These changes occurred mostly in the Republic of Buryatia, in the eastern part of the lake with predominantly gentle shores [24].

This study focuses on the assessment of potential damage to rare plant species on the southeastern coast of Lake Baikal as a result of a potential water-level rise.

Despite the presence of few studies of the level regime of Lake Baikal, covering its various aspects from hydrological modeling to its impact on avifauna [21,23,25–27], there are practically no works devoted to inundation zone modeling at high water levels and the assessment of its impact on coastal vegetation, including rare species.

The main provisions of the article are as follows:

(1) The creation of digital elevation models made it possible to carry out the hydrological modeling of inundation zones at extremely high water levels;
(2) On the obtained territories, fieldwork was carried out to count the number of rare species subjected to flooding;
(3) Losses of rare plants at different water levels with a step of 0.10 m were determined and potential economic damage was estimated.

These provisions are the basis for a given study aimed at assessing and minimizing the impact of water-level fluctuations on the unique flora of Lake Baikal. By modeling flood zones and estimating the abundance of vulnerable plants, ecological and economic damage can be quantified, which emphasizes the need for strict regulation of water levels to preserve biodiversity.

2. Materials and Methods

2.1. Study Area

Lake Baikal is located in the Asian part of Russia, within the Irkutsk Oblast (the western part of the lake) and the Republic of Buryatia (the eastern part of the lake). The total area of the lake is 31,722 km^2 and its length is 636 km [28]. The length of the shoreline reaches more than 2000 km [28]. It is the deepest lake on the planet and also the largest in terms of freshwater volume (Figure 1).

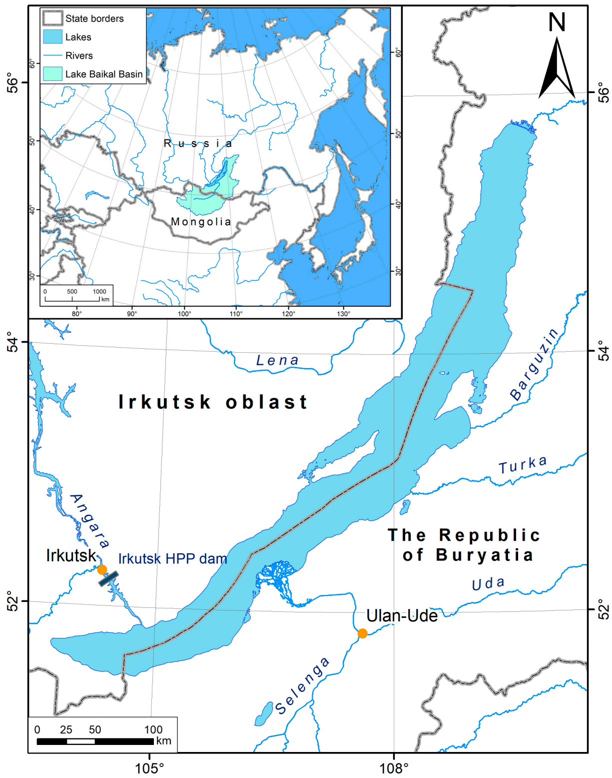


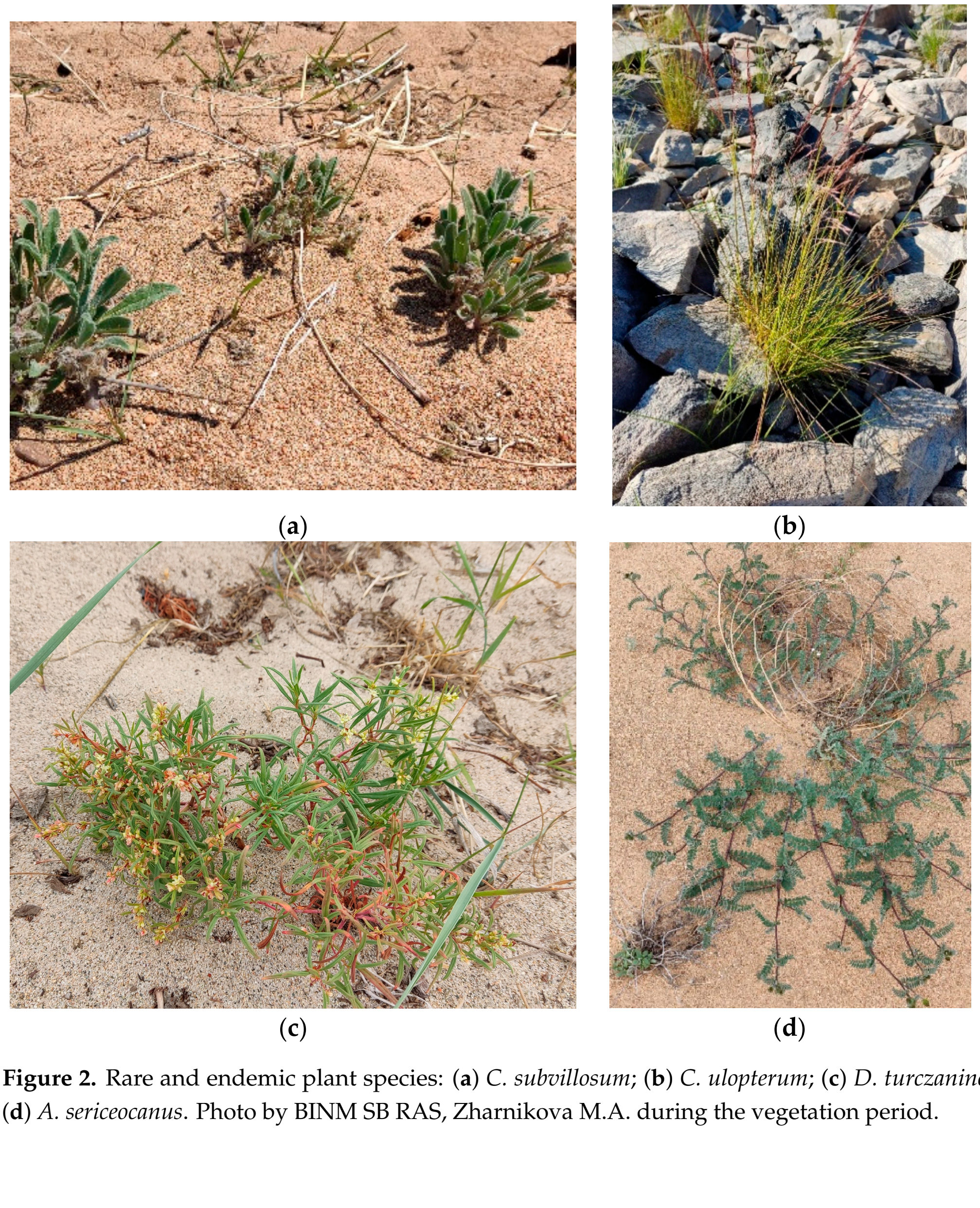
Figure 1. Location of study area. The research on high water levels' impact on rare plant species was carried out on the southeastern coast of Lake Baikal.

The largest rivers flowing into the lake are the Selenga, the Upper Angara, and the Barguzin rivers. Collectively, these rivers provide over 70% of the lake's surface inflow. There is only one river flowing out of the lake, the Angara, which has been used for the construction of a hydroelectric power plant. The water area of Lake Baikal is surrounded by mountain ranges on all sides. The most prominent of these mountain ranges are Primorsky, Baikalsky, Verkhne-Angarsky, Barguzinsky, and Khamar-Daban. Along the western coast, these mountain ranges extend close to Baikal, forming steep banks. In contrast, the southeastern coast is distinguished by more gentle and wide shores. The presence of bays and coves is minimal, with the most notable examples being Chivyrkuisky, Barguzinsky, Proval, and Listvennichny.

Lake Baikal is located within a sharply continental climate zone that is distinguished by short, hot summers and long, cold winters. Temperatures can vary from −40 to +35 °C. The large volume of water in Lake Baikal exerts a warming effect, thereby reducing the annual temperature amplitude in the vicinity of the lake. The basin of Lake Baikal is situated within the borders of Russia and Mongolia, where droughts are a recurring phenomenon. The distribution of precipitation in the study area is primarily influenced by topographical features, with annual precipitation ranging from 250 to 1400 mm. The predominant seasonality of precipitation is evident in the summer months, accounting for 60 to 70 percent of the annual total [29]. The seasonal dynamics of Lake Baikal are characterized by a maximum water level in October and a minimum in April.

2.2. Object of Study

The flora of Lake Baikal shores is distinguished by a prevalence of endemic species, which have evolved in response to unique environmental conditions, thereby facilitating the conservation of paleoendemics and the emergence of neoendemics. However, species exhibiting a combination of unique and specific natural characteristics in their habitats, in conjunction with substantial natural and anthropogenic pressures, are particularly vulnerable. Changes in water regime and recreational load can lead to the disturbance of the natural habitat of rare plant species, potentially leading to their injury and gradual destruction. The species growing on the littoral zone, i.e., the sandy surf strips and gravels along the eastern shore of Lake Baikal, are the first to experience the negative impact of the water-level regime: *Deschampsia turczaninowii* Litv., *Craniospermum subvillosum* Lehm., *Corispermum ulopterum* Fenzl., and *Astragalus sericeocanus* Gontsch (Figure 2). According to the Red Data Book of the Republic of Buryatia, all of these species are classified as rare, with no current risk of extinction. However, their population sizes are limited, and their distribution is so restricted that they may face extinction under the threat of unfavorable changes in habitat, whether natural or anthropogenic in origin. These species correspond to category 3 of the Red Data Book of the Russian Federation and Near Threatened (NT) categories of the IUCN Red List [30]. Exogenous geomorphological processes along the lake's shoreline, alterations in water level, contamination, and the accumulation of industrial and domestic waste, along with substantial recreational impact, collectively pose a threat to the viability of these rare populations.



(**a**) (**b**) (**c**) (**d**)

Figure 2. Rare and endemic plant species: (**a**) *C. subvillosum*; (**b**) *C. ulopterum*; (**c**) *D. turczaninowii*; (**d**) *A. sericeocanus*. Photo by BINM SB RAS, Zharnikova M.A. during the vegetation period.

Deschampsia turczaninowii—herbaceous dense turf polycarpic of the Poaceae family, endemic to the shore of Lake Baikal. It grows on sandy–pebbly, stony substrates near the water's edge, within the splash zone. It is sporadically distributed and does not form closed-stand communities [30].

Craniospermum subvillosum—herbaceous, short-rooted, rosette-forming perennial plant of the Boraginaceae family. It is an obligate psammophyte; a rare, endemic species; a Paleogene relict of a psammophytic desert–steppe landscape and cenotic group; and a xerophytic ancient Mediterranean flora. It flowers in June and fruits in early July. Its reproduction is by seed. The species grows in patches, small populations, or groups of individuals in a narrow band on coastal sandy surf berms and beaches and rarely on weakly sodded banks and stony slopes [30].

Corispermum ulopterum—herbaceous annual plant of the Amaranthaceae family, endemic to the shores of Lake Baikal. It grows on the sandy or sandy–rocky shores of Lake Baikal, mainly as a part of *Leymus secalinus* communities developing along coastal banks [30].

Astragalus sericeocanus—herbaceous long-rooted polycarpic plant of the Fabaceae family, endemic to the shores of Lake Baikal. It is a tall plant with ascending 30–50 cm long shoots, whitish–grayish from dense semi-branching white mossy pubescence. Blooms in June to early August and fruits in August. It reproduces by seeds. The geographical distribution of this species is limited to two localities: the southeastern coast of Lake Baikal (Peski area, between the Turka River and the village of Gremyachinsk) and Yarki Island at the mouth of the Upper Angara River [30]. It grows in small populations, often single specimens, on coastal shifting sands. It grows as part of mixed herb–astragalus–oxytropis lanata psammophyte communities devoid of a closed stand vegetation cover.

2.3. Estimation of Rare Plant Abundance

The study of populations was carried out according to the methods recommended for the study of rare species [31–33]. Geobotanical descriptions of plant communities were carried out, and the area, number, density, age, and spatial structure of the populations of rare species were determined. For small populations of *A. sericeocanus*, *C. ulopterum*, and *D. turczaninowii*, a continuous (direct) count of each species was conducted within the area they inhabited. *C. subvillosum*, which has a stripe-like pattern of distribution along the shore, was counted by determining the density of the species in 1 m^2 survey plots. In small, sparse populations, a complete enumeration of all individuals was carried out. The age structure was determined using standard population-based methods for detecting the ontogenetic state of individuals [34]. To assess the nature of the spatial distribution of species, field mapping was performed. The coordinates of habitat boundaries or individual plant specimens were recorded using a GPS receiver.

2.4. Inundation Modelling

The most important step in inundation modeling is the selection of a digital elevation model (DEM). The accuracy of global DEMs, including those derived from the Shuttle Radar Topographic Mission (SRTM), the Advanced Land Observing Satellite (ALOS), and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), among others, typically range from a few meters in height to tens of meters in plane. This level of accuracy is insufficient for determining inundation zones when the level of Lake Baikal changes from 457.0 to 457.85 m. The scarcity of large-scale maps was addressed through the implementation of SfM (structure-from-motion) technology to obtain DEMs [35,36]. For this purpose, digital aerial photography of key areas with rare plant species was carried out according to [37]. Digital aerial photography was carried out by using a DJI Mavic

Pro unmanned aerial vehicle (UAV) from an altitude of 150 m. The image pixel size on the terrain at the selected flight altitude does not exceed 9 cm, which corresponds to the scale of the topographic plane M 1:1000. At least 70% of the endlap and sidelap of images were ensured. Georeferencing was performed using a network of ground control points (GCP), with black and white squares clearly visible on the images serving as the GCPs. GCP georeferencing was performed using two dual-frequency GNSS (global navigation satellite system) receivers operating in Real Time Kinematic mode with georeferencing to points of the National Geodetic Network. The GCP coordinates and elevations were determined with the mean square error of measurement 2.5 mm $\pm$ 0.3 mm/km in plane and 5 mm $\pm$ 0.5 mm/km in elevation.

The processing of aerial images in Agisoft Metashape Professional 2.0 [38] software resulted in digital elevation models. The modeling of inundation zones as a result of Lake Baikal water-level fluctuations was carried out. These zones were determined in the ranges 455.54–456.00 and 457.00–457.85 m with a ten-centimeter step. The boundaries of the intersection of the water surface with the terrain relief were determined at each level employing the "contour list" tool of the ArcGIS Desktop 10.8. Consequently, vector polygons were obtained.

2.5. Estimating the Damage Cost

The calculation of the damage cost to objects of the flora was carried out in accordance with the Order of the Ministry of Natural Resources of the Republic of Buryatia of 30 November 2020, No. 480-PR "On Approval of Taxes for Calculation of the Amount of Damage Caused to Objects of the Flora Listed in the Red Data Book of the Republic of Buryatia and their Habitat as a Result of Violation of Legislation in the Field of Environmental Protection and Nature Management" [39].

According to the approved tax rates, the damage for one specimen of a shoot or rosette of a herbaceous angiosperm (flowering plant), fern-like plant, or lycopsid plant, regardless of its size, was estimated at 300 rubles. At the same time, for activities such as the destruction, extraction, and collection of objects of flora, as well as for the destruction of their growing places (i.e., habitats) within the Central Ecological Zone of the Baikal natural territory, the amount of damage was calculated at doubled tax rates.

3. Results and Discussion

The issue of regulating the level of Lake Baikal has been discussed since the construction of the Irkutsk hydropower plant (HPP) in the late 50 s. After its completion, the level of Lake Baikal has become dependent on the discharge through the HPP dam, in addition to surface and underground inflow.

The amplitude of annual water-level fluctuations increased from 82 cm in the natural state to 94 cm following the regulation of the reservoir [40]. In subsequent years, the water level of Lake Baikal repeatedly exceeded the standard storage level of 457.00 m within the Pacific system (the optimal level of a reservoir that can be maintained by a dam over an extended period). Again, this led to negative consequences on the eastern coast [27].

The causes of this water-level surcharge were multifaceted, including natural water inflow fluctuations and the strategic accumulation of water resources to ensure safety at new construction sites along the lower pool in Irkutsk [24]. The ecosystem of the Baikal coast is also impacted by low water levels. Therefore, the decrease in the water level to 455.30 m between 1980 and 1982 led to the drying and wind erosion of the shores, which contributed to the intensive development of abrasion processes. This was particularly evident with the subsequent rise in the water level to the normal storage level and above, especially on the shores formed from loose sediments (most of the southeastern and eastern shores of the lake and some parts of its western coast) [27].

In order to prevent similar situations, on 26 March 2001, the Government of the Russian Federation issued Resolution No. 234 “On Limit Values of Lake Baikal Water Level in the Course of Economic and Other Activities”, which established minimum and maximum levels at 456.00 and 457.00 m, respectively. From 2001 to 2014, the level of Lake Baikal remained within the established range. However, from 2015 to 2018, the level of the lake dropped below 456 m four times. This was due to incorrect inflow prediction in the previous year, excessive water mass drawdown, and a subsequent low water period in the lake basin [23] (Figure 3).

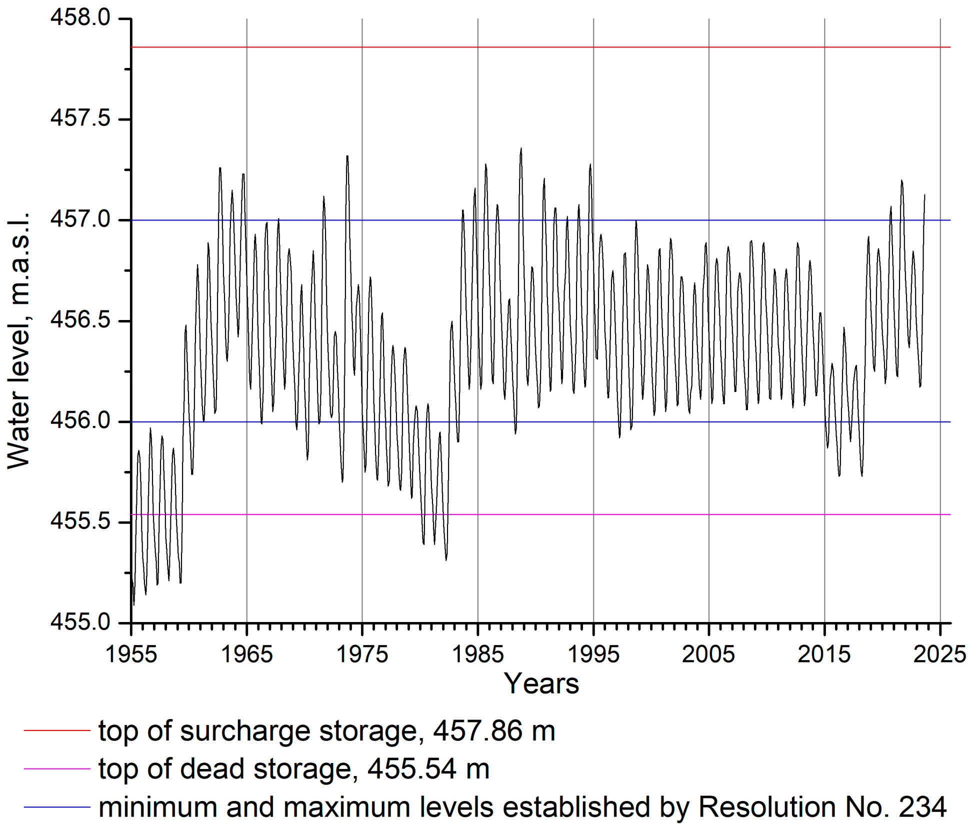


Figure 3. Plot of the water-level changes of Lake Baikal. Compiled by the authors based on data on the long-term monitoring of Lake Baikal water levels conducted by Rosvodresurs (https://voda.gov.ru, accessed on 16 October 2024).

Following the transition from a low-water period to a high-water period, the water level exhibited an upward trend, surpassing 457.00 m in 2020, 2021, and 2023 [41]. This was facilitated by the impossibility of discharging large amounts of water downstream (more than 4000 m^3/s) due to the threat of the inundation of a part of Irkutsk. Each time, the Government of the Russian Federation was forced to introduce special Resolutions that allowed the regulation of the water level of Lake Baikal in the range of 455.54–457.85 m. The recent water-level elevations have expectedly led to the inundation of coastal areas, the intensification of abrasion, and the disruption of infrastructure in the upper pool (Lake Baikal). Therefore, there is a need for scientific substantiation of the optimal use of Baikal water resources in order to minimize damage to the environment and technosphere in the water-level fluctuation zone of the lake. Water-level regulation should be based on a comprehensive assessment of potential damages to economic and natural objects at high and low water levels [42] (Figure 3).

Field studies of rare plant species vulnerable to fluctuations in water levels were conducted during the growing season of 2022 on the southern and eastern coast of Lake Baikal. The selection of areas with the location of rare species was conducted according to the Red Data Book of the Republic of Buryatia [30]. In the course of fieldwork, rare plant species were recorded at eight sites: the vicinity of Babushkin town; the sandy spit of Posolsky sor bay; the Lemasovo area; in the vicinity of the villages of Gremyachinsk, Goryachinsk, Turka, and Ust-Barguzin; and the coast of Barguzin Bay (Chivyrkuisky Isthmus) (Figure 4). A total of three populations of *D. turczaninowii*, two populations of *C. ulopterum*, one population of *A. sericeocanus*, and seven populations of *C. subvillosum* were identified. The number of plants of each population was counted, and the number of individuals subjected to inundation at different lake water levels was identified within vector polygons (Table 1).

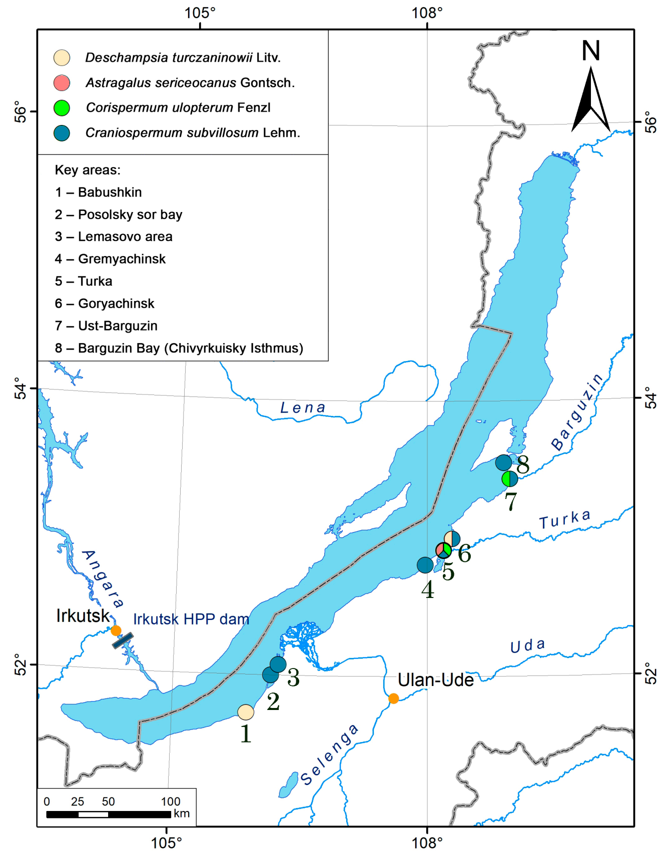


Figure 4. Key areas with rare plant species along the southeastern shore of Lake Baikal. Circles denote the presence of species in the location. Yellow—*D. turczaninowii* (2 locations); pink—*A. sericeocanus* (1 location); green—*C. ulopterum* (2 locations); blue—*C. subvillosum* (7 locations).

Table 1. Abundance of rare plant species subject to inundation at different water levels of Lake Baikal.

Lake Baikal Water Level	*Craniospermum subvillosum*	*Deschampsia turczaninowii*	*Corispermum ulopterum*	*Astragalus sericeocanus*	Total, Pcs.
457.00–457.10	0	373	0	0	373
57.10–457.20	83	373	0	0	456
457.20–457.30	107	373	0	0	480
457.30–457.40	137	373	0	0	510
457.40–457.50	213	373	0	0	586
457.50–457.60	482	373	0	0	855
457.60–457.70	803	373	21	0	1197
457.70–457.85	4737	373	30	24	5164
Total. pcs.	4737	373	30	24	5164

D. turczaninowii is the most vulnerable species to the risk of inundation due to its growth directly adjacent to bodies of water. All of its habitats are subject to inundation, with elevations ranging up to 457.10. Despite the fact that the *D. turczaninowii* has high resistance and is capable of renewal and vegetative reproduction through the rooting of storm-torn parts of turf and rosettes, any change in the level of Lake Baikal may lead to changes in habitat conditions and its potential extinction [43,44]. A total of 373 individuals were affected by the inundation at the three survey sites. In the vicinity of the Goryachinsk village, two relatively large populations were recorded on a stony substrate with a predominance of the generative stage and a density of 6–7 species per 1 m^2. During the 2022 fieldwork, the *D. turczaninowii* population in the vicinity of Babushkin was already partially inundated.

A. sericeocanus has been observed to inhabit the high terraces. However, within the proximity of Turka village, a population of 24 individuals was documented to fall within the flood zone, specifically at elevations exceeding 457.70 m. The estimated density within this area was recorded to be 0.06 per square meter. The high water level of Lake Baikal does not pose a direct threat to the main part of the population located at this site on sand dunes. The second habitat of the species in the northern part of Lake Baikal (Yarki Island), which is listed in the Red Book, was not surveyed during the 2022 field season. The island is subject to flooding, which is likely to exacerbate the total losses and damage costs.

The number of *C. subvillosum* specimens in the flood zone reaches 4737. In the vicinity of the villages of Goryachinsk, Gremyachinsk, and on the Chivyrkuisky Isthmus, the *C. subvillosum* grows in a continuous line, in contrast to the areas around Babushkin, Posolsk, and Lemasovo, where the distribution area is disjunctive. The surveyed populations are at different ontogenetic stages, with the majority being in the virginile stage. The predominance of seedlings and juvenile species was observed on the beaches near Turka, while in the populations of Gremyachinsk and at the northern end of the Chivyrkuisk Isthmus, there is a predominance of generative species. The population density ranged from 8 to 30 individuals per 1 m^2.

Therefore, the plants inhabiting shallow waters and subject to flooding at elevations above 457.10 m will be affected first. The main bulk of *C. subvillosum*, which is confined to the surf zone, is inundated at water levels from 457.70 m. High water levels combined with wind–wave activity will result in the destruction of its habitat. As an example, the monitoring site of the Transbaikal National Park established in 2015 for observations of *C. subvillosum* [45] has been subjected to erosion and is already half washed away by waves (Figure 5).

(**a**) (**b**)

Figure 5. *C. subvillosum* monitoring site in the Transbaikal National Park. (**a**) Photo by MBU DO "Podlemorye", 13 June 2019. (**b**) Photo by BINM SB RAS, Zharnikova M.A., 29 June 2023.

C. ulopterum is not abundant in the study habitats. It is observed in small populations on sandy hillocks in the vicinity of Goryachinsk and Ust-Barguzin. The population density is 0.03 species per 1 m^2. It is estimated that a minimum of 30 species will be exposed to the inundation zone at a height above 457.60 m. The remaining species are projected to experience detrimental impacts due to the destruction of their habitats by autumn storms.

The losses of rare species from inundation were defined under the condition of the static state of the water surface of the lake. However, exogenic relief-forming processes in the coastal zone resulting from an increase in water level lead to the disturbance of ecotopes. Thus, when the water level in the lake increases, shoreline erosion, a reduction in the length and areas of beaches, sand washout, and the erosion of spits in river mouths and bays, especially strongly manifested in the period of active wave activity or during storms, is inevitable. This aspect requires additional research.

The cost estimation of damage from the rise of Lake Baikal's water level was carried out in accordance with the standards approved in standardized methods. The total cost damage is calculated by multiplying the tax rate (600 rubles) by the number of individuals lost. Damage to rare plant species listed in the Red Data Book of the Republic of Buryatia at high water levels of Lake Baikal is presented in Table 2.

Table 2. Damage cost to rare plant species.

Lake Baikal Water Level	*Craniospermum subvillosum*	*Deschampsia turczaninowii*	*Corispermum ulopterum*	*Astragalus sericeocanus*	Total Damage Cost, Thousand Rubles *
457.00–457.10	0	223.80	0	0	223.80
457.10–457.20	49.80	223.80	0	0	273.60
457.20–457.30	64.20	223.80	0	0	288.00
457.30–457.40	82.20	223.80	0	0	306.00
457.40–457.50	127.80	223.80	0	0	351.60
457.50–457.60	289.20	223.80	0	0	513.00
457.60–457.70	481.80	223.80	12.60	0	718.20
457.70–457.85	2842.20	223.80	18.00	14.40	3098.40

* Increment total.

It should be noted that the established taxes for causing damage to red-listed plants are uniform and do not depend on the status of the object. In this regard, the implementation of a differential taxation system, tailored to the specific characteristics of each species and their status (i.e., relict, endemic, rare, vulnerable, endangered, etc.), is deemed essential. Since these categories reflect the quantitative and qualitative composition of the flora, it is advisable to implement a differential system of taxation. For example, the price for a single specimen of *C. subvillosum* (a relict, endemic, rare species with low abundance) is unreasonably low and should be revised upwards.

A review of publications concerning rare and endemic plant species of Lake Baikal's coast [46–50] identified the necessity for additional research in the following areas: (1) integrated ecological–biological and molecular–genetic studies of plants; (2) the influence of abiotic factors on their condition; (3) the impact of recreational activities; (4) the mechanisms of species adaptation to climatic changes and anthropogenic load; and (5) the development of measures (as well as an assessment of their effectiveness) for the protection, conservation, and restoration of populations.

The use of water resources of Lake Baikal must be executed in a manner that ensures that the regulation of water levels does not inflict harm (or, at the very least, causes the least possible damage) to the region's flora and fauna while concurrently minimizing damage to socio-economic objects. At the same time, the preservation of the unique ecological system of Lake Baikal—a UNESCO World Heritage Site—appears to be a priority goal. In the context of reducing damage and mitigating the impact of water-level fluctuations on vegetation and fauna, it is reasonable to use the concept of nature-based solutions aimed at preserving and improving biodiversity and contributing to the provision of a range of ecosystem services. There are three levels of ecosystem management: minimal intervention, low intervention, and high intervention or extensive ecosystem management [51].

Minimal intervention (or its absence) implies the preservation of the current state of ecosystems; for example, the creation of specially protected natural areas. One of the ways to preserve rare and endemic Baikal psammophytes is to reduce the anthropogenic load (primarily tourist activity) [52]. High water levels and prolonged standing water are detrimental to vegetation and should be avoided [53]. Thus, limiting water-level fluctuations above 457.00 m is a priority recommendation to prevent damage to the endemic flora. It is acknowledged that during periods of extreme high-water years, it is not feasible to adhere to this restriction [54]. Therefore, a temporary rise in the water level by the minimum possible layer should be permitted.

Minor intervention implies the sustainable restoration of disturbed ecosystems through a variety of approaches. When rare plant species are threatened with extinction, measures for their reintroduction must be developed and implemented. Such measures may include the collection and creation of a seed bank, the conducting of laboratory and field reproduction trials, the sowing of seeds in disturbed habitats, and the organization of monitoring observations.

Extensive intervention requires significant financial expenses and involves the construction of protective structures or even the creation of new ecosystems. In our opinion, for Lake Baikal, one approach to protect highly productive areas from inundation (Selenga and Upper Angara River deltas) could be the construction of a dam. However, given the current restrictions on the construction of hydraulic structures in the Central Ecological Zone of the Baikal Natural Territory, this type of intervention is not permissible and, in terms of costs, not feasible.

The current procedure for state environmental monitoring of the unique ecological system of Lake Baikal was established by Resolution of the Government of the Russian Federation No. 260 of 18 February 2023. The failure to include flora in the scope of monitoring is a substantial oversight that demands prompt rectification. Currently, the monitoring of rare and endemic plant species is limited to protected areas.

4. Conclusions

In recent years, due to low-water and high-water years, the problem of the water-level regime of Lake Baikal has become relevant again. In the present study, the potential loss of four rare plant species along the Lake Baikal shoreline due to high water levels was assessed, and cost estimates of the resulting damages were calculated. These findings, as part of the comprehensive evaluation of potential environmental and socio-economic impacts, will facilitate the determination of the most effective regulatory measures to minimize harm.

The measures for the preservation of rare plant species inhabiting the coast of Lake Baikal were proposed in this paper. Primarily, the measures include the limitation of water-level fluctuations up to 457.00 m, and in periods of extremely high water levels, the allowance of the minimum possible exceeding of the level. In future research, a comprehensive approach is essential. It should commence with ecological studies and culminate in the development and implementation of specific measures for the protection and conservation of rare plant species, accompanied by comprehensive monitoring. It is recommended that the state monitoring of plant life be included in the regulatory legal acts of different levels of the Russian Federation.

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