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RESEARCH ARTICLE

Functional ecology characteristics of key community-forming aquatic and semi-aquatic plant species in Teletskoye Lake (Republic of Altai, Russia)

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Abstract

This study explores five primary morpho-functional traits – photosynthetic canopy height, leaf mass, leaf area, specific leaf area, and seed mass – of 17 community-forming species of aquatic and semi-aquatic plants in Teletskoye Lake: *Alopecurus aequalis*, *Caltha palustris*, *Carex acuta*, *C. vesicaria*, *Eleocharis palustris*, *Equisetum fluviatile*, *Myriophyllum sibiricum*, *Petasites radiatus*, *Ranunculus reptans*, *Ranunculus trichophyllus*, *Potamogeton alpinus*, *Potamogeton × cognatus*, *P. gramineus*, *P. maackianus*, *P. perfoliatus*, *P. praelongus*, *Subularia aquatica*. The greatest leaf mass and area were observed in the hygrohelophyte *Caltha palustris* and the helophyte *Petasites radiatus*, whereas the smallest were noted in the miniature amphibious plants – *Subularia aquatica* and *Ranunculus reptans*. The highest specific leaf area (SLA) values (leaf area per unit mass) were found in true aquatic plants – hydrophytes. The macrophytes from the Potamogetonaceae family, which are characterized by endozoochoric dispersal, showed the highest seed mass indices, while the primarily hydrochoric annuals such as *Alopecurus aequalis* and *Subularia aquatica* displayed the lowest. Statistically significant differences were identified in SLA between floating and submerged leaves in the Potamogetonaceae family, notably between *Potamogeton alpinus* and *Potamogeton gramineus*, with submerged leaves showing significantly higher SLA values than floating leaves.

Keywords
Adaptations, fruit (seed) mass, functional traits, leaf area, leaf mass, macrophytes, photosynthetic canopy height, specific leaf area, vascular plants

Introduction

Functional ecology bridges several disparate disciplines, serving as a unifying principle between evolutionary ecology, evolutionary biology, genetics, genomics, and traditional ecological research. Plant functional ecology principles and approaches are applied to interpret the primary adaptations of plants to their environment, including climate (Diaz et al. 2013; Lefcheck et al. 2014; Gaüzère et al. 2020). Since the functional traits of plants underpin our understanding of how aquatic ecosystems function, community productivity, and intra- and inter-species interactions, as well as plant adaptations to changing environmental conditions, they serve as a powerful tool for assessing global changes in freshwater ecosystems (Iversen et al. 2022). According to current understanding, functional plant traits in freshwater ecosystems are less studied compared to terrestrial ones (Iversen et al. 2022). Global research on plant functional ecology, including aquatic species, is actively conducted through the MAP project (Macroecology of Aquatic Plant-functions, https://www.maptraits.com), which gathers data on functional traits of over 3500 non-woody aquatic plant species.

Lake Teletskoye, the largest water body in the Republic of Altai, and the second-largest freshwater reserve in the country, has been part of the UNESCO World Heritage List since 1998. Located in the northeastern part of the Altai Mountains at an elevation of 434 meters above sea level, its waters primarily host communities of *Potamogeton perfoliatus* and *P. praelongus*, while the shallow semi-aquatic areas are dominated by *Carex acuta* and *Equisetum fluviatile* (Zarubina and Sokolova, 2007) – perennials with effective vegetative reproduction.

The aim of this study was to explore the variation in morpho-functional characteristics of aquatic and riparian plants across a depth gradient, using the dominant plant species of Lake Teletskoye as examples. Objectives included: 1) investigating the patterns of change in functional traits of leaves and seeds, as well as the height of the photosynthetic layer of macrophytes along the depth gradient in oligotrophic water body, exemplified by Lake Teletskoye; and 2) assessing the functional differences between floating and submerged leaves of heterophyllous species.

Materials and methods

Lake Teletskoye, located in the northeastern part of the Altai Mountains at an elevation of 434 meters above sea level, is of tectonic origin. It covers an area of 223 km², with a length of 77.8 km and a maximum width of 5.2 km, the average width being 2.9 km. Its maximum depth reaches 325 meters, with an average of 124 meters, and the annual average water temperature is around +4°C. Administratively it lies within the Turochaksky and Ulagansky Districts of the Republic of Altai. The lake is surrounded by mountains ranging from 1200 to 2000 m a.s.l. in height, and its vegetation is characterized as mountain taiga. Near the lake, dark coniferous taiga predominates. Part of the lake's water area belongs to the Altai Biosphere Reserve. Its shores are mainly rocky or composed of large boulders and rubble, having either a narrow shoreline strip or cliffs that descend below the waterline (Selegey and Selegey 1978). Conditions suitable for the development of aquatic and riparian vegetation are primarily found at the alluvial fans at river mouths (rivers Chulyshman, Kyga, Kamga, Samysh, etc.), as well as at rare sites with a defined littoral zone (settlements of Artybash, Yogach).

The material for this article was collected during comprehensive expeditionary works by the Institute for Water and Environmental Problems SB RAS, aimed at studying the biota of Teletskoye Lake from 2021 to 2023. Several shallow waters of Teletskoye Lake located in the Turochaksky and Ulagansky Districts were surveyed using an inflatable boat, hydrobotanical rakes and a Garmin eTrex Vista portable navigator (with GPS receiver). Plants were identified with an Altami PS0745-T stereoscopic microscope. Vascular plant identification was conducted using keys and descriptions by L.I. Lisitsyna and V.G. Papchenkov (2000), V.G. Papchenkov (2007) and A.A. Bobrov (Nikolin 2020).

During the 2021–2023 expeditions, material was collected on the functional-ecological characteristics of 17 coenosis-forming species of aquatic and semi-aquatic plants located at different positions in the depth profile (Table 1, Figure 1).

Table 1. Sampling locations, dates and depth for macrophyte samples from lake Teletskoye

№	Species	Latitude, N	Longitude, E	Sampling location	Sampling date	Sampling depth, sm
1	*Alopecurus aequalis* Sobol.	51°43.99'	87°33.20'	Turochaksky District, Koldor River bay	21.07.2022	30
2	*Caltha palustris* L.	51°43.99'	87°33.20'	Turochaksky District, Koldor River bay	21.07.2022	20
3	*Carex acuta* L.	51°47.96'	87°43.16'	Turochaksky District, Kamga River bay	09.08.2021	0
4	*C. vesicaria* L.	51°43.99'	87°33.20'	Turochaksky District, Koldor River bay	21.07.2022	0
5	*Eleocharis palustris* L.	51°47.96'	87°43.16'	Turochaksky District, Kamga River bay	28.07.2022	20

№	Species	Latitude, N	Longitude, E	Sampling location	Sampling date	Sampling depth, sm
6	*Equisetum fluviatile* L.	51°43.99'	87°33.20'	Turochaksky District, Koldor River bay	11.08.2021	20
7	*Myriophyllum sibiricum* Kom.	51°21.86'	87°44.84'	Ulagansky District, waterbody behind Kyrsai Cape, Chulyshman River mouth area	12.08.2021	60
8	*Petasites radiatus* (J. F. Gmel.) J. Toman	51°46.62'	87°22.06'	Turochaksky District, Oyer River bay	19.07.2022	20
9	*Ranunculus reptans* L.	51°47.56'	87°15.91'	Turochaksky District, Artybash village	21.08.2023	0
10	*Ranunculus trichophyllus* Chaix	51°47.96'	87°43.16'	Turochaksky District, Kamga River bay	08.08.2021	40
11	*Potamogeton alpinus* Balb	51°47.96'	87°43.16'	Turochaksky District, Kamga River bay	08.08.2021	80
12	*P. × cognatus* Asch. et Graebn.	51°47.28'	87°16.38'	Turochaksky District, Yogach village	07.08.2021	100
13	*P. gramineus* L.	51°47.96'	87°43.16'	Turochaksky District, Kamga River bay	08.08.2021	40
14	*P. maackianus* A. Benn	51°47.56'	87°15.91'	Turochaksky District, Artybash village	24.08.2023	150
15	*P. perfoliatus* L.	51°47.28'	87°16.38'	Turochaksky District, Yogach village	07.08.2021	150
16	*P. praelongus* Wulf	51°47.56'	87°15.91'	Turochaksky District, Artybash village	07.08.2021	200
17	*Subularia aquatica* L.	51°21.86'	87°44.84'	Ulagansky District, waterbody behind Kyrsai Cape, Chulyshman River mouth area	12.08.2021	10

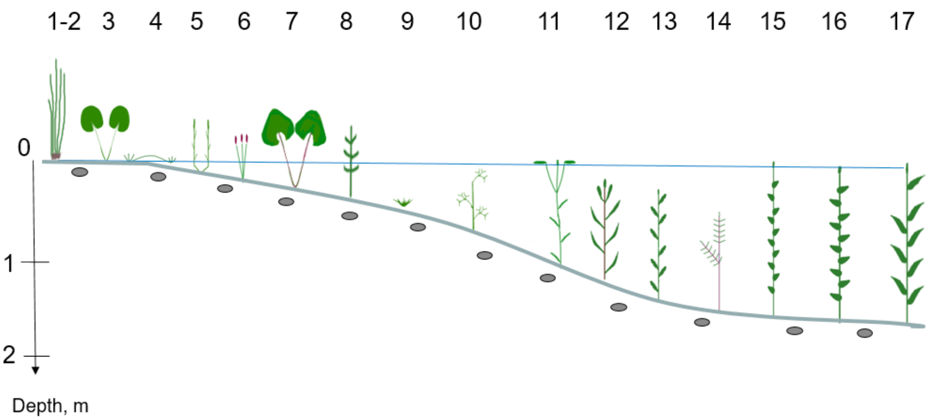


Figure 1. Generalized schematic profile of the littoral zone vegetation of Lake Teletskoye (showing the main coenosis-forming species). **Key: Hygrohelophytes: 1–2** – *Carex* spp., **3** – *Caltha palustris*, **4** – *Ranunculus reptans*, **5** – *Alopecurus aequalis*. **Helophytes: 6** – *Eleocharis palustris*, **7** – *Petasites radiatus*, **8** – *Equisetum fluviatile*. **Hydrophytes: 9** – *Subularia aquatica*, **10** – *Ranunculus trichophyllus*, **11** – *Potamogeton gramineus*, **12** – *P. alpinus*, **13** – *P. maackianus*, **14** – *Myriophyllum sibiricum*, **15** – *Potamogeton perfoliatus*, **16** – *P.* × *cognatus*, **17** – *P. praelongus*.

In this study, we investigated five primary morpho-functional traits of plants including leaf mass, leaf area, specific leaf area (leaf area/mass), seed mass, and photosynthetic canopy height. Measurements of these key functional traits (FT) were conducted on healthy, undamaged plants as part of the MAP project. For each species, the height of the photosynthetic layer was measured–defined as the shortest distance from the top, well-developed leaves to the substrate (soil, lake bed, rocky surface). At least ten plants were sampled to measure the height as one of the key functional traits, with additional measurements taken in some cases. For leaf metrics, three leaves were sampled from different parts of each of the ten plants, later considered as one statistical sampling for analysis. To determine leaf area, leaves from each species were straightened, photographed, and their areas were quantified using the ImageJ software. In the case of *Equisetum fluviatile*, the leaves are reduced to scales, and the photosynthesizing units measured were the branches.

To determine the mass of leaves and fruits, both were dried to a constant weight in an oven at temperatures between 60–80°C prior to weighing. For leaves and fruits weighing more than 1 gram with significant size, weighing was performed using an MBP-150 scale, while in all other cases, measurements were taken on an Ohaus Explorer Pro (EP) analytical balance with a precision of 0.1 mg, and from 2023, on a Gosmetr VL-120M semi-microbalance with a precision of 0.00001/0.0001. The seed weights of *Alopecurus aequalis* and *Subularia aquatica* were calculated by weighing 10(30) seeds and dividing the result by 10(30). Specific leaf area (SLA) were calculated (area/mass ratio). Based on the collected data, diagrams were created using STATISTICA 10 software. Ecological groups related to moisture (hydrophytes, helophytes, hygrohelophytes) were classified according to the system proposed by V.G. Papchenkov et al. (2006). By amphibians we mean species that grow in the shoreline and easily survive flooding and drying conditions.

Results

Height of the photosynthetic layer

The highest values of the photosynthetic canopy height were observed in *Potamogeton praelongus*, followed by significant heights in *Carex acuta* and *C. vesicaria*. *Subularia aquatica* was the shortest plant in our study sample, with similar heights observed in *Ranunculus reptans*, which, like *Subularia aquatica*, is an amphibious species (Robionek et al. 2020) (Fig. 2, Suppl. material 1: Table 1).

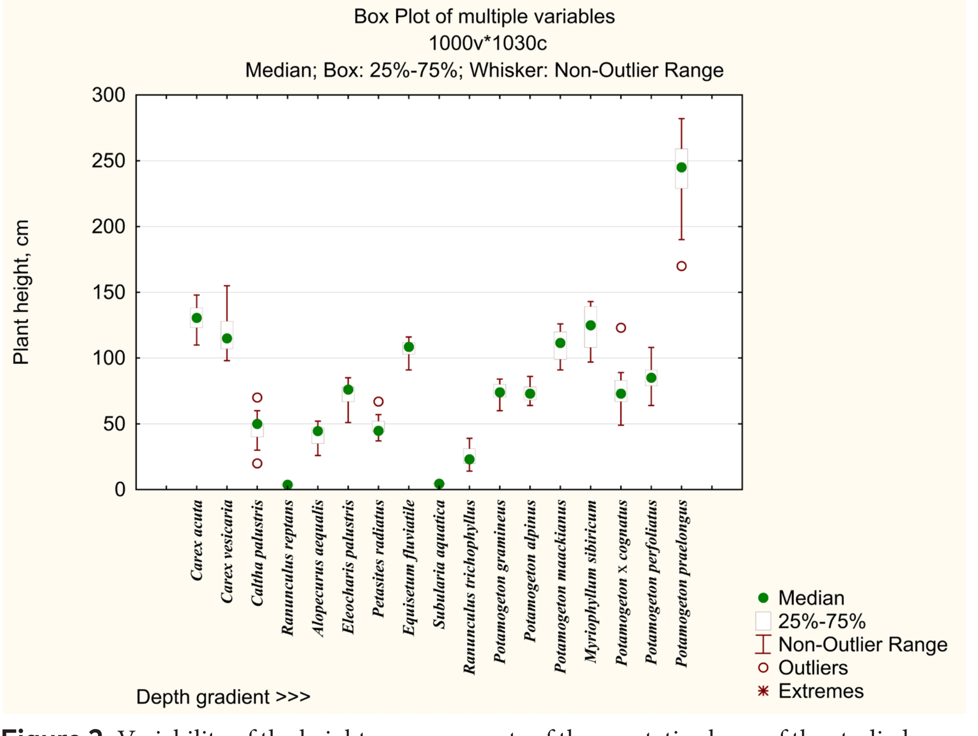


Figure 2. Variability of the height measurements of the vegetative layer of the studied macrophytes along the depth gradient, cm.

Functional leaf traits

The results of the **leaf area** measurements are presented in Suppl. material 1: Table 2. The **mass of the leaves** of the aquatic and riparian plants we studied are provided in Suppl. material 1: Table 3. Due to the significant variation in the mass and area of the macrophytes' leaves in Lake Teletskoye, we have presented the height values on a logarithmic scale.

The diagrams showing the variability of leaf mass along the depth gradient (Fig. 3) and area (Fig. 4) demonstrate that different variations of mass and area of the photosynthetic unit (leaf) occur along the depth gradient.

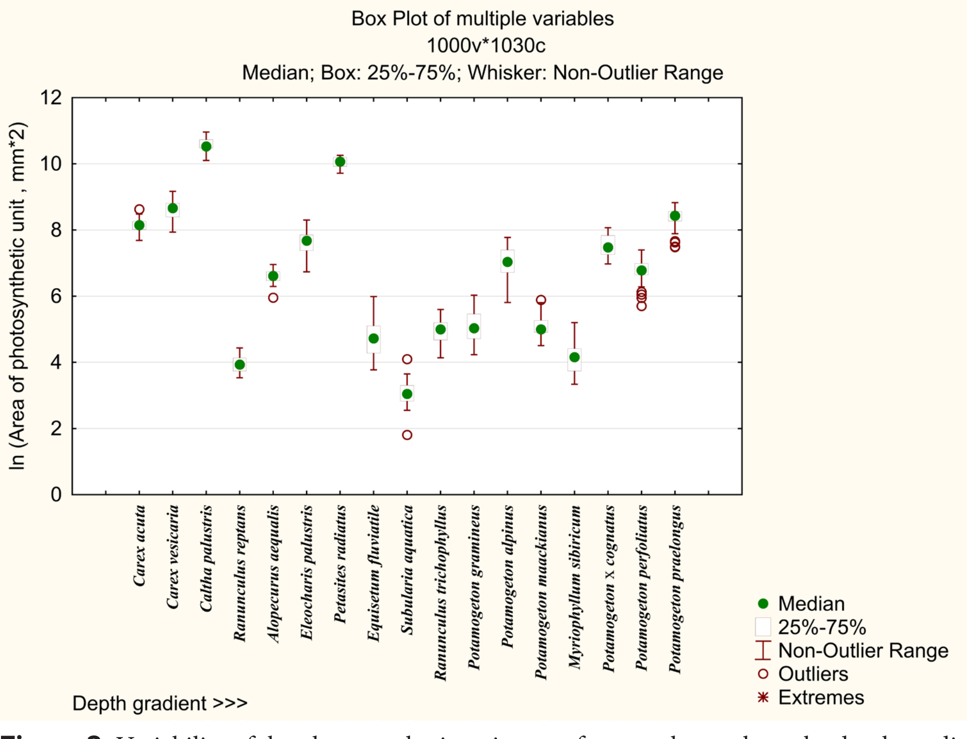


Figure 3. Variability of the photosynthetic unit area of macrophytes along the depth gradient.

The highest values for leaf area and mass are characteristic of the tall hygrohelophyte *Caltha palustris*, as well as the helophyte *Petasites radiatus*, both of which are classified as competitive strategists in Ramensky-Grime's life strategy scheme. For *Petasites radiatus*, the average weight of the leaf blade was 3000 mg (absolutely dry weight), and for *Caltha palustris*, it was 2738 mg (absolute dry weight).

Relatively high values for these metrics were observed in tall hygrohelophytes such as the sedges *Carex acuta* and *C. vesicaria*, as well as in *Potamogeton praelongus*, for which these traits appear to be an adaptation to growing at significant depths and also characterize this species as a competitor. The smallest values for leaf mass and area were observed in *Subularia aquatica* and *Ranunculus reptans*.

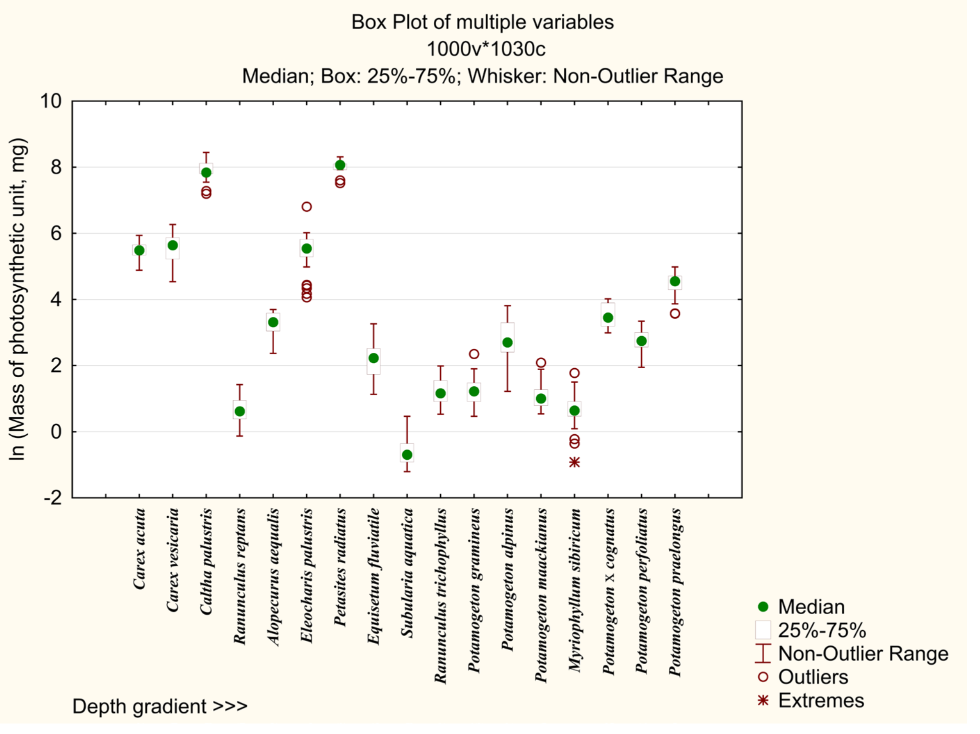


Figure 4. Variability of leaf mass of macrophytes along the depth gradient.

As shown in Suppl. material 1: Table 4 and the diagram (Fig. 5), the **specific leaf area** (SLA – leaf area divided by mass) values allow us to conclude that submerged leaves of *Potamogeton alpinus* have the highest measurements for this criterion, at 69.4 mm^2/mg, followed by *P. perfoliatus* at 58.3 mm^2/mg.

Additionally, the lowest specific leaf area (SLA) values were observed in hygrohelophytes – water-edge plants such as *Carex acuta*, *C. vesicaria*, *Caltha palustris*, and in helophytes like *Eleocharis palustris*, *Equisetum fluviatile*, and *Petasites radiatus*. Thus, the smallest SLA values were demonstrated by riparian plants. Generally, a lower SLA, or greater leaf thickness, is considered an adaptive trait in plants, facilitating more intense maximum photosynthesis (Utkin et al. 2008). Relatively high specific leaf area values were observed in true aquatic plants – hydrophytes.

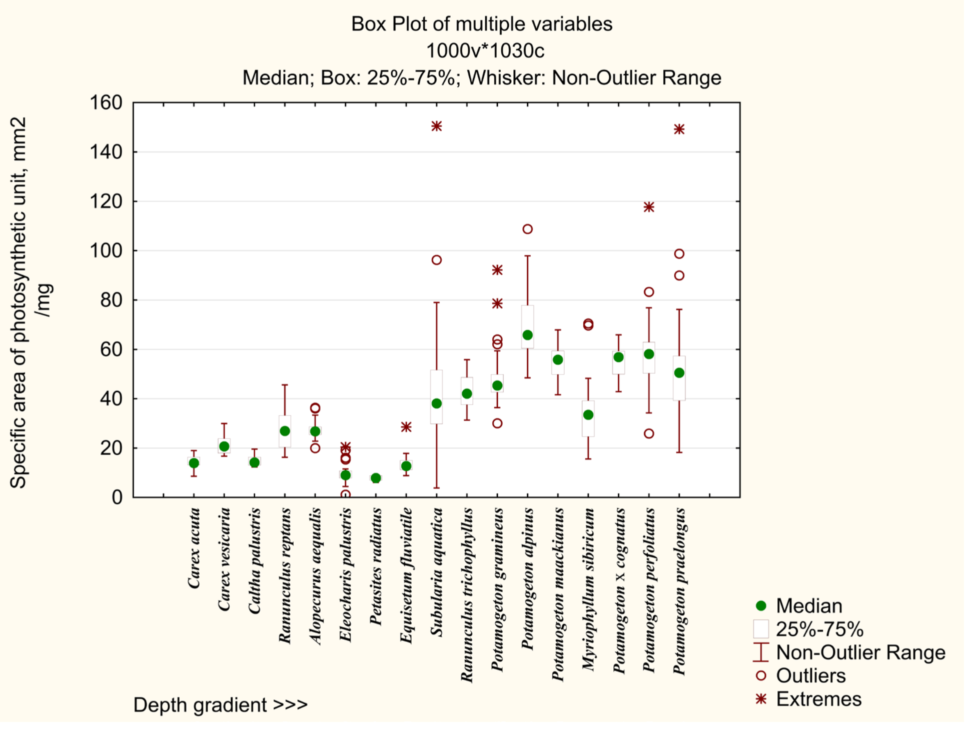


Figure 5. Specific Leaf Area (SLA) of macrophytes from Lake Teletskoye along the depth gradient, in mm^2/mg.

Seed mass (diaspores)

Undoubtedly, *Equisetum fluviatile* possesses the smallest mass of generative diaspores; however, we did not determine the spore mass of this plant as part of this study. In the available literature, descriptions of *E. fluviatile* typically focus on the general morphology and structural characteristics of the spores, yet precise metric or quantitative data on spore mass are not provided (Marmottant et al. 2013; Bower 1894). The hybrid *Potamogeton cognatus* does not produce seeds, which is generally characteristic of pondweed hybrids. The smallest seed mass among the macrophyte species we studied is typical for annual plants such as *Alopecurus aequalis*, *Subularia aquatica*, while the largest are found in members of the pondweed family (*Potamogeton alpinus*, *P. gramineus*, *P. perfoliatus*, *P. praelongus*) (see Fig. 6, Suppl. material 1: Table 5). *Ranunculus trichophyllus* also has low seed weight values. It is a short-lived form (Movergoz and Bobrov, 2016). The species cannot be considered an annual, since in the spring, renewal occurs from fragments of the previous year, but these fragments do not survive until the next season, dying off by the beginning of the summer period and for this reason, it cannot be considered a perennial (unpublished message of E.A. Movergoz).

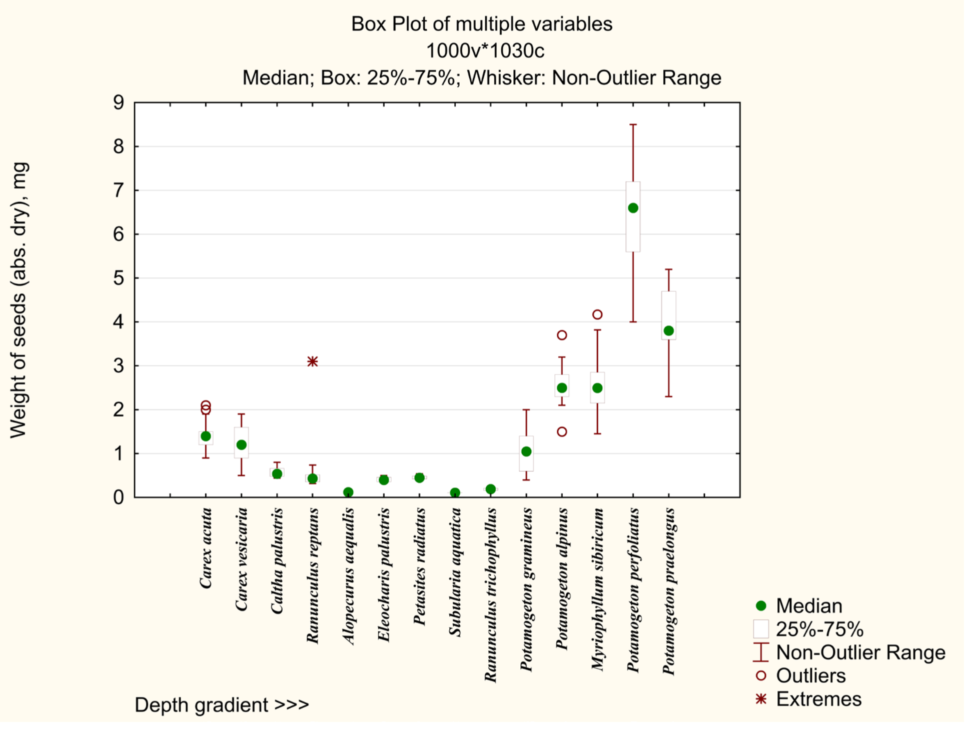
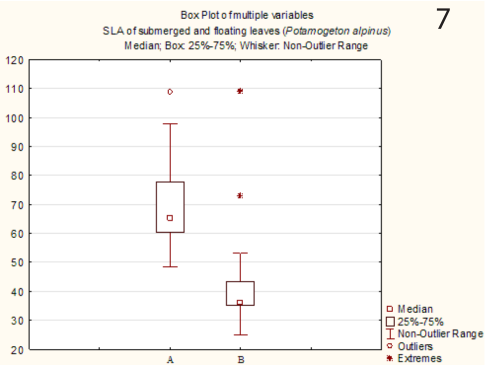


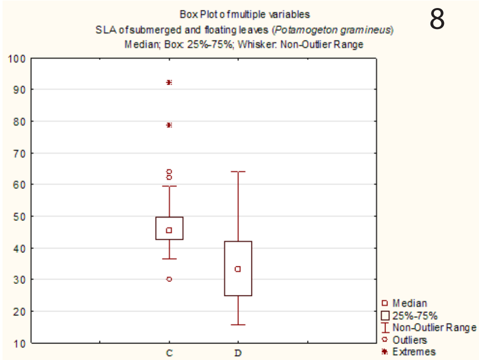
Figure 6. Variability of seed mass of macrophytes along the depth gradient, mg.

Comparison of leaf metrics in heterophyllous pondweeds

During the comparative analysis of the leaves of *Potamogeton alpinus* and *P. gramineus*, both submerged and floating, we found that the submerged leaves of both species of pondweeds have larger areas (see Suppl. material 1: Tables 6 and 7) compared to floating leaves.

Furthermore, we examined how floating and submerged leaves of heterophyllous plants differ in an important characteristic such as specific leaf area (SLA). Graphical representations of the nature of the samples are presented in Figures 7–8. Using the Student's t-test ($P \leq 0.05$) for independent samples in STATISTICA, statistically significant differences were identified between the SLA values of floating and submerged leaves for both representatives of the pondweed family – for both *Potamogeton alpinus* and *Potamogeton gramineus*. Thus, functional differences between floating and submerged leaves of heterophyllous aquatic plants have been identified. The specific leaf area values of submerged leaves were higher than those of floating leaves.





Figures 7–8. 7. Specific Leaf Area (SLA) values of *Potamogeton alpinus*. A – SLA of submerged leaves, B – SLA of floating leaves. **8.** Specific Leaf Area (SLA) values of *Potamogeton gramineus*. C – SLA of submerged leaves, D – SLA of floating leaves.

Discussion

Overall, across all functional traits, the presence of rather large deviations from the median values is notable. These deviations indicate that functional characteristics within a single species can vary significantly. Most likely, this is associated with different functional leaf traits of various ages, as they were taken from different parts of the plant, and also with slightly differing growth conditions of the collected plants (depth, substrate type, etc.).

Potamogeton praelongus exhibited the highest measurements of photosynthetic layer height, followed by the species *Carex acuta* and *C. vesicaria*. The shortest species in the sample were the amphibious species – *Subularia aquatica* and *Ranunculus reptans*. Being amphibious, these species easily tolerate conditions of drying and flooding in the littoral zone.

Despite the relatively low absolute heights at Lake Teletskoye, typical helophytes such as reeds, bulrushes, and cattails were almost absent from the vegetation cover. Thus, the left part of the profile does not include tall species (reeds and bulrushes often reach heights of 2 meters and more), but it does include tiny plants that have gained an advantage due to the presence of available niches in the shallows of Lake Teletskoye.

Leaf area (LA) is the most common indicator of leaf size and is defined as the one-sided or projected area of an individual leaf, expressed in mm^2. Typically, the consequences of excessively high or low temperatures, drought, radiation exposure, and nutrient deficiency lead to relatively small leaves (i.e., a reduction in leaf area). When considering changes in leaf surface area among different species within specific climatic zones, these changes may be associated with so-called allometric factors (plant size, branch size, anatomy and morphology, leaf quantity, number of developing lateral buds) and the species' ecological strategy regarding changing environmental conditions, potential nutrient deficiency/excess, etc. (Pérez-Harguindeguy et al. 2016). In our study, large leaf area and mass effectively characterize the life strategies of species, as well as the adaptive features of aquatic plants to low light and oxygen levels. The highest values of leaf area and mass are characteristic of the tall hygrohelophyte *Caltha palustris*, as well as the helophyte *Petasites radiatus*, which, according to Ramensky-Grime's classification of life strategies, are classified as powerful competitors. Relatively high values of these indicators were observed in the tall hygrohelophytes – *Carex acuta*, *C. vesicaria*, as well as in hydrophyte *Potamogeton praelongus*, where, apparently, this adaptation to grow at significant depths characterizes this species as a competitor as well. According to our results, among the dominants of Lake Teletskoye, the smallest values of leaf mass and area were also observed in the most miniature amphibious plants – *Subularia aquatica* and *Ranunculus reptans*. It can be hypothesized that this serves as one of the adaptations of amphibious species *Subularia aquatica* and *Ranunculus reptans* to abrupt changes in water levels during the vegetation period.

Specific leaf area (SLA) – the ratio of leaf area to leaf mass – is used as a fundamental indicator for characterizing photosynthesis, respiration, transpiration, micronutrient content, and chlorophyll concentration instead of leaf mass indicators, as it is considered the most plastic morphological indicator of the leaf (Pérez-Harguindeguy et al. 2016). Among the dominants of vegetation of Lake Teletskoye, the lowest SLA values were observed in hygrophytes – plants at the water's edge: *Carex acuta*, *Carex vesicaria*, *Caltha palustris*, and in helophytes – plants at the water-air interface: *Eleocharis palustris*, *Equisetum fluviatile*, *Petasites radiatus*. Thus, the lowest SLA values were observed in shoreline plants. Although the SLA values of *Subularia aquatica* varied, the median is close to this indicator of true hydrophytes. *Ranunculus reptans* and *Alopecurus aequalis*, which are traditionally classified as hygrophytes, have SLA values closer to hydrophytes than some helophytes. It should be noted that typically, a lower SLA, or greater leaf thickness, is considered an adaptive trait of plants, promoting more intense maximum photosynthesis (Utkin et al. 2008). Relatively high values of specific leaf area were observed in true aquatic plants – hydrophytes, which are associated with a larger leaf area and more aerenchyma in the leaves. This also reflects the adaptive characteristics of aquatic plants to low light availability, oxygen, and carbon dioxide, which are often limiting factors in aquatic ecosystems (Pan et al. 2023), as the diffusion coefficients of gases such as carbon dioxide (CO_2) and oxygen (O_2) in surface waters are approximately 104 times lower than in the atmosphere. Due to these lower diffusion rates in internal waters, submerged freshwater plants require more than a 12-fold equilibrium concentration of CO_2 in the air to achieve saturated photosynthesis (Maberly and Madsen 1998). The quantity and quality of light change due to reflection, scattering, and absorption by the water surface after exponential decrease from the surface to deeper areas (Ragni and D'Alcalà 2004).

Seed mass refers to the dry weight of seeds, typically expressed in grams or milligrams. The nutrient reserves stored in seeds contribute to survival, providing nourishment to the embryo in the early stages of its development, which is particularly valuable in conditions of deep shade, drought, and other relatively unfavorable conditions. A larger nutrient reserve is usually characteristic of larger seeds. Smaller seeds are typically buried deeper in the soil, especially if their shape is close to spherical, which contributes to their longevity in seed banks. Interspecific differences in seed mass also have important taxonomic significance, as more closely related taxa are more likely to have similar seed masses. The smallest seed masses among the macrophyte species we studied are characteristic of annual plants like *Alopecurus aequalis*, *Subularia aquatica* and short-lived form *Ranunculus trichophyllus*. Their primary dispersal strategy involves producing a large number of small seeds with minimal nutrient reserves, which are primarily dispersed by water currents (i.e., hydrochory). These species are considered conditional explerents (ruderals) since they occupy the shallows. In contrast, in mesotrophic and eutrophic water bodies, the shallows are usually occupied by helophytes that are typically competitors. Typical helophytes such as reeds, cattails, and bulrushes are almost absent in the vegetation cover of Teletskoye Lake. Most explerent (ruderal) plants are annuals (less often biennials) that produce a large number of seeds. *Subularia aquatica* is also a patient (stress tolerator) strategist with a narrow ecological niche, preferring the shallows of cold, oligotrophic water bodies with significant water fluctuations. In contrast, members of the pondweed family follow a different seed dispersal strategy. Their seeds are large and contain a significant reserve of nutrients. The dispersal of such seeds primarily occurs through their consumption by various animal species (i.e., endozoochory), particularly ducks (ornithochory).

It has been shown above that for the heterophyllous pondweeds *Potamogeton alpinus* and *Potamogeton gramineus*, submerged leaves have greater absolute and relative (SLA) measurements compared to floating leaves. It can be assumed that underwater conditions are more "shaded" for the leaves and higher SLA promotes the maintenance of normal photosynthetic function under resource-limited conditions.

Our data are consistent with findings from comparisons of leaf traits between alpine aquatic and terrestrial herbaceous plants on the Tibetan Plateau, where submerged leaves demonstrated extremely high SLA, while grasses exhibited the lowest (Yang et al. 2021). Moreover, another study on boreal aquatic plants highlighted differences between aerial and submerged leaves not only in mesophyll structure but also in chlorophyll and carotenoid content (Ronzhina et al. 2004). The adaptation of submerged leaves to low light conditions and slow CO_2 diffusion is also associated with an increased proportion of pigments in the chloroplasts of submerged leaves compared to aerial leaves (Ronzhina et al. 2004).This suggests significant differences among community-forming species of aquatic and riparian vegetation in Lake Teletskoye along the depth gradient, not only in terms of morpho-functional parameters but also in the density of photosynthetic elements in the mesophyll of leaves.

Conclusions

The greatest values for leaf mass and area were observed in the hygrohelophyte *Caltha palustris* and the helophyte *Petasites radiatus*, which are classified as strong competitors in Ramensky-Grime's life strategy scheme. The smallest values were recorded in the tiny amphibious plants *Subularia aquatica* and *Ranunculus reptans*, which likely reflects the adaptation of these species to significant water level fluctuations during the growing season.

The specific leaf area (area/mass) values were highest in true aquatic plants – hydrophytes. This is associated with the larger leaf area and greater amount of aerenchyma in the leaves, reflecting the adaptive features of aquatic plants to the scarcity of light, oxygen, and carbon dioxide.

The highest seed mass values among the macrophyte species we studied were found in members of the Potamogetonaceae family, which typically rely on endozoochory for seed dispersal. The smallest seed mass values were recorded in annual plants primarily dispersed by hydrochory, such as *Alopecurus aequalis*, *Subularia aquatica*, and and short-lived form *Ranunculus trichophyllus*.

Statistically significant differences were identified between the SLA values of floating and submerged leaves in members of the Potamogetonaceae family *Potamogeton alpinus* and *Potamogeton gramineus*. The specific leaf area of submerged leaves was significantly higher than that of floating leaves.

At Lake Teletskoye, in the absence of tall helophytes in the littoral zone, miniature patient (stress tolerator) plants and conditional explerents (ruderals) that produce a large number of small seeds have gained an advantage.

Functional ecology methods make it possible to assess the adaptive features of dominant vegetation in aquatic environments and appear promising for characterizing aquatic and riparian vegetation, which is typically composed of monodominant communities.

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Supplementary material 1

Table 1. Heights of the vegetative parts of the studied macrophytes (cm)
Table 2. Area of the photosynthetic unit of the studied macrophytes (mm^2)
Table 3. Mass of the photosynthetic unit of the studied macrophytes (absolute dry weight, mg)
Table 4. Specific leaf area of the studied macrophytes (mm^2/mg)
Table 5. Seed mass of the studied macrophytes (absolute dry weight, mg)
Table 6. Comparative characteristics for floating and submerged leaves of *Potamogeton alpinus* (Lake Teletskoye, Kamga River Bay)
Table 7. Comparative characteristics for floating and submerged leaves of *Potamogeton gramineus* (Kamga River Bay)

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