

Research Article

Effects of water depth on the growth of an invasive species, *Myriophyllum aquaticum*

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Abstract

The aquatic plant *Myriophyllum aquaticum*, native to South America, has been introduced to China as an aquarium ornamental plant species over the past 20 years and has now established itself as an invasive species in multiple regions of southern China. In the present study, we conducted a controlled pot experiment with *Myriophyllum aquaticum* planted at seven different water depths (0, 25, 50, 75, 100, 125, and 150 cm) to investigate its growth patterns and adaptive mechanisms in various aquatic environments. As expected, underwater light decreased exponentially with increasing water depth. Spectral analysis indicated significant attenuation across all wavelength bands, with the blue light band being reduced to a greater extent than the red light band, consequently leading to a gradual elevation in the red-to-blue ratio (Red/Blue) with depth, which has a significant effect on the survival rate of *M. aquaticum*. With an increase in water depth, the survival rate of *M. aquaticum* showed a decreasing trend; the plants did not survive at a depth of 150 cm. The effect of water depth on the growth and reproduction of *M. aquaticum* is evident. The growth indices, namely plant height, the number of stem nodes, internodes, the number of branches, the number of tillers, root length, wet weight, and the RGR were all shown to decrease with increasing water depth. Growth conditions gradually diminished with the increase in depth: the Chl-a content of the *M. aquaticum* leaves gradually decreased, and when the water depth was ≥ 50 cm, the chlorophyll synthesizing ability of the leaves gradually decreased. Increased water depth – and the corresponding stress of low light – resulted in an increase in the malondialdehyde content of the leaves. The results of this experiment demonstrate that *M. aquaticum* is more likely to become established in shallow-water areas (depth up to 25 cm).

Key words: Water depth, light, alien species, growth adaptation, survival rate



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Introduction

Submerged plants play an important role in maintaining the structure and function of aquatic ecosystems (Li et al. 2017) and are important components of food webs (Liu et al. 2020). As important primary producers, they not only provide food and habitat for microorganisms and aquatic animals in freshwater systems (Gu et al. 2016) but are also key to controlling eutrophication and cyanobacterial blooms (Zhou et al. 2017). Submerged plants also adsorb and immobilize suspended solids in water, thus decontaminating and clarifying surface waters (Saleh et al. 2020); for these reasons, submerged plants have been widely used in ecosystem reconstruction and ecological restoration.

Hydrological conditions are the main determinants of plant community structure and productivity in lake ecosystems (Ren et al. 2020). Water depth (WD) affects the growth and metabolism of submerged plants by integrating environmental conditions, such as light, underwater pressure, water temperature, oxygen, and nutrients (Yuan 2007). Photosynthetic efficiency tends to decrease dramatically under low-light conditions in deep water (Min et al. 2019). Therefore, studying the responses of submerged plants to WD can contribute to the understanding of hydrological regulation in ecosystem management (Liu et al. 2017). It has been shown that water level and flood duration have a large effect on wetland macrophyte communities, especially on submerged plants (Maltchik et al. 2007). Casanova and Brock reported the effect of WD on macrophyte establishment (Casanova and Brock 2000); however, in that study, the maximum WD was only 60 cm. Subsequently, Wersal and Madsen investigated the growth response of *Myriophyllum aquaticum* and its individual structures, especially biomass and plant height, in depths as much as 137 cm. However, the effect of changes in WD – and the resulting decrease in light – on *M. aquaticum* is not completely known (Wersal and Madsen 2011). Photosynthesis is one of the most important metabolic activities in the growth and reproduction of submerged plants (Li 2007). Light intensity decreases with increasing WD, and when the level of light falls below the photosynthetic compensation point, submerged plants die off (Wu et al. 2021). The morphological plasticity of submerged plants is an important adaptive mechanism in response to changes in the external environment, in particular the fluctuations in water levels (Fan et al. 2015). The results of previous studies have shown that, in *Potamogeton maackianus* and *Potamogeton malaianus*, more biomass is allocated to stems, resulting in greater plant height in deeper waters, and in *Vallisneria spiralis*, biomass allocation is more towards the leaves, resulting in enhanced light harvesting (Fu et al. 2012). Havens et al. (2004) found that short-term reductions in water level favored an explosive growth of submerged plants, thus increasing the abundance of submerged plants in the water column (Havens et al. 2004). Wang showed that enzymatic activity (Superoxide dismutase (SOD) and peroxidase (POD)) decreases with increasing WD (SOD and POD maintain ROS balance in plants (Wang 2019). Under stresses like waterlogging, ROS metabolism dysregulation generates O_2^- , H_2O_2 , and $\cdot OH$. This triggers lipid peroxidation, compromises membrane integrity, and causes physiological metabolic disorders), whereas the opposite is true for malondialdehyde (MDA) content (Wang 2019).

Myriophyllum aquaticum is a perennial submerged or aquatic herb native to South America (Li et al. 2022). It mainly relies on vegetative propagules for asexual reproduction, and the vegetative propagation rate is relatively fast (Guo et al. 2019). In this study, a controlled aquatic system, with a depth gradient of 0–150 cm was designed in order to measure the growth characteristics, chlorophyll

a and MDA content, and other growth indices of *M. aquaticum* under different water depths. A better understanding of the factors that drive the depth tolerance of this invasive species will enable more effective prevention and control measures.

Materials and methods

Experimental design

This study was conducted in Qingshan Lake (30°14'6.70"N, 115°3'17.02"E), a typical urban lake in the middle reaches of the Yangtze River in China. A stainless steel floating frame was installed in Qingshan Lake, where the water depth is 152±6 cm. The water quality parameters of the enclosure were as follows: secchi disk transparency (SD) 87±3.7 cm (at the beginning of the experiment) and 46±2.2 cm (at the end of the experiment). Before the experiments, relatively uniform *M. aquaticum* plants, each with a height of approximately 15±0.5 cm, were selected and planted in polyethylene pots (the pot is about 12 cm high, nine plants per pot, arranged in concentric circles) containing 10 cm of Qingshan Lake substrate that had been filtered through a 10-mesh sieve to remove shells. The potted plants were then placed in the enclosure in Qingshan Lake at a depth of 40 cm to be pre-cultivated for 2 days. In the experimental enclosure, a stainless steel frame was installed 30 cm above the water surface (Figure 1), and the different water depths were established by suspending the pots by nylon rope of different lengths. The water depth was measured as the distance from the top of the pot to the water surface: 0, 25, 50, 75, 100, 125, and 150 cm. Six replicate treatments were performed for each depth, totaling 42 pots.

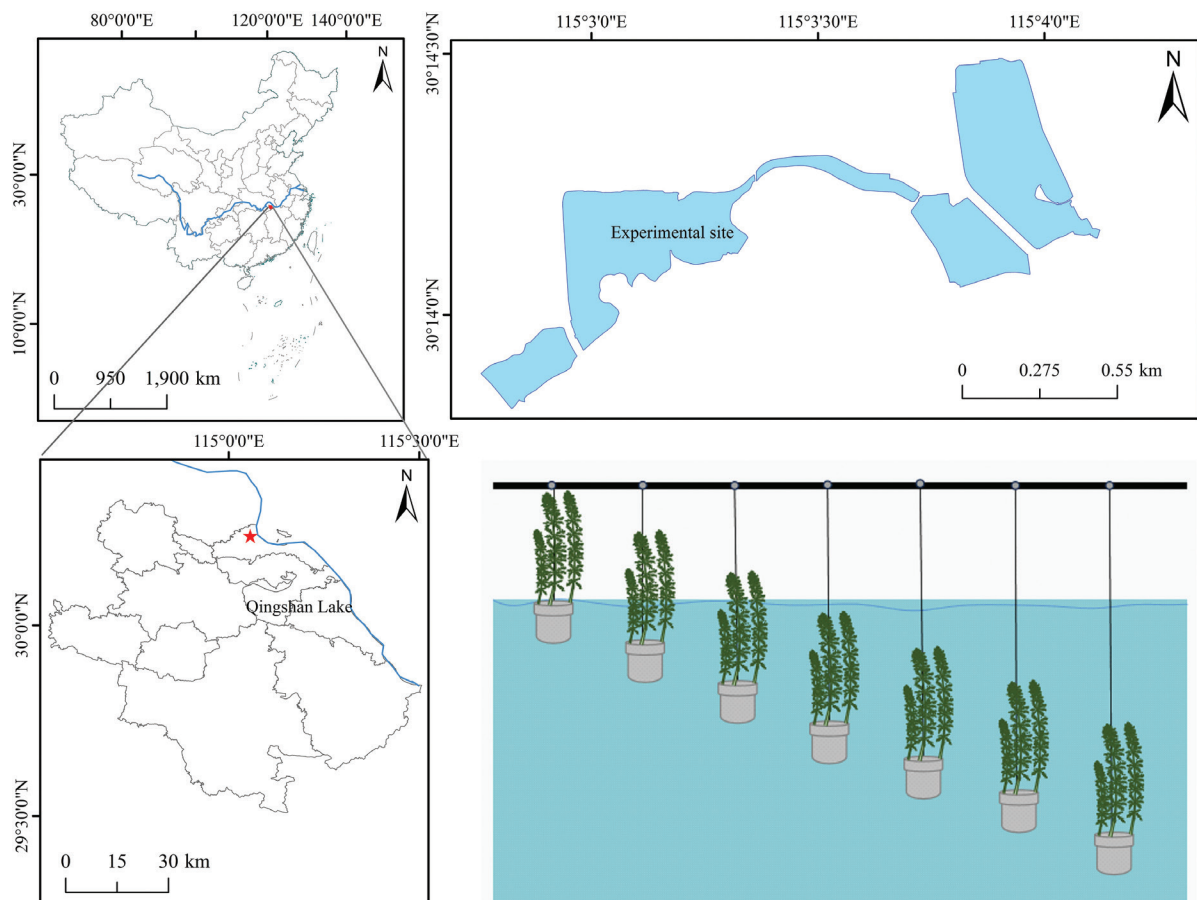


Figure 1. Location map of the study area.

Measurement of growth indicators

The experimental period was 40 days, with measurements of relevant growth indicators of *M. aquaticum* taken every 10 days. At each measurement, six plants were randomly selected from each treatment group, pulled out of the pots, rinsed with water to remove the impurities adsorbed on the surface of the plant, drained, and measured for height, root length, number of branches, and number of tillers. An analytical balance was used to measure the fresh weight and Relative Growth Rate (RGR) of the plants (Sutton 1985).

$$\text{RGR} = \ln(W_f / W_i) / D \quad (1)$$

Where W_i and W_f are the wet weights of the plants before and after the experiment, respectively, and D is the number of days in the experiment.

Underwater light intensity was measured every 10 days using a ZDS-10W illuminance meter (Shanghai Jiading Xuelian Instrumentation Factory). Spectral data (TriOS RAMESES) was measured on days 0 and 40. To minimize shading interference, the sensor was positioned away from the boat and calibrated against ambient air before each reading. Visible-light irradiance was quantified at 20 cm depth intervals to plot spectral profiles for the experimental area.

The light intensity was measured daily at 12:00–13:00 at the surface and at the experimental depths (0, 25, 50, 75, 100, 125, 150 cm). The average value of three measurements at each depth was taken to represent the light intensity (I_x) and reported in international units ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$). This data were used to calculate the light attenuation coefficient, as follows (Li et al. 2010):

$$K = \frac{1}{Z} \ln \frac{E(z)}{E(0)} \quad (2)$$

where K is the optical attenuation coefficient, Z is the depth, $E(z)$ is the irradiance at depth z , and $E(0)$ is the initial surface irradiance.

The Chl-*a* and MDA contents of the apical leaves of *M. aquaticum* were also measured once every 10 days. MDA was measured using the thiobarbituric acid method (Langhans and Tibbitts 1997; Wang and Huang 2015), and Chl-*a* by ethanol extraction spectrophotometry (Wang and Huang 2015).

Data analysis

Data statistical analysis was performed using Excel, GraphPad Prism 10.1.2, and SPSS 24.0 software. One-way analysis of variance (ANOVA) was used to examine the effects of water depth gradients at different growth stages on the growth and related physiological indicators of *M. aquaticum*. Characteristic diagram of the underwater visible spectrum were plotted using Origin 2019, ArcGIS 10.2 was used to draw a general map of the study area.

Results and analysis

Effect of water depth on the underwater light environment

With increasing water depth (WD), underwater illumination decreased exponentially (Figure 2c). The light attenuation coefficient rose linearly with WD (Fig-

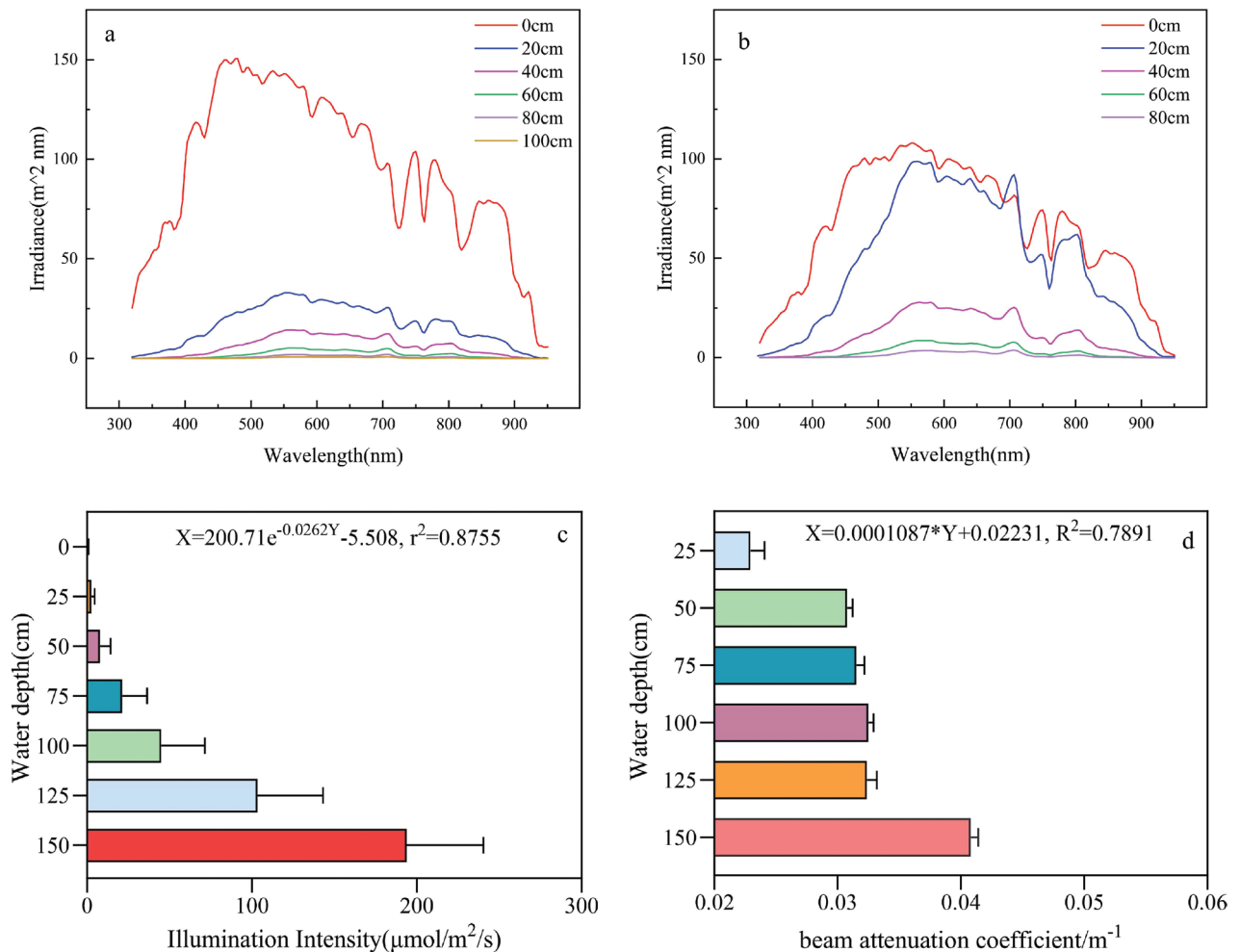


Figure 2. The influence of water depth on the underwater light environment: **a)** characterization of the underwater spectral distribution at the beginning of the experiment; **b)** characterization of the underwater spectral distribution at the end of the experiment; **c)** changes in illumination intensity with water depth; **d)** change in light attenuation coefficient with water depth (at the end of the experiment).

ure 2d, Suppl. material 1: fig. S2a, b, c). Under high transparency (pre-experiment, SD > 100 cm), the intensity of visible light decreases significantly between the water surface and a depth of 20 cm below the surface. Beyond that depth, the rate of decrease in light intensity was relatively small. Under low transparency (experiment end, SD < 100 cm), attenuation was minimal near the surface but accelerated with depth.

WD significantly influenced underwater spectral characteristics. All wavelengths attenuated with increasing WD, but blue light (400–500 nm) attenuated faster than red light (600–700 nm). Consequently, the red/blue ratio increased exponentially with WD (Suppl. material 1: fig. S1a, b). Furthermore, underwater spectra showed that as water depth increased, the maximum irradiance shifted toward the long wavelength band, and the underwater spectra were most strongly attenuated in the blue light band, followed by the green and red light bands. When water transparency was high, the maximum irradiance occurred at approximately 560 nm, and with an increase in WD, there was no significant change in the band of maximum irradiance (Fig. 2a). When water transparency was low, as water depth increased, the maximum underwater irradiance was at around 560 nm, and the wavelength at which maximum irradiance occurs shifted toward the red light wavelength band (Fig. 2b).

Changes in growth indices of *M. aquaticum* under different water level

Survival rate

WD significantly affected *M. aquaticum* survival (Figure 3). At mid-experiment (day 10-30), groups with WD > 25 cm exhibited leaf reddening and branch breakage. At termination, survival was 100% at 0 cm WD but decreased with increasing depth, reaching 0% at 150 cm WD.

Plant height

WD significantly affected *M. aquaticum* height (Figure 4a), with deep water (≥ 50 cm) inhibiting growth. Plants at WD ≥ 50 cm (heights: 22.6 ± 0.6 , 20.9 ± 0.7 , 18.3 ± 0.5 , 22.3 ± 2.3 cm; NS differences) were significantly shorter ($p < 0.05$) than those grown in shallow water (66.2 ± 4.0 cm at 0 cm WD; 57.4 ± 0.3 cm at 25 cm WD).

Number of stem nodes and internodes

The number of stem nodes and internodes in the different WD treatment groups differed ($p < 0.05$) and decreased with increasing WD (Figure 4b, c). The number of stem nodes and internode in the treatment group with WD ≥ 50 cm was significantly smaller than that of WD 0 and 25 cm ($p < 0.05$).

Branches and tillers

The branching and tillering ability of the plants gradually decreased with increasing WD (Figure 4d, e); branching (55 ± 0.5) and tillering (1.67 ± 0.58) were highest at WD 0 cm. At WD ≥ 50 cm, there was no tillering. At WD 75-150 cm, the plants had

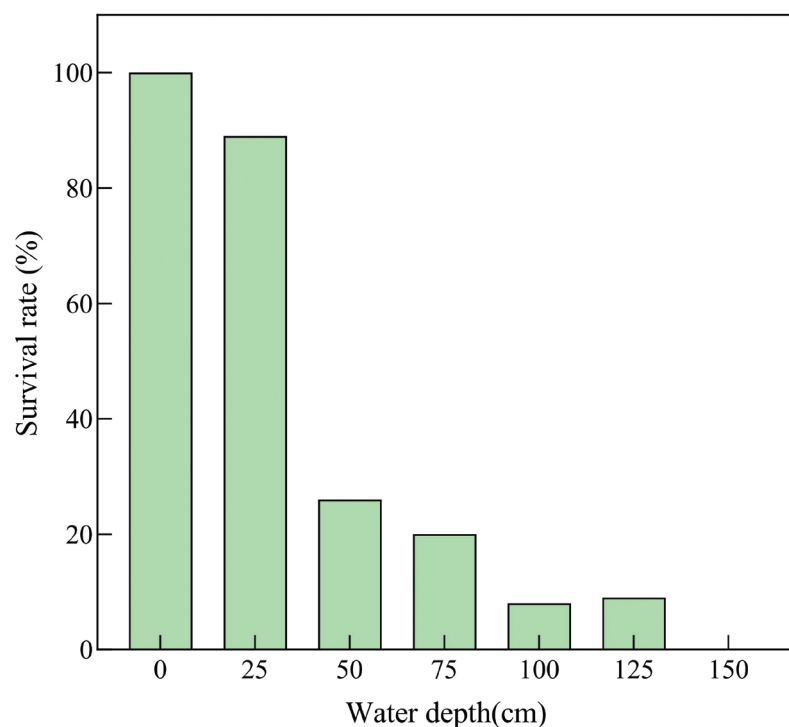


Figure 3. Survival rate of *M. aquaticum* at different water depths.

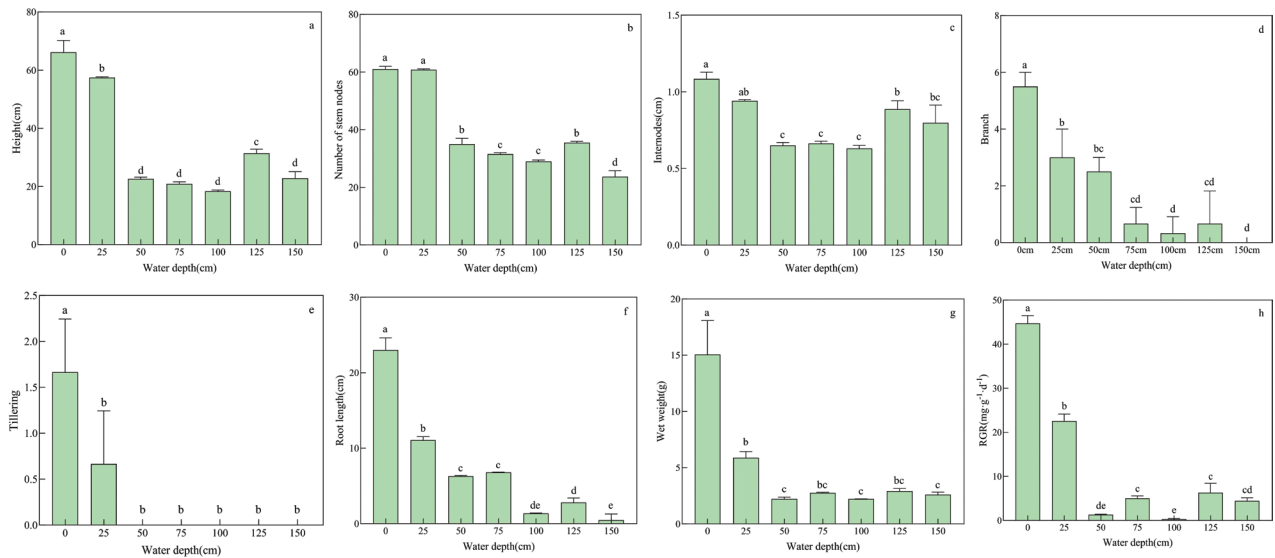


Figure 4. Growth and wet weight responses of *M. aquaticum* to different water depths (The letters a, b, c, and d in the figure represent whether there are significant differences between groups).

fewer branches, and there were no significant differences in the number of branches between the 75–100, 100–125, and 125–150 cm treatment groups. ($p > 0.05$).

Root length

WD had a significant effect on the root length of *M. aquaticum* (Figure 4f); root length gradually decreased with increasing WD. Some plants had no roots. In the case of plants at the shallowest depth (0 cm), the root length was 23 ± 1.13 cm, which is 2.13 and 8.21 times the root length of the plants at 25 and 150 cm.

Wet weight and RGR

WD consistently affected wet weight and RGR (Figure 4g, h). RGR peaked at 0 cm WD (44.73 ± 1.27 $\text{mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$), exceeding the 25 cm WD value by 1.98-fold. When the water depth reached 50 cm or less, the relative growth rate was relatively low. The 100 cm WD group showed significantly lower RGR (0.29 ± 0.15 $\text{mg} \cdot \text{g}^{-1} \cdot \text{d}^{-1}$, $p < 0.05$) than that of the other six treatment groups (including 125 and 150 WD). Wet weight at 25 cm WD (5.88 ± 0.56 g) was 61% lower than at 0 cm (15.06 ± 3.03 g), while wet weight > 50 cm WD (2.54 ± 0.32 g) was 80% lower than at 0 cm (Twenty days after the start of the experiment, the *M. aquaticum* in the 150 cm water depth treatment group gradually declined).

Changes of Chl-a content and MDA in *M. aquaticum* with increasing WD

Water depth exerted a significant influence on the Chl-a content of *M. aquaticum* (Figure 5a). In the surface water treatments (0 cm and 25 cm depth), Chl-a contents were 7.25 ± 0.09 mg/L and 6.79 ± 1.99 mg/L, respectively. Both values were significantly higher ($p < 0.05$) than those observed in deeper water treatments. However, between 50 and 125 cm WD, Chl-a content decreased drastically. The measured values were 0.61 ± 0.03 mg/L (50 cm), 0.40 ± 0.01 mg/L (75 cm), 0.33 ± 0.14 mg/L (100 cm), and 0.48 ± 0.05 mg/L (125 cm). Crucially, no statistically significant differences ($p > 0.05$) were detected among these four deeper treatment groups.

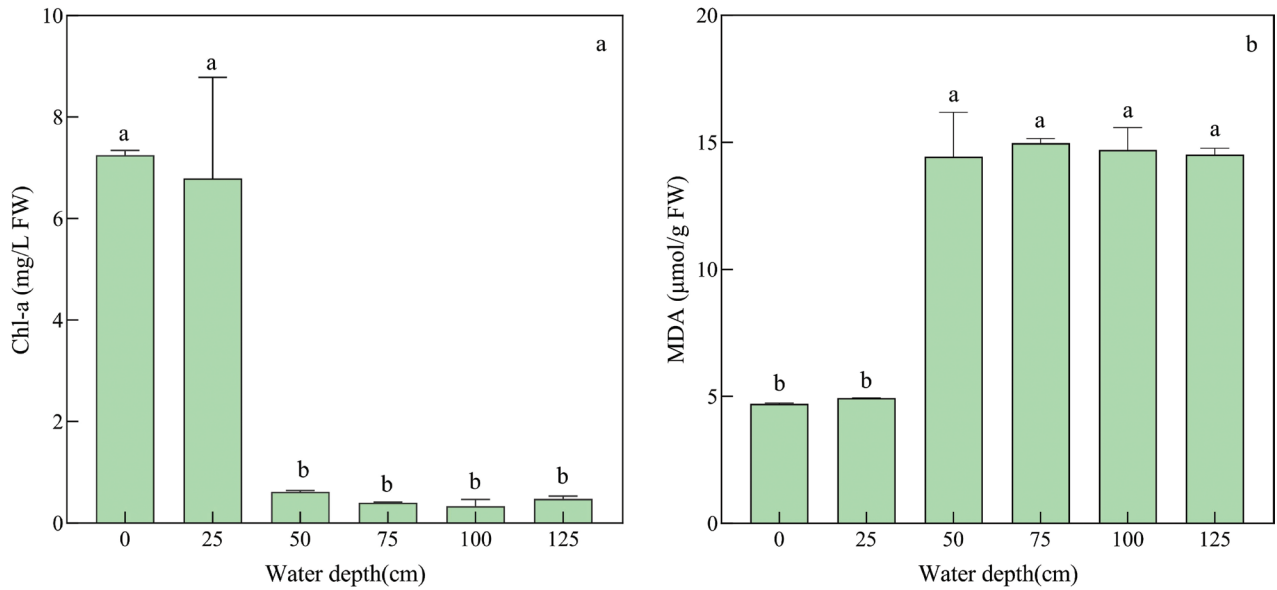


Figure 5. Ecophysiological traits of *M. aquaticum* at different water depths.

Water depth also significantly affected the malondialdehyde (MDA) content in *M. aquaticum* (Figure 5b). MDA levels generally exhibited an initial increase followed by stabilization with increasing water depth. At the end of the experiment, plants in the 0 cm and 25 cm depth treatments showed relatively low MDA contents of $4.71 \pm 0.03 \mu\text{mol/g}$ and $4.94 \pm 0.01 \mu\text{mol/g}$, respectively. In contrast, MDA concentrations were substantially higher (exceeding $14 \mu\text{mol/g}$) at depths ≥ 50 cm. Notably, plants at the 150 cm depth underwent senescence and mortality.

Principal component analysis of different traits of *M. aquaticum*

Principal component analysis (PCA) was used to integrate 11 growth physiological indicators, including RGR, internodes, plant height, survival rate, Chl-a, root length, stem node number, wet weight, branches, tillers, and MDA, to assess the overall impact of water depth gradients on *M. aquaticum*. The Kaiser-Meyer-Olkin (KMO) measure was 0.79, and Bartlett's sphericity test was significant ($\chi^2 = 474.35$, $p < 0.001$), indicating that the data were suitable for PCA. Based on the principle of eigenvalues greater than 1, one principal component (PC1) was extracted, explaining 83.43% of the variance (Table 1), indicating that the physiological responses of plants under different water depth treatments were highly correlated (Table 1).

All 10 growth indices (RGR, internode length, plant height, survival rate, Chl-a, root length, stem node number, wet weight, branch number, and tiller number) exhibited high positive loadings (0.891–0.982), indicating that these traits are highly positively correlated and collectively reflect “overall growth vigor.” MDA exhibited a negative load (–0.499), suggesting an inverse relationship between oxidative stress and growth vitality.

Discussion

Influence of WD on morphological characteristics and biomass of *M. aquaticum*

Extreme floods or droughts can severely impede the growth of macrophytes (Julian et al. 2011); conversely, submerged plant communities develop rapidly when WD

Table 1. Principal component loading matrix (PC1) of physiological growth indicators for *M. aquaticum*.

Physiological growth indicators	PC1 loading	Contribution direction
RGR	0.982	↑
internodes	0.975	↑
height	0.975	↑
survival rate	0.965	↑
Chl-a	0.947	↑
root length	0.945	↑
Number of stem nodes	0.939	↑
Wet weight	0.928	↑
Branches	0.897	↑
Tillers	0.891	↑
MDA	-0.499	↓
Eigenvalue	9.178	
Variance contribution	89.50%	
accumulate %	89.50%	

Note: ↑ indicates strong growth vitality and low stress level; ↓ indicates that growth is inhibited and the degree of stress is high.

is suitable for their growth (Wu et al. 2021). Changes in the optical components (Chl-a, TSS, and CDOM) of water quality in aquatic ecosystems affect the growth of submerged plants by influencing water transparency and underwater light environment (Padiál and Thomaz 2008). Water transparency, which is widely used in the assessment and calculation of the trophic state index and light attenuation coefficient of the water, can be used as a reference index for the determination of underwater light intensity. Changes in the underwater light environment mainly refer to changes in the light intensity and quality. The morphology and biomass of submerged plants have been shown to respond to aquatic characteristics, in particular the underwater light intensity and spectral distribution (Stefanidis and Papastergiadou 2019).

In the present study, the growth of *M. aquaticum* was negatively affected by the increase in WD: at day 20 of the experiment, the treatment group at WD 25 cm began to show reddening of the leaf blades of the terminal branches, and branch breakage gradually appeared with time. The height of the plants was significantly affected by WD; plants grown at greater depth were shorter in length, which is similar to the results obtained in a study by Li et al. on the response of *Vallisneria spiralis* to changes in WD (Li et al. 2021). In the present study, the light intensity at WD 150 was less than 1% of the incident light at the water surface and did not support growth of *M. aquaticum*; plants in this group did not survive. A similar conclusion was obtained by Xu and Huang in a study of the restoration and reconstruction of damaged aquatic ecosystems (Xu and Huang 1998); the authors reported that with increasing WD, light intensity gradually became a limiting factor for the growth of submerged plants.

In response to environmental stresses, the aboveground parts of plants undergo morphological changes, such as changes in the number of stem nodes, spacing between nodes, and leaf length and width (Hussner et al. 2009; He et al. 2022). In the present study, the number of nodes, spacing between nodes, number of branches and tillers, and the root length all decreased with increasing WD. The number of nodes and the spacing between nodes were shortened when WD exceeded 25 cm, and there were no tillers when WD exceeded 50 cm. These results demonstrate that the *M. aquaticum* plants were responding to the stress of low

light levels in deeper water: plant resources shifted from nutrient uptake to more efficient photon capture; reduced wet weight allocation to underground root systems and altered the distribution of wet weight among branches, allocating most of the energy to the main stem, thus maximizing photosynthesis to survive. These findings are similar to the results of the study of *Myriophyllum spicatum* by Strand and Weisner. (Strand and Weisner 2001). In a study of *E. nuttallii* by Szabó et al., plants grown at low light levels were found to invest more energy in apical branch elongation, resulting in a better light capture position; the response involved higher elongation rate, lower branching capacity, and lower light compensation point (Szabó et al. 2019; Szabó et al. 2020).

The trend in the growth characteristics of *M. aquaticum* with increasing WD was similar to that reported in a previous study (Hussner 2009). Both RGR and biomass were subject to varying degrees of stress with increasing water depth. The RGR at WD 0 cm was approximately $44.73 \text{ mg}\cdot\text{g}^{-1}\cdot\text{d}^{-1}$, and at WD 25 the RGR decreased to half the value at 0 cm. At the end of the experiment, the wet weight of *M. aquaticum* at 0 cm increased 6.69 times, whereas the wet weight of the plants at WD of 50 cm and deeper was only 1.15 times the original wet weight. PCA results further highlighted that water depth served as an overarching factor regulating the growth of *M. aquaticum*, with its effects exerted through the coordinated response of multiple traits.

Thus, these results collectively indicate that aquatic macrophytes lose their morphoplasticity conducive to plant growth in extremely deep waters or under conditions of extremely low light intensity

Influence of WD on the physiological characteristics of *M. aquaticum*

The effect of light quality on plant physiology and morphology is more complex than that of light intensity. Red and blue light – the wavelengths most absorbed by chlorophyll in plant leaves – have a more pronounced effect on photosynthesis than do other wavelengths (Pfündel and Baake 1990). Chl-a, the molecule essential for photosynthesis (Johkan et al. 2010), serves as an indicator of plants' capacity to absorb, transfer, and convert light energy. Its concentration is strongly influenced by external factors such as light intensity and nutrient availability, making it a valuable biomarker for assessing plant growth status.

In the present study, the ratio of red light to blue light (Red/Blue) gradually increased with increasing water depth, and the Chl-a content of *M. aquaticum* leaves basically showed a gradual decreasing trend, which was similar to the findings of Hernández and Kubota (Hernández and Kubota 2016). At WD ≥ 50 cm, the chlorophyll synthesis ability of the *M. aquaticum* plants gradually decreased with increasing depth until 150 cm and the plants gradually died. At the end of the experiment, the SD of the water body was relatively low, and the concentrations of chlorophyll a, suspended matter and other substances in each water layer were all relatively high, absorbing most of the incident light in the scattered water (Mayora and Devercelli 2019). As the water column accumulates impurities, blue light (short wavelength) is diminished to a greater degree than red light; consequently, Red/Blue rapidly increased at the end of the experiment, further accelerating the decline of the *M. aquaticum* plants in the deep water treatment group.

MDA serves as an indicator of lipid peroxidation, reflecting the degree of cell membrane lipid peroxidation and the intensity of plant responses to stress conditions, thereby determining plant growth performance and stress resistance capacity under adverse environments (Ahmed et al. 2002). In the present study,

it was found that WD and low light stress had a significant effect on the MDA content of *M. aquaticum*, and MDA concentration generally increased progressively with water depth until plateauing beyond a certain threshold, which was similar to the results obtained by Hao et al. (2020) in their study on the effect of WD on the physiological state of *Vallisneria natans* (Hao et al. 2020). The MDA content at 0, 25 cm underwater remained at a relatively low level, indicating that *M. aquaticum* was subjected to less stress. Sytsma and Anderson came to a similar conclusion: submerged growth of *Myriophyllum aquaticum* was used only to survive the short overwintering period and the low-temperature condition (Sytsma and Anderson 1993), or survive under environmental disturbances but cannot maintain prolonged submergence. Current research on *M. aquaticum* shows that populations of this species become established in shallow waters. In shallow waters, fragmented stems of *M. aquaticum* rapidly develop roots and shoots to grow above the water surface, floating their stems horizontally while progressively forming adventitious roots. If *M. aquaticum* in deep water areas cannot grow its branches above the water surface in the short term, it will gradually wither away.

These findings contribute to a better understanding of the growth conditions of the invasive species, *M. aquaticum*. However, further research is required to fully understand how exactly the species invades rivers and lakes.

Conclusions

In this study, we investigated the effects of different water depths on the morphological characteristics and physiological indices of the exotic species *Myriophyllum aquaticum* through *in situ* experiments, aiming at discovering the growth and physiological adaptive strategies of this species at different water depths. The main conclusions are as follows.

In general, *M. aquaticum* tolerates submergence at depths of 0–125 cm; however, under prolonged submergence at 50 cm or deeper, plant growth declined, as indicated by decreased plant height and RGR. Chl-a content also gradually decreased with increasing water depth, and MDA content showed a gradual increase. This study demonstrates that *M. aquaticum* can acclimate to short-term deep-water and low-light stress conditions through plastic growth strategies and morphological plasticity. However, prolonged deep-water exposure suppresses the photosynthetic capacity of *M. aquaticum*, leading to its continuous deterioration. The most suitable water depth range for the establishment of *M. aquaticum* populations is 0–25 cm.

Author contribution

ML and XW conceived the idea and designed the methodology. ML, HL and ZF conducted the experiment. ML and XW explored the software and prepared the figures. ML and HL collated the data. ML wrote the manuscript. WL made the revisions and translation. XW and XG significantly contributed to the manuscript writing and critical review.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary material.

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Supplementary material 1

Supplementary figures

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Data type: docx

Explanation note: **fig. S1.** The variation law of underwater red/blue light with water depth (WD): **a)** The variation of the red/blue ratio with WD at the beginning of the experiment; **b)** The variation of the red/blue ratio with WD at the end of the experiment. **fig. S2.** Change in light attenuation coefficient with water depth. **a, b,** and **c** represent the light attenuation coefficients at days 10, 20, and 30 of the experiment.

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