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BIOECOLOGY, BIOMASS AND PRODUCTIVITY INDICATORS OF *PERSICARIA AMPHIBIA* (L.) DELARBRE ACROSS DIFFERENT LOCAL HABITATS IN SAMARKAND REGION (UZBEKISTAN)

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ABSTRACT

This article comprehensively examines the biomass and productivity of *Persicaria amphibia* (L.)., a dominant hydrophilic plant widespread in various types of water bodies in the Samarkand region. The study was conducted at sites across the region with diverse hydrological and ecological conditions, including the Taylak, F. Kasimov, Akdarya Reservoir and Zarafshan National Nature Park. These sites differ in water supply levels, water-level stability, water-exchange rates, and substrate composition. *P. amphibia* (Polygonoideae), an aquatic macrophyte rich in dietary polyphenolics, is used as a traditional remedy and culinary herb. Nevertheless, *P. amphibia* from the Balkan region has been insufficiently studied and underutilized. Here, the cytotoxicity and antimicrobial properties of the previously chemically characterized ethanol extract from the aerial parts of *P. amphibia* were tested. The following methods were carried out: the MTT assay, qRT-PCR, microdilution assay, *Chromobacterium violaceum* screening assay (monitoring of quorum sensing, QS), and the agar plating method (antifungal activity). The study was conducted to determine the cytotoxic effects of *P. amphibia* against lung cancer cells (A549) and to assess its combination with the cytostatic doxorubicin (Dox). A dose-dependent decrease in cell viability (up to 82% reduction) and additive interactions of the tested agents were noted. Both alone and in combination with Dox, *P. amphibia* reduced Nrf2 expression ($P < 0.05$). In terms of antimicrobial effects, *P. amphibia* exhibited an antipathogenic effect since it disrupted QS communication, which was evident through the inhibition of violacein production of *C. violaceum* CV025. The antifungal screening revealed that *P. amphibia* induced significant growth inhibition of *Aspergillus* spp. (28.23%). Based on the obtained results, further examination of the potential use of *P. amphibia* in modern phytotherapy and diet-derived cancer chemoprevention is encouraged.

***Keywords*:** Macrophytes, *P. amphibia*, Biomass, Productivity, Water bodies, Samarkand region.

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1. INTRODUCTION

Hydrophilic plants in aquatic and riparian ecosystems hold significant ecological-biological and practical importance. They contribute to the stability of the aquatic environment and the cycling of organic matter, and they serve as a primary food source for hydrobionts. The biomass and productivity parameters of these plants are predominantly influenced by water level, soil moisture, and climatic conditions, exhibiting considerable variation across years and seasons. Consequently, these indicators are essential for effective ecological monitoring. *P. amphibia,* as an English native plant, is a rhizomatous perennial, one of the rather amphibious plants. Its aquatic

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form contains water-soluble sugars, starch, and protein. *P. amphibia* have up to 18% tannins in stems and rhizomes. Previous studies have confirmed the anti-inflammatory activity of live bacterial roots, but no studies on bioactivity are known (Maksimović et al., 2023). A novel fungal endophyte, *Clohesyomyces symbioticus* sp. nov., isolated from the roots of the aquatic plant Persicaria amphibia, highlights the diversity of endophytic fungi associated with aquatic vegetation and their potential role in host adaptation and ecological interactions (Arnold & Sandberg, 2021). The analysis of organic acid composition in species of the genus Persicaria revealed significant variability in metabolite profiles, indicating their potential pharmacological value and chemotaxonomic importance (Chistyakova et al., 2022). Taxonomic revisions within the genus Persicaria have identified new species and provided updated diagnostic keys, thereby improving classification and species delimitation (Funez & Hassemer, 2018). Achene macro- and micromorphological characteristics have been shown to possess high systematic value for species differentiation within Persicaria from the temperate Himalayan region (Gillani et al., 2025). Molecular and morphological analyses confirmed the taxonomic identity of Persicaria amphibia and emphasized its status as a significant terrestrial weed in northern Greece (Gitsopoulos et al., 2013). Variations in phytohormone content in the generative organs of Persicaria amphibia were found to depend on environmental growth conditions, indicating physiological plasticity of the species (Grygorchuk, 2012). In the Samarkand region of Uzbekistan, a series of scientific studies have been conducted to investigate medicinal and other economically valuable plant species, with a particular focus on evaluating the biomass yield of their raw materials (Bobokandov et al., 2024; Isomov et al., 2025). Scanning electron microscopy has proven effective for distinguishing species of the genus Persicaria based on microstructural morphological traits (Gudkova et al., 2022). Molecular phylogenetic analysis clarified evolutionary relationships within the genus Persicaria and supported the taxonomic placement of species based on DNA sequence data (Kim & Donoghue, 2008). Morphological description and distributional data of Persicaria amphibia were expanded, providing additional information on its diagnostic characters and habitat range (Kundakçı et al., 2024). Azaphilone compounds (montagnuphilones A–G) isolated from a fungal endophyte associated with submerged roots of Persicaria amphibia demonstrated the biochemical potential of endophytic microorganisms inhabiting aquatic plants (Luo et al., 2017). *P. amphibia* is a perennial rhizomatous plant belonging to the knotweed family Polygonaceae L., widely distributed in water bodies with depths of 0.3–1.5 m, including reservoirs, slow-flowing rivers, and canals, and muddy, organic-rich substrates in wetlands and marshy areas (Fig. 1). Cryptophyte, helophyte. Holarctic species. Indicator species for brackish water bodies. Distributed in the Urgut, Dzhambay, Taylak, and Ishtikhan districts of the Samarkand region. Medicinal, tanning, and fodder plant (Tashpulatov et al., 2019; Shernazarov et al., 2024). In the Samarkand Region, it ranks among the dominant aquatic macrophyte species, exhibiting pronounced phenotypic plasticity by altering leaf and stem morphology in response to fluctuations in water level. It forms dense floating phytocenoses on the water surface and, under favorable conditions, accumulates substantial biomass. These biomass levels play a key role in organic matter cycling and can confer dominance within aquatic ecosystems. Across water bodies, the species helps regulate oxygen regimes, trap sedimentary particles, and provide fish with refuge habitats. Consequently, investigating its biomass and productivity characteristics holds significant importance for the rational utilization of natural resources and for effective ecological monitoring efforts. Within the irrigation canals, rivers, and reservoirs of Uzbekistan, *P. amphibia* commonly co-occurs with species of *Potamogeton*, *Phragmites*, and *Typha* to form mixed phytocenoses, and it serves as a valuable indicator in assessments of aquatic ecosystem condition. In light of the above, the primary objective of the present study is to determine the spatial variation in biomass and productivity parameters of *P. amphibia* across different local habitats in the water bodies of the Samarkand Region. Advances in global development and industrial progress have caused serious heavy metal pollution in the ecological environment due to increasing human activities such as mining, thermal power plants, new municipal and industrial formations, as well as uncontrolled wastes, including chemicals, pesticides, herbicides, fertilizers, heavy metal-based products, batteries, and other various wastes (Cay et al., 2025). *P. amphibia*, also known as water knotweed, belongs to the Polygonaceae family and has two types: terrestrial and aquatic. We report the chloroplast genome of *P. amphibia* obtained through de novo assembly of Illumina paired-end reads produced by total DNA sequencing (Choi at al., 2022). Wetland surveys revealed the current distribution and ecological status of knotweed species, including Persicaria, emphasizing their adaptability to diverse hydrological conditions (Neacsu et al., 2025). Ethnobotanical studies documented the traditional uses and ecological importance of Persicaria amphibia and related species, highlighting their medicinal and cultural significance in mountainous regions (Paniagua-Zambrana et al., 2025). Leaf epidermal anatomical characteristics were shown to have significant taxonomic value for distinguishing species of the genus Persicaria, supporting their use in systematic studies (Yasmin et al., 2010). The *P. amphibia* complex exhibits significant morphological variation depending on its habitat, existing in either aquatic or terrestrial forms. Traditionally, four distinct elements have been recognized based on morphological features along with their distinct geographical distributions. Recent studies suggest that

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the Asian element may be genetically distinct from the European and American elements (Ballestas et al., 2024). A biomorphological analysis of three biomorphs of *P. amphibia,* characterized by features of shoot formation under different environmental conditions, has been carried out from the perspectives of a systematic approach and modular organization (Lelekova et al., 2019). *P. amphibia*, a member of the Polygonaceae family, exists in both aquatic and terrestrial forms. It is native to North America, Asia, Europe, and some parts of Africa. This study aimed to determine genetic diversity within and among populations of *P. amphibia* and to investigate the distribution characteristics of each population, providing insights into the genetic structure and conservation of *P. amphibia* (Choi et al., 2025). Recent studies emphasize the importance of environmental factors in determining plant growth, productivity, and adaptive responses across different habitats. Mustanov et al. (2026) reported that agronomic practices and microbial inoculants significantly affect plant productivity and nitrogen fixation, highlighting the role of external factors in regulating plant development. Similarly, Isomov et al. (2026) demonstrated that the biochemical composition of *Cynara scolymus* L. is closely linked to environmental conditions, indicating that habitat variability influences metabolite accumulation. In the present study, we evaluate the biomass and nutritive value of living and dead shoots of *P. salicifolia*, and their capacity to accumulate heavy metals and nutrients, making them potential phytoremediators. Species such as *Azolla caroliniana* and *Lemna minor* contribute both to improved fish nutrition and to enhanced water quality through nutrient uptake, supporting integrated and eco-efficient aquaculture systems (Rakhmonov et al., 2025; Rakhmonov et al., 2026). The living and dead parts attained their highest phytomass during autumn (Shaltout et al., 2014). Environmental factors affecting the expression of amphicarpic traits in *P. thunbergii* are not well studied. We thus conducted a mesocosm experiment to investigate the effects of nutrients on the amphicarpic traits of *P. thunbergii* (Kim et al., 2016).

Although *Persicaria amphibia* is widely distributed and ecologically dominant in freshwater ecosystems, an integrative assessment linking its biomass productivity with its molecular and pharmacological activities remains lacking. In particular, the relationship between ecological performance under varying hydrological conditions and the accumulation of biologically active compounds with cytotoxic and antipathogenic potential remains insufficiently elucidated. Addressing this gap is crucial for understanding the species' dual ecological and biomedical significance. Therefore, the present study aims to provide a multidisciplinary evaluation of *P. amphibia*, generating evidence that supports its sustainable exploitation as both a functional component of aquatic ecosystems and a promising natural source for anticancer and antimicrobial applications.

Fig. 1: *Persicaria amphibia* (L.) and its natural habitat (*photo by Y. Tashpulatov*).

2. MATERIALS AND METHODS

The Samarkand Region is located in the central part of the Republic of Uzbekistan, at an altitude of 570-650 meters above sea level. The climate of the Samarkand Region can be divided into two zones. The northern and western parts have a continental climate, while the rest (center, south, and east) have a subtropical inland climate. Both climates feature hot, dry summers and somewhat cold winters. The average annual temperature is 16.5°C, with an average January temperature of 0.2°C and an average July temperature of 27.0°C. The absolute minimum temperature was -22°C, while the absolute maximum was 44°C. On average, the region receives 310-330 mm of precipitation annually (most of which falls in spring and autumn). The growing season lasts 218-220 days.

The Samarkand Region is a region in central Uzbekistan, covering approximately 1,000 square kilometers, located in the Zeravshan River valley. The region comprises 14 districts and borders Tajikistan and three regions of Uzbekistan (Navoi, Jizzakh, and Kashkadarya). The terrain is varied: mountains (Nuratau and the Zeravshan Range)

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in the north and south, and plains. The main water sources of the Samarkand region are the Zarafshan River (about 70% of the water) and its Akdarya branch, as well as a system of reservoirs and irrigation canals that supply agriculture and provide water.

The investigations were conducted in various districts of the Samarkand Region, specifically in water bodies located in Taylak, F. Kasimova, Akdaryo Reservoir, and Zarafshan National Nature Park. When selecting sites, the presence of permanent water bodies, the stability of the natural population of the studied plant species, and various manifestations of anthropogenic load were taken into account. These study sites represent areas within the Samarkand Region where aquatic macrophytes are both commonly encountered and relatively abundant. The primary aim was to determine the biomass parameters of the dominant forage macrophytes (Fig. 2) distributed in these locations and to develop recommendations for their utilization in livestock farming.

In each study area, multiple observation points were selected, and measurements were taken to determine the density of plant shoots (number per 1 m²), as well as the fresh and dry biomass of aboveground organs. Dry mass was quantified using standard drying methods. The collected data underwent statistical analysis, with mean values and confidence intervals calculated at a significance level of $P \leq 0.05$. Correlation analysis was employed to evaluate the relationship between shoot density and biomass parameters.

3. RESULTS AND DISCUSSION

P. amphibia is a widely distributed dominant and subdominant species in the water bodies of all investigated areas. Analysis of the data across the study sites revealed that *P. amphibia* occurs in the highest abundance in the constantly moist, water-saturated zones of the Akdarya Reservoir, particularly along the inflowing irrigation ditches, rice paddies, canals, and within the reservoir's protected zone. In this area, at populations (Choi et al., 2022; Hamrayeva et al., 2025), shoot density ranged from 12.4 to 16.3 shoots per 1 m². The corresponding fresh biomass was 225.0 ± 8.1 to 270.3 ± 9.7 g/m², while dry biomass ranged from 57.8 ± 2.1 to 73.0 ± 2.7 g/m² (Table 1). The next-highest values were recorded in the Taylak water bodies.

At populations 1–3 in the Taylak, shoot density ranged from 10.1 to 14.3 shoots per 1 m². The corresponding fresh biomass was 233.1 ± 8.3 to 244.1 ± 8.7 g/m², and dry biomass ranged from 55.4 ± 2.1 to 59.4 ± 2.2 g/m². The lowest values were recorded at populations 4–6 in the F. Kasimova settlement, located in the Samarkand District. In this area, shoot density varied from 7.1 to 11.2 shoots per 1 m², with fresh biomass ranging from 159.2 ± 5.7 to 220.3 ± 7.9 g/m² and dry biomass from 43.8 ± 1.6 to 59.3 ± 2.2 g/m² (Table 1).

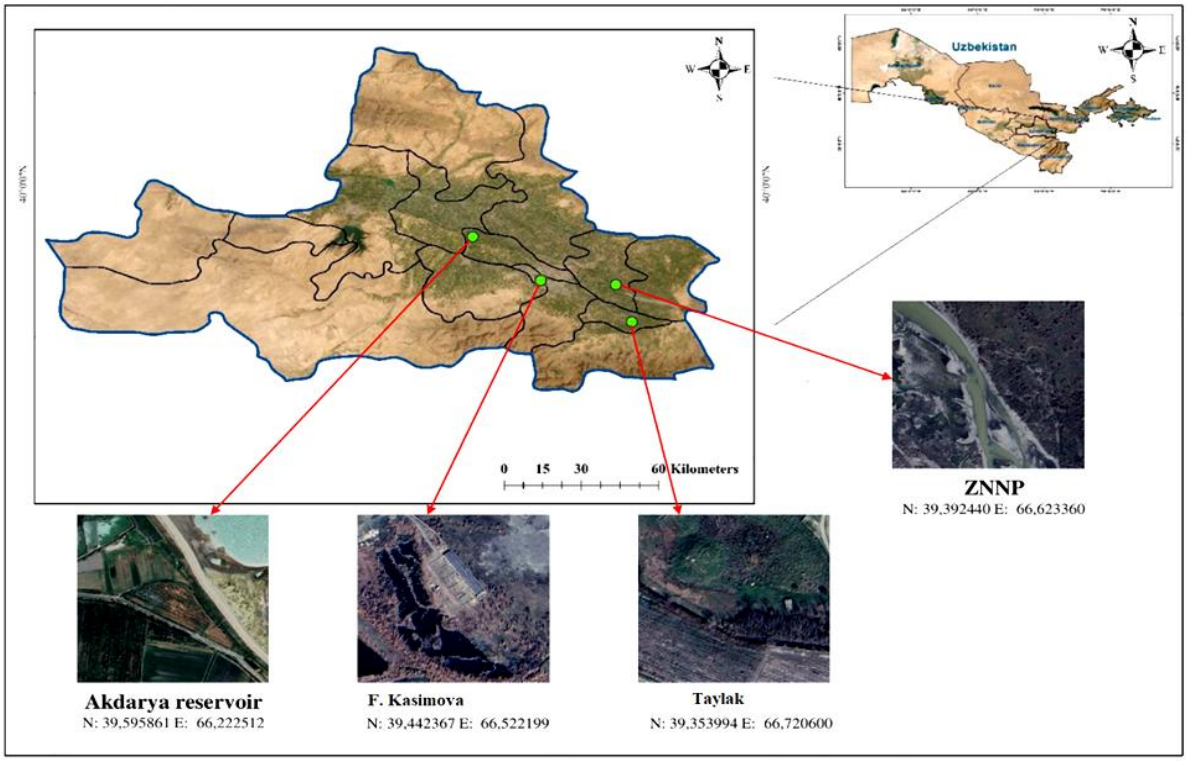

Fig. 2: Map-scheme of the study areas and their coordinates.

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Table 1: Biomass parameters of *P. amphibia* across different study sites in the Samarkand Region

Populations	Shoot density (shoots/m²)	Biomass parameters, per 1 m² (kg)	
		Fresh weight (g/m²)	Dry weight (g/m²)
Taylak			
1	10.1	244.1 ± 8.7a	57.1 ± 2.1a
2	10.1	236.0 ± 8.5a	55.4 ± 2.1a
3	14.3	233.1 ± 8.3a	59.4 ± 2.2a
F.Kasimova			
4	8.2	162.2 ± 5.8b	43.8 ± 1.6b
5	7.1	159.2 ± 5.7b	46.6 ± 1.7b
6	11.2	220.3 ± 7.9a	59.3 ± 2.2a
Akdarya Reservoir			
7	12.4	225.0 ± 8.1a	66.4 ± 2.5a
8	11.4	238.9 ± 8.6a	57.8 ± 2.1a
9	16.3	270.3 ± 9.7a	73.0 ± 2.7a
Zarafshon National Nature Park			
10	12.3	218.0 ± 7.8a	62.3 ± 2.3a
11	11.1	211.3 ± 7.6a	60.1 ± 2.2a
12	9.0	189.9 ± 6.8b	51.2 ± 1.9b

Letters (a, b) indicate statistical groupings: values sharing the same letter are not significantly different ($P<0.005$), whereas values with different letters differ significantly. Populations from Taylak, Akdarya Reservoir, and Zarafshon National Nature Park generally exhibited higher shoot density and biomass (group a), while F. Kasimova populations showed lower values (group b). These differences likely reflect variations in local environmental conditions and habitat quality.

According to the study findings, *P. amphibia* is one of the prominent emergent aquatic macrophytes widely distributed across various water bodies in the Samarkand Region. It exhibits high ecological plasticity and substantial productivity potential. The data presented in Table 1 demonstrate considerable spatial variation in the species' biomass and productivity parameters. These differences are closely associated with the hydrological, trophic, and anthropogenic conditions prevailing in the respective water bodies. At populations (Mitsch et al., 2015; Barko et al., 1986), in the Taylak, the shoot density of *P. amphibia* ranged from 10.1 to 14.3 shoots per 1 m², with fresh biomass reaching 233.1 ± 8.3 to 244.1 ± 8.7 g/m². The corresponding dry biomass values were 55.4 ± 2.1 to 59.4 ± 2.2 g/m². The relatively high biomass accumulation observed in this area can be attributed to the stable hydrological regime of the water environment, persistent soil saturation, and sufficient nutrient availability.

In the water bodies located in the F. Kasimova settlement area (Bornette & Puijalon, 2011; Isomov et al., 2024), shoot density ranged from 7.1 to 11.2 shoots/m². Fresh biomass varied between 159.2 ± 5.7 and 220.3 ± 7.9 g/m², while dry biomass ranged from 43.8 ± 1.6 to 59.3 ± 2.2 g/m². The relatively lower biomass values observed in this area may be attributed to intense anthropogenic pressure on the water bodies, seasonal fluctuations in water level, and partial mechanical damage to the vegetation.

The highest biomass and productivity parameters were recorded in the Akdarya Reservoir area (Hamrayeva et al., 2025; Cay et al., 2025). Here, shoot density ranged from 11.4 to 16.3 shoots/m², fresh biomass from 225.0 ± 8.1 to 270.3 ± 9.7 g/m², and dry biomass from 57.8 ± 2.1 to 73.0 ± 2.7 g/m². These elevated values can be explained by the relatively calm hydrological regime of the reservoir (low water flow and stable water level), the well-developed sedimentary layer (rich in organic matter), and the nutrient-enriched aquatic environment (high availability of nitrogen, phosphorus, and other essential elements). Such conditions favor vigorous growth and the formation of dense phytocenosis by *P. amphibia*, thereby reinforcing its dominant status in these habitats.

In the area of the Zarafshon National Nature Park along the Zarafshon River (Lelekova et al., 2019; Choi et al., 2022), the biomass parameters of *P. amphibia* were relatively stable and moderate, with fresh biomass ranging from 189.9 ± 6.8 to 218.0 ± 7.8 g/m² and dry biomass from 51.2 ± 1.9 to 62.3 ± 2.3 g/m². The comparatively good preservation of natural conditions in this protected area (low anthropogenic impact, natural hydrological rhythm, and buffer zones) ensures stable development and consistently moderate-to-high biomass accumulation for the species. These results confirm the high ecological potential of aquatic macrophytes in protected natural reserves such as national parks.

Based on the pooled average values across all study sites, the shoot density of *P. amphibia* was 11.1 ± 2.0 shoots/m², fresh biomass 217.35 ± 7.8 g/m², and dry biomass 57.7 ± 2.1 g/m². The obtained results indicate that *P. amphibia* is one of the key species in the water bodies of the Samarkand Region, playing a major role in forming significant phytocenoses and contributing substantially to the biological productivity of aquatic ecosystems.

Analysis of the mean values across the study sites revealed that, while the average fresh biomass of *P. amphibia* exhibited statistically significant variation among the observation points in different areas, the differences

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in dry biomass were comparatively modest and less pronounced (Fig. 2).

The fresh biomass deviated from its overall mean by as much as –36.8 g/m² (lowest) to +99.6 g/m² (highest). In contrast, dry biomass showed much smaller deviations, ranging from –0.4 g/m² (lowest) to +8.0 g/m² (highest) relative to the mean. The highest values for both fresh and dry biomass were consistently recorded in the Akdaryo Reservoir area, whereas the lowest values were observed in the F. Kasimova site.

During our investigations, a correlation analysis was performed to assess the relationship between shoot density (number of shoots per 1 m²) of *P. amphibia* and the fresh and dry biomass of its aboveground organs. The results indicated a moderately strong positive correlation between shoot density and both fresh and dry biomass. Specifically, the correlation coefficient (r) was 0.75 for fresh biomass and 0.84 for dry biomass (Fig. 3).

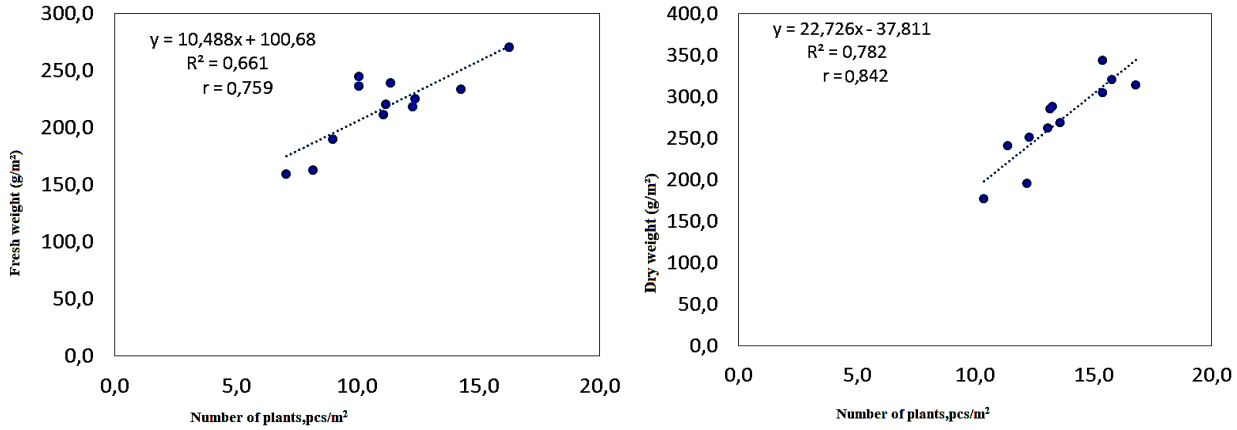

Fig. 3: Correlation between the number of plants at observation points and the fresh and dry biomass weight.

The study findings demonstrate that productivity parameters of *P. amphibia* vary substantially across different water bodies in the Samarkand Region. Data presented in Table 2 indicate that the species' occupied area and per-hectare productivity of fresh and dry biomass are strongly dependent on local environmental conditions.

In the Taylak, the area occupied by *P. amphibia* ranged from 0.02 to 0.03 ha. Per-unit-area productivity was estimated at 46.2 ± 1.9 to 70.8 ± 2.9 g/m² for fresh biomass and 55.4 ± 2.3 to 59.4 ± 2.5 g/m² for dry biomass. The relatively high productivity in this area can be attributed to the stable hydrological regime of the water bodies (consistent water levels and low flow variability) and to favorable conditions that support robust plant development.

Table 2: Productivity parameters of *P. amphibia* across study sites

Observation points	Total occupied area, hectare	Per-unit-area productivity	
		Fresh biomass productivity (g/m²)	Dry biomass productivity (g/m²)
Taylak			
1	0.02	48.2 ± 2.0a	57.1 ± 2.4a
2	0.03	70.8 ± 2.9a	55.4 ± 2.3a
3	0.02	46.2 ± 1,9a	59.4 ± 2.5a
F.Kasimova			
4	0.02	33.2 ± 1.3b	43.8 ± 1.8b
5	0.01	15.9 ± 0.6b	46.6 ± 2.0b
6	0.01	22.0 ± 0.9b	59.3 ± 2.5a
Akdaryo Reservoir			
7	0.06	135.0 ± 7.8c	66.4 ± 2.8c
8	0.05	119.4 ± 8.3c	57.8 ± 2.4a
9	0.05	135.1 ± 9.4c	73.0 ± 3.1c
Zarafshon National Nature Park			
10	0.04	87.2 ± 7.6c	62.3 ± 2.6c
11	0.03	63.3 ± 7.3c	60.1 ± 2.5a
12	0.03	56.9 ± 6.6b	51.2 ± 2.2b

Letters (a, b, c) indicate statistical groupings; values sharing the same letter are not significantly different (P>0.05), whereas values with different letters differ significantly (P<0.05).

In the water bodies of the F. Kasimova settlement area, the area occupied by *P. amphibia* ranged from 0.01

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to 0.02 ha. Fresh biomass productivity per unit area was 15.9 ± 0.6 to 33.2 ± 1.3 g/m², while dry biomass productivity ranged from 43.8 ± 1.8 to 59.3 ± 2.5 g/m². The relatively lower productivity at this site is likely attributable to anthropogenic factors (proximity to human settlements, agricultural runoff, and recreational pressure), high water-level variability, and mechanical disturbances to aquatic vegetation (e.g., trampling, channel maintenance, or grazing).

The highest productivity parameters were observed in the Akdaryo Reservoir area. Here, the occupied area by *P. amphibia* was 0.05–0.06 ha, with fresh biomass productivity reaching 119.4 ± 8.3 to 135.1 ± 9.4 g/m² and dry biomass productivity ranging from 57.8 ± 2.4 to 73.0 ± 3.1 g/m². These superior results can be explained by the nutrient-rich conditions of the reservoir (elevated levels of organic matter and essential macronutrients from inflowing irrigation channels) and the relatively calm hydrological regime (low flow velocity, stable water depth, and reduced turbulence), which collectively favor vigorous vegetative growth and high biomass accumulation.

In the area of the Zarafshon National Nature Park along the Zarafshon River, the area occupied by *P. amphibia* ranged from 0.03 to 0.04 ha. Fresh biomass productivity per unit area was 56.9 ± 6.6 to 87.2 ± 7.6 g/m², while dry biomass productivity ranged from 51.2 ± 2.2 to 62.3 ± 2.6 g/m². The observed stability in productivity parameters in this site reflects the relatively well-preserved natural conditions, including low anthropogenic disturbance, natural hydrological dynamics, and effective protection measures within the national park.

Correlation analysis results (Fig. 2) revealed a moderately strong positive correlation between shoot density and fresh biomass ($r = 0.75$) and a strong positive correlation with dry biomass ($r = 0.84$). These relationships confirm that increases in shoot density directly contribute to higher overall productivity in *P. amphibia*, with dry biomass showing a closer association, possibly due to more stable carbon allocation patterns under varying environmental conditions.

The obtained results underscore that *P. amphibia* represents a significant source of biological productivity in aquatic ecosystems of the Samarkand Region. Determining the productivity parameters of naturally occurring plants with potential applications across various sectors of the national economy is of considerable importance for developing future utilization prospects and for ongoing monitoring of their quantitative status in natural habitats.

To this end, the present study specifically aimed to evaluate the productivity parameters of the utilizable organs of the studied plant species in the investigated areas. As mentioned earlier, *P. amphibia* holds considerable importance not only as a natural forage plant for livestock production but also as a promising candidate for utilization in aquaculture and fisheries (e.g., as supplementary feed or habitat enhancement for fish). The area covered by this species across the study sites was precisely quantified (Table 1). Concurrently, harvestable fresh- and dry-biomass productivity was determined at each observation point (Table 2). The data in the tables clearly indicate that the largest occupied areas are in the Akdaryo Reservoir (up to 0.06 ha) and the Zarafshon National Nature Park (up to 0.04 ha), substantially greater than in other locations. However, the per-hectare fresh biomass productivity in the Zarafshon National Nature Park (135.0 g/ha) and dry biomass productivity (66.4 kg/ha) are noticeably lower than the corresponding values in the Akdaryo Reservoir area (fresh: 87.2 kg/ha; dry: 62.3 kg/ha). This trend persists even when averaged across the sites. The smallest occupied areas were recorded in the F. Kasimova settlement area.

Regarding productivity parameters, observations in the Akdaryo Reservoir area demonstrated clear leadership. Although the Zarafshon National Nature Park ranked second in shoot density per 1 m² and in corresponding fresh and dry biomass values, the observation points in the Akdaryo Reservoir covered a relatively larger area and exhibited the highest overall productivity indicators for the species. The lowest productivity values were recorded in the Taylak. Relative to the overall mean fresh productivity (69.4 kg/ha), the lowest deviation was –45.7 kg/ha and the highest +60.4 kg/ha. For dry productivity (mean 57.7 kg/ha), the deviations ranged from –7.8 kg/ha (lowest) to +11.4 kg/ha (highest).

In the Samarkand Region, the P. amphibia population surrounding the Akdarya Reservoir exhibited the highest performance across all measured parameters. The lowest values were consistently recorded in the F. Kasimova settlement area, while intermediate levels were observed in the Taylak and Zarafshon National Nature Park. This pattern can be attributed to the favorable conditions in the high-performing sites: consistent and regular water supply throughout the entire vegetation period, sufficient and sustained moisture in the substrate where the plant grows, optimal ecological characteristics of the water body (nutrient availability, stable physicochemical properties, low turbulence, and adequate light penetration) that support vigorous growth, development, and reproduction of the species, as well as relatively negligible anthropogenic impact (limited human interference, absence of intensive mechanical disturbance, and effective buffering from agricultural, urban, or recreational pressures).

These conditions are known to strongly influence the establishment and biomass production of aquatic macrophytes, particularly in littoral and wetland ecosystems, where water-level stability and nutrient availability determine plant survival and growth (Crosland et al., 2024; Wang et al., 2025; Tang et al., 2026).

In addition, substrate saturation and hydrological stability have been identified as critical factors regulating

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recruitment success and biomass accumulation of amphibious species of the genus Persicaria (Scorsim et al., 2024; Wang et al., 2025).

Furthermore, nutrient-rich environments significantly enhance the growth and reproductive performance of wetland macrophytes, while disturbance and flooding variability may reduce seed production and population persistence (Crosland et al., 2024; Tang et al., 2026).

These results confirm that P. amphibia is highly sensitive to hydrological stability, substrate saturation, water quality, and the level of human disturbance, achieving its maximum productivity in relatively undisturbed, nutrient-rich, and hydrologically stable habitats such as reservoir buffer zones and protected natural areas. This is consistent with observations that Persicaria amphibia exhibits strong morphological and ecological plasticity depending on habitat conditions and performs best under stable aquatic environments (Ballestas et al., 2024; Cay et al., 2025).

The present study demonstrated considerable spatial variation in the productivity parameters of *P. amphibia* across different aquatic habitats in the Samarkand Region. Fresh biomass exhibited statistically significant differences among observation points, whereas variation in dry biomass was comparatively smaller (Fig. 2). These results corroborate findings from other aquatic macrophyte studies that report greater sensitivity of fresh biomass to local environmental conditions compared to dry biomass, which can be less variable due to internal plant resource allocation patterns (e.g., López-Pozo et al., 2023).

The observed positive correlations between shoot density and both fresh ($r = 0.75$) and dry biomass ($r = 0.84$) indicate that higher shoot densities generally correspond to increased productivity. Similar relationships have been documented in other aquatic macrophytes, whereby shoot/plant density is a reliable predictor of biomass accumulation in wetland plant communities. In our study, the Akdaryo Reservoir consistently exhibited the highest productivity values for both fresh and dry biomass, followed by sites in the Zarafshon National Nature Park, while the F. Kasimova area showed the lowest values. These spatial differences likely reflect variations in local hydrological stability, nutrient availability, and anthropogenic disturbance. This pattern aligns with previous research indicating that aquatic plant productivity is strongly influenced by water regime, nutrient levels, and human impact. For instance, biomass and nutrient storage in marsh vegetation such as Typha spp. and Chara spp. show higher productivity in nutrient-rich, stable hydrological conditions than in nutrient-poor or disturbed habitats. Similar trends have been observed among emergent and floating aquatic plants in other regions, where sites with higher nutrient availability or stable water levels supported greater shoot density and biomass (Rojas-Galaviz et al., 1990). Although *P. amphibia* has not been as widely studied as some other macrophytes, our results are consistent with the general understanding that productivity in aquatic macrophytes is a function of both biotic factors (e.g., density and growth rate) and abiotic environmental conditions. The relatively high productivity observed in the Taylak and Akdaryo Reservoir populations may be attributed to favorable hydrological regimes and nutrient inputs, which enhance growth potential, whereas lower productivity in the F. Kasimova populations likely reflects greater anthropogenic influence and unstable water conditions. These findings are broadly in agreement with other studies emphasizing the detrimental effects of human disturbance on aquatic plant growth and biomass accumulation (Mustafa & Hayder, 2021).

Overall, the results suggest that *P. amphibia* is an important component of local aquatic ecosystems, contributing to primary productivity and biomass formation. The variability observed across sites highlights the need for habitat-specific management practices to conserve and utilize this species effectively in wetland and fisheries contexts. Future research should explore productivity responses to specific physicochemical gradients and long-term environmental change to better integrate *P. amphibia* into ecosystem service assessments and sustainable resource planning.

4. CONCLUSION

The results of this study indicate that the biomass and productivity of *P. amphibia* are primarily determined by water supply, substrate moisture content, and anthropogenic disturbance intensity. In areas with consistent water availability and stable ecological conditions, the species exhibited the highest biomass accumulation and productivity. In the water bodies of the Samarkand Region, the peak biomass of *P. amphibia* occurs in summer. Annual productivity parameters show no substantial variation across sites. Key ecological factors—water temperature, nutrient availability, and depth—directly influence biomass and productivity.

P. amphibia serves as an important component in maintaining the stability of aquatic ecosystems. It is a widely distributed dominant hydrophilic species in the water bodies of the Samarkand Region. The biomass and productivity parameters of the species vary significantly among sites. A moderately strong positive correlation was found between shoot density and both fresh and dry biomass. The findings confirm that the productivity of *P. amphibia* is closely linked to the ecological status of aquatic habitats. Maximum biomass accumulation occurs in areas with low anthropogenic pressure and high water quality. *P. amphibia* can be effectively used as a valuable

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bioindicator for assessing the ecological condition of water bodies in the Samarkand Region.

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Author's Contributions: This study was a collaborative effort among all authors. Sohib Muminov, Khudaynazar Yunusov, Akhtam Nurniyozov, Shavkat Shernazarov, Suroj Kurbanboev, Nilufar Abdurashidova, Umida Bozorova, Buston Islamov, Farruxjon Xasanov, Zarifa Saidmurodova, Kurbangul Aytbayeva, Kydyrbay Kaipov, Nodirjon Bobokandov and Yigitali Tashpulatov contributed to the study design and data analysis. Sohib Muminov, Khudaynazar Yunusov, Akhtam Nurniyozov, Shavkat Shernazarov, Nodirjon Bobokandov, Yigitali Tashpulatov conducted the laboratory experiments, analyzed the data, interpreted the results, and drafted the manuscript. All authors reviewed and approved the final manuscript.

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