Phenotypic Plasticity of *Pistia stratiotes* (Fam. Araceae) in Estuarine and Freshwater Environments

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***Abstract*—**The environment can induce changes in the individual's behavior at a morphological or physiological level and such changes may be crucial to the survival in heterogeneous and variable conditions. This study aims to evaluate how Pistia stratiotes, commonly known as water cabbage, adapt to changing environment, more specifically in saline environment. Physico-chemical parameters of the above-mentioned aquatic environments were analyzed. Plant measurements such as leaf width, leaf length, number of leaf veins, fresh weight and length of roots were also determined and the densities of P. stratiotes in each environment were computed as well. A two-sample t-test was used to examine differences between the two plant groups. The results showed that there was a significant variation in the plant's traits between estuarine and freshwater environments confirming the occurrence of phenotypic plasticity of P. stratiotes when exposed to varying environmental condition.

***Keywords*—** plasticity, estuarine, freshwater, environment.

I. Introduction

ENVIRONMENT-dependent responses are an important component in the life-history of species, since this theory seeks to explain how the patterns of growth, maintenance and reproduction of an organism influence its fitness [1]. Plant ecologists and evolutionary biologists frequently examine patterns of phenotypic variation across variable environments or genetic identities. Too often, we ignore the fact that most phenotypic traits change throughout growth and development of individual plants, and that rates of growth and development are highly variable. Plants growing in different environments are likely to grow at different rates, and will be of different sizes and stages of development at a particular age.

When resource allocation varies in response to environmental changes, the plant may modify its morphology or physiology in order to adapt to the new conditions. This process is known as phenotypic plasticity [2]. Aquatic plants, notably, show this adaptive capacity and are better able to respond to their habitat, permitting higher survival rates for the population [3]. Therefore, phenotypic plasticity represents a central feature for evolutionary biology, since it has an adaptive nature [4].

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Salinity levels control, to a large degree, the types of plants and animals that can live in different zones of the estuary. Freshwater species may be restricted to the upper reaches of the estuary, while marine species inhabit the estuarine mouth. Some species tolerate only intermediate levels of salinity while broadly adapted species can acclimate to any salinity ranging from freshwater to seawater. Another role played by saline water in an estuary involves flocculation of particles. Flocculation is the process of particles aggregating into larger clumps. The particles that enter an estuary dissolved in the fresh water of rivers collide with the salt water, and may flocculate or clump together and increase turbidity.

Phenotypic plasticity has been defined as a change in the phenotype expressed by a single genotype in different environments. Reference [5] recognized that phenotypic plasticity could itself be under genetic control and therefore subjected to selective pressure. Nevertheless, a population could respond to an extremely variable environment by becoming both more plastic and more genetically variable. Literature suggests that phenotypic plasticity can evolve when there is sufficient genetic variation due to genetic correlations with other traits that are under selection or to genetic drift. Since phenotypic plasticity influences environmental tolerance, different plastic responses may contribute to differences in the range of environments that species inhabit. Aquatic plants, notably, show this adaptive capacity and are better able to respond to their habitat, permitting higher survival rates for the population [3]. The factors driving the plant phenotypic plasticity may come from biotic or abiotic origins, such as resource availability, sediment heterogeneity and plant density [6,7].

Water cabbage, *Pistia stratiotes*, of the Family Araceae is a floating herb [8]. This species is native to the Amazon and is widely distributed among Brazilian wetlands where it spreads as a weed. It is one of the most studied aquatic plants because of its great ecological importance. It is a habitat for aquatic animals such as young fishes, minnows and insects, and it serves as food for the manatee, an Amazonian species. Moreover, the plant is able to remove heavy metals, nutrients and sediments from the water [9]. The understanding of phenotypic plasticity will be crucial for predicting changes in species distribution, community composition, and crop productivity under global change conditions. The study aimed to evaluate how *Pistia stratiotes* adapt to changing environment more specifically on saline environment.

II. Materials and Methods

A. Study Area

The study was conducted along Agusan River, Butuan City. The first site is located at 09°00.669N and 125°30.516E (mouth of the Agusan river), while Site 2 is approximately five kilometres from the mouth of the river. It is an isolated lake in which the main source of water is coming from the spring with a location of 08°55.339N and 125°33.148E.The physico-chemical parameters were noted using HAC ecological multi-parameter. These parameters were collected as basis for comparison.

B. Plant Sampling and Morphometrics

Plants were collected in September 2015. In this study, the term "individual" is defined as a compact clone of plants possessing one or more leaf (Figure 1). The density of *P. stratiotes* was estimated by the following criteria based on the percentage of water surface covered by the plant: low densities - less than 50% of water surface covered by rosettes; high densities - more than 50% of water surface covered by rosettes [10, 3]. Thirty individuals in each sampling sites were collected. None of the individuals displayed inflorescences or traces of sexual reproduction.

Fig. 1: Individual plant of *P. stratiotes* in (A) freshwater and (B) estuarine environments

The collected plant materials were placed in plastic bags and transported to the laboratory for processing. The following traits were measured in each individual: number of leaf veins, leaf blade length, leaf blade width, root length, and fresh weight.

C. Data Analysis

To examine if there is a difference in the measured variables between the two populations of *P. stratoites*, the two-sample t-test was used.

III. Results and Discussion

A. Physico-Chemical Parameters

Salinity is simply a measure of the amount of salts dissolved in water. An estuary usually exhibits a gradual change in salinity throughout its length, as fresh water entering the estuary from tributaries mixes with seawater moving in from the ocean and changes their physico-chemical parameters. The organisms that live with these changing environments will make their adaptations in order for them to survive. These changes were observed in *P. stratiotes* as they adapt to increased salinity. This species is highly adaptable and able to survive in estuarine environments. Table I shows the physico-chemical parameters between freshwater and estuarine environments where *P. stratiotes* tends to grow.

TABLE I: Physico-Chemical Analysis in the Two Sampling Sites

Parameters	Type of Environment	N	Mean	F	t	p-value
Salinity	Estuarine	3	4.93	1.678	31.018	0.0001*****
	Freshwater	3	20.6			
DO	Estuarine	3	2.92	3.987	11.567	0.0002*****
	Freshwater	3	2.52			
pH	Estuarine	3	5.33	1.432	4.234	0.1672
	Freshwater	3	5.21			
Temperature	Estuarine	3	28.5	1.175	3.987	0.241
	Freshwater	3	29.1			

*$\alpha = 0.05$

As shown in Table I, water salinity in estuarine environment was significantly higher than freshwater environment. An opposite result was obtained in Dissolved Oxygen (DO), in which the estuarine environment significantly has more oxygen content than the freshwater. Other physico-chemical parameters like pH and water temperature have no significant difference between the said sites. These results confirmed that the sampling areas were really freshwater and estuarine environments. These kinds of environments can change the adaptations of the species living within the area.

B. Morphological Plasticity

Leaf width represents a measure of plant growth, which can be affected by different stresses, including salt stress. The results listed in Table II below demonstrate the response of the leaf to salt stress. Generally, the results showed a significant decrease in leaf width as the salinity increase (Figure.2). These results agree with [11], who reported in their study that the increasing concentrations of sodium chloride (NaCl) caused stress to the moth bean plant (*Vigna aconitifolia* L.) which lead to decreased leaf width. This notable decrease could be explained by the negative effect of salt on photosynthesis that lead to the reduction of plant growth, leaf growth, and chlorophyll content [12].

Moreover, there is also a significant decrease of leaf length, numbers and veins in every plant individuals taken from the estuarine environment as compared to those taken from the freshwater environment. These results are possibly due to the accumulation of NaCl in the cell walls and cytoplasm of the older leaves. At the same time, their vacuole sap accumulates more salt and, thereby increases the concentration of salt inside the cells, which ultimately leads to their quick death and cut down. The above results were also confirmed in the study of [12] on the different level of salinity on plants.

The decrease in leaf length of *P. stratiotes* in estuarine environments may be due to the ability of the plant to decrease the size of its lamina so as to compensate for the dehydration due to absorbed molecules of salts. This in turn dissolves salt ions that have accumulated and leads to the subsequent decreased in fresh weight [13]. Also, in the study made by [14] on common vetch (*Vicia sativa* L.), he reported a decreased in the fresh and dry weight of the shoot systems of plants with high concentrations of NaCl. They explained that under osmotic stress, an important consideration is to accumulate osmotically active compounds called osmolytes in order to lower the osmotic potential. These are referred to as compatible metabolites because they do not apparently interfere with the normal cellular metabolism. Molecules like glycerol and sucrose were discovered by empirical methods to protect biological macromolecules against the damaging effects of salinity.

TABLE II: T-test Results on the Leaf Characteristics Between Estuarine and Freshwater Environments

Leaf Characteristic	Type of Environment	N	Mean	F	t	p-value
Length	Estuarine	30	87.567	1.434	29.038	0.0001*
	Freshwater	30	31.200			
Width	Estuarine	30	41.900	4.0493	12.759	0.0001*
	Freshwater	30	26.633			
Weight	Estuarine	30	2.8933	1.7685	3.923	0.0002*
	Freshwater	30	2.0567			
Number of Veins	Estuarine	30	8.8667	1.2545	10.544	0.0001*
	Freshwater	30	5.9333			

*$\alpha = 0.05$

Fig. 2: The leaf width of *P. stratiotes* in (A) freshwater and (B) estuarine environment showing thier morphological differences

In terms of the density of plants, freshwater environment has a higher density of *P. stratiotes* compared to the estuarine environment. In high plant density, space for horizontal growth is restricted, therefore larger petioles and larger leaf surfaces allow an increase in the size of the active photosynthetic area, providing higher exposure to light and enhancing the competitive ability of the individual [10]. When the plant produces more photosynthates they can invest in processes such as growth and maintenance, enhancing survival rates. In high density plants, leaf blade may be important to increase photosynthesis rates.

C. *Variations in the Root System of P. stratiotes*

The root structure is usually considered a highly plastic trait [15], and root length has been considered an important property to evaluate the degree of plant adjustment to new environmental conditions [6]. The competition for resources when in high density may have influenced the morphology of the root of *P. stratiotes* in the freshwater environments. There is not enough space for lateral development of the roots hence, the plant obtain insufficient amount of nutrients. The plant would then compensate by increasing its root lengths in order to better acquire the resources dispersed in the water such as nutrients and oxygen. In this study, longer root lengths were observed in the freshwater population of *P. stratiotes* as compared to the estuarine population. This characteristic seems to be useful in densely crowded conditions, since longer roots may offer an adaptive advantage for individual to explore the environment around them [10].

IV. Conclusion and Recommendations

Excess amount of salt in the water adversely affect the growth and development of *P. stratiotes* as well as the morphological characteristics in leaves and roots of this species. Plant phenotypic plasticity may come from biotic or abiotic origins, such as resource availability, sediment heterogeneity and plant density. When resource allocation varies in response to environmental changes, the plant may modify its morphology or physiology in order to adapt to the new conditions. The results of this study reinforce the knowledge that ecological factors lead to plant adaptation and selection.

However, the real impact of salinity to the morphology of aquatic plants is still controversial and more studies are needed to evaluate such patterns.

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