Consequences of Flow Turbulence: Biomass Partitioning and Plastic Responses in Morphology

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Abstract: *Water movement has a major influence on plant growth in aquatic ecosystems. Although the plants growing in shallow lakes and wetlands are not experiencing mean flow, they also experience water movement as flow turbulence. The objective of the current study was to observe the variations of morphology and biomass partitioning in Egeria densa and Chara fibrosa when exposed to three different turbulence levels. Chara fibrosa has been observed to have shorter internodal lengths, less number of internodes when exposed to increased turbulence, while reducing the lateral branching. Egeria densa has been observed to reduce biomass gain and lateral branching while increasing the shoot:root ratio. Morphological variations of C. fibrosa and E. densa are more or less similar while their responses to flow turbulence directed towards their survival in respective condition.*

Keywords: *Flow turbulence,Egeria densa,Chara fibrosa,Morphoplogy,Biomass*

1. INTRODUCTION

Understanding of the behaviour of aquatic species and their interactions with the environmental parameters are very important for assessing the impact of development projects on floral dynamics, for achieving the goal of sustainable development. Movement of water is a primary factor that regulates the growth and distribution of macrophytes (Madsen et al., 2001), as well as it experience many variations in proceeding development projects. Macrophytes growing in flowing water, such as rivers experience the forces caused by current velocity. Macrophytes grown in lentic environments such as shallow lakes, wetlands do not experience mean flow, however they experience turbulence caused by waves and wind-induced currents. Water movement has both beneficial and adverse effects on plant growth (Madsen et al., 2001). High current velocities and wave action has been observed to reduce plant growth and damage to existing colonisations. Water movement in small scale has been observed to reduce thickness of diffusion boundary layer hence increasing the nutrient uptake (Nishihara and Ackerman, 2006). Plants exposed to current have been observed to show different plastic responses, some of them are highly favorable for their survival at the respective environment. For instance, some species have been observed to be shorter in length, high in belowground biomass allocation in the exposure to current (Szmeja and Galka 2008).

The objective of the current study is to identify the morphological variations and growth in two different submerged aquatic species, *Egeria densa* and *Chara fibrosa*. In which *C. fibrosa* is a species of characean algae, while *E. densa* is an angiosperm.

2. MATERIALS AND METHODS

The experiments were conducted in 6-L (15.7x15.7x24.5 cm^3) microcosms with a water depth of 20.5 cm for a period of 12 weeks under controlled laboratory conditions. An experimental setup was consisted of four microcosms, among them three had different turbulent conditions and the other was the control. The experiment was conducted in duplicate with two exactly same experimental setups under same environmental conditions. The temperature was maintained at 23 ± 2 ^{o}C in a room with fluorescent lighting. The light intensity ranged from 270-240 µmol m^{-2} s^{-1}, and all of the microcosms were subjected to a 12 h/12 h light/dark period.

2.1. Turbulence generation and quantification

Turbulence was generated by vertically oscillating horizontal grids at three oscillating frequencies: 1, 2 and 4 Hz (O'Brien et al. 2004; Hondzo and Lyn 1999). The grid spacing (M) was 2.5 cm and the grid was made of 5-mm square Plexiglas rods (Hondzo and Lyn 1999), with a resulting solidity of 38% (De Silva and Fernando 1994). The stroke length (S) was 3 cm, and the grids were oscillated from the top of the tank the mean grid position being 2 cm below the tank top.

The horizontal velocity profile of the tanks was measured with a two dimensional current meter (SF-5712, Tokyo- keisoku Corporation, Japan). The water velocity was measured at nine different points, which were symmetrically distributed over the area; additionally, the velocity profile was measured at four depths (6, 9, 12 and 15 cm from tank top) for each of the nine points. All of the nine measurements were averaged to calculate the turbulence of velocity in each depth in each tank. Because oscillating grids generate nearly isotropic and homogeneous turbulence, the vertical component should be the same as the measured horizontal component and was thus not measured (De Silva and Fernando 1994). The time constant of the current meter (response time) was 0.05 s, and the measurements were carried out at a 10 Hz frequency for 1 min. The voltage signal was converted to velocity by a calibration graph after the data were extracted with the GL200_800-APS software Version 1.01 (Graphtec Corporation, Japan).

2.2. Plant material and growth conditions

The apical tips obtained from a laboratory culture were planted in the tanks; eight tips were positioned in each tank on peaty sediment that was collected from a nearby pond (Akigasei park, Saitama, Japan). The sediment was passed through a 1-mm sieve to remove debris and floating matter, and a 4-cm layer of sediment was added to each tank. The sediment was used with the purpose of supporting anchorage of plants and providing micronutrients to the media. The plants were allowed to grow in the experimental tanks for two weeks prior to the start of the experiments.

The water column nutrient concentrations were maintained at 0.143 ± 0.014 mM Nitrate and 0.016 ± 0.003 mM Phosphate through the addition of $NaNO_3$ and K_2HPO_4 (Analytical grade reagents, Wako, Japan). The nutrient concentrations were measured weekly according to the standard methods listed in the APHA (1998), and the concentrations were adjusted to fall within the appropriate range by addition and gentle mixing of the previously mentioned stock solutions. The dissolved inorganic carbon in the water was measured with a total organic carbon analyzer (TOC 5000 A, Shimadzu Co. Ltd., Japan), and ranged from 0.467 ± 0.016 mM. The water ammonia concentration was analyzed with the phenate method (APHA 1998), and was determined to be negligible.

2.3 Sampling and laboratory analysis

Plants were harvested at the end of the experiment period (12 weeks). Plant length, branching patterns, length of the branches were measured for *E.densa,* while the number of internodes, internodal length were measured for *C. fibrosa*. The plants were oven dried at 70 °C for 72 h and the dry weight (DW) of the shoots and roots was measured separately.

2.4. Statistical analysis

All of the data are presented as the mean ± SD. The homogeneity of variance test and Levene's check for equality of variances were performed on the data sets prior to the statistical analysis to verify the assumptions of normal distribution and homogeneity of variances. Differences among the various groups were analysed using one way ANOVA to check for significance with post-hoc Tukey's test. For all of these analyses, the SPSS for Windows (Release 13, SPSS Inc., Chicago, IL, USA) statistical software package was used.

3. RESULTS AND DISCUSSION

Measured turbulence velocity fluctuations at each tank are shown on Table 1. Control had no turbulence variation. Turbulence velocity fluctuations were chose to be in the range of turbulence velocity fluctuations observed in natural environment.

Table 1 : Measured turbulence velocity fluctuations (u') at each depth for each tank

Depth (cm)	Turbulence of velocity, u' (cm s^{-1})		
	High	Medium	Low
6.0	2.86 ± 0.79	1.86 ± 0.79	0.81 ± 0.16
9.0	2.64 ± 0.99	1.41 ± 0.58	0.68 ± 0.15
12.0	1.61 ± 0.53	1.30 ± 0.41	0.65 ± 0.08
15.0	1.62 ± 0.44	1.36 ± 0.27	0.67 ± 0.12

Average biomass of the plants exposed to turbulence was significantly reduced in *E. densa* (ANOVA, P<0.05) and the weight to length ratio indicated that biomass gain of the plants were significantly retarded by exposure to flow turbulence (Table 2). The linear weight was 0.57 times lesser in the exposure to high turbulence compared to the plants in the control tank. Mean while shoot:root ratio was decreased in the exposure to high turbulence, showing that biomass allocation for roots become increasing to increase its anchorage capacity, which is a common observation for most plants (Szmeja and Galka, 2008).

Table 2: Average shoot biomass per plant, shoot:root ratio and weight:length ratio of *E. densa* exposed to different turbulent levels, at the end of experimental period

Level of turbulence	Average shoot biomass (g DW/plant)	Shoot: root ratio	Weight/ Length ratio (mg DW/ cm length)
High	0.06 ± 0.004	6.05 ± 0.06	2.52 ± 0.38
Medium	0.23 ± 0.023	5.79 ± 0.16	3.37 ± 0.33
Low	0.28 ± 0.016	7.76 ± 0.18	2.91 ± 0.04
Control	0.37 ± 0.058	9.90 ± 0.34	4.36 ± 0.20

Chara fibrosa showed clear morphological variations when exposed into turbulence. Number of internodes per plant reduced significantly (ANOVA, P<0.05) while a reduction of internodal length also was observed (Table 3). Usually the maximum internodal length was observed in the basal part of the shoot, while the maximum internodal length was more than two times lesser in the exposure to high turbulence. Same has been observed in other studies also with shorter internodal lengths at basal parts in shallow lakes (Asaeda et al., 2007).

Table 3: Number of internodes, average number intermodal length and maximum intermodal length of *C. fibrosa* at the end of the experiment period

Level of turbulence	Number of internodes	Average internodal length	Maximum internodal length
High	2.3 ± 0.6	1.13 ± 0.06	1.60 ± 0.10
Medium	5.7 ± 2.1	1.40 ± 0.68	1.85 ± 0.50
Low	7.0 ± 1.0	1.46 ± 0.76	2.45 ± 0.07
Control	9.3 ± 0.6	2.32 ± 1.09	4.00 ± 0.87

Plastic responses of plant morphology has been observed to reduce the force on the plant when they are exposed to current by many authors (Puijalon and Bornette, 2006; Shutten and Davy, 2000). Clonal growth patterns have an influence in current velocity and vise versa. Both species showed (Table 4) results agreeing for these observations in the exposure to the flow turbulence also. Lateral branching of the plants were reduced and the branch length was also reduced. They were more preferred to be singular units at the exposure to the turbulence may be because lateral branching may enhance drag force they experience.

Table 4: Average number of branches per plant and average branch length (cm) of *E. densa* and *C. fibrosa* exposed to different turbulent levels, at the end of experimental period

	High	Medium	Low	Control
Average number of branches per plant				
E. densa	1.00 ± 0.00	1.75 ± 0.50	2.00 ± 0.82	3.50 ± 1.73
C. fibrosa	0.00 ± 0.00	0.75 ± 0.50	2.75 ± 0.96	3.25 ± 0.96
Average branch length (cm)				
E. densa	3.28 ± 0.95	4.95 ± 1.33	5.44 ± 1.45	7.54 ± 2.34
C. fibrosa	0.00 ± 0.00	0.88 ± 0.65	1.78 ± 0.39	5.13 ± 2.60

Plants exposed to water movement has been observed to show different plastic responses and observed to be depending on their own morphology. Species such as *Myrophyllum spicatum*, *Elodea canadensis* has been observed to have more streamlined shapes, when living in moving water and it has been observed that there is a tendency to reduce the drag force by this shape (Sand Jensen, 2008). These morphological variations have been observed to be outcome of variations of plant hormone metabolism and catabolism as well as stress responses of the plants (Ellawala et al., 2011a Ellawala et al., 2011b).

4. CONCLUSIONS

Plants exposed to turbulence show significant morphological variations and biomass partitioning as results of the exposure to flow turbulence. They may reduce the growth and biomass gain of the plant. In fact it is beneficial for the survival of the plant in that respective environment, since it can reduce the force exerted on the individuals.

5. ACKNOWLEDGEMENTS

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