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Exploring the influence of detrital loading of *Eichhornia crassipes* on water properties under different nutrient gradients in mesocosm experiments

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Abstract

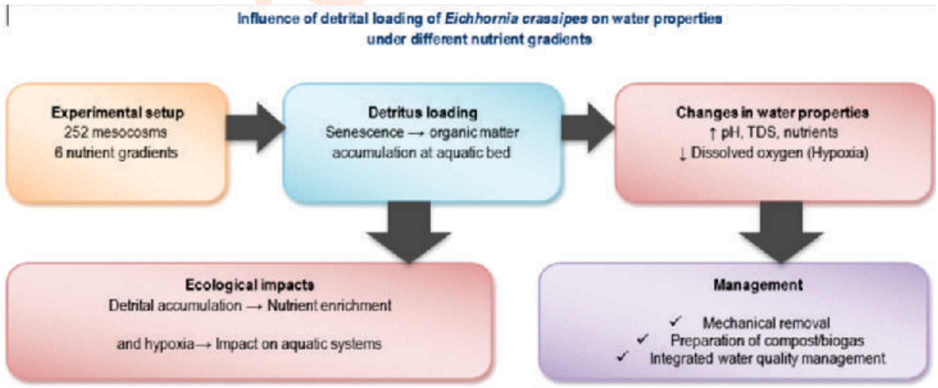
Aim: This mesocosm study assessed the ecological impacts of the detrital loading of *Eichhornia crassipes* (water hyacinth) on aquatic ecosystems by analyzing changes in the water physico-chemical properties across six nutrient gradients, mesotrophic, eutrophic, and hyper-eutrophic, each at low and high levels. The study focused on detritus-induced hypoxia in nutrient-rich systems and aimed to inform effective management strategies for *E. crassipes* invasions.

Methodology: A total of 252 mesocosms were established in a randomized block design using modified Hoagland solution adjusted to represent six nutrient levels. *E. crassipes* plants were acclimatized for 15 days before stocking, and control sets were maintained separately. Water quality parameters and detrital loading were monitored fortnightly, with data analyzed using One-way ANOVA, PCA, regression, and cluster analysis.

Results: Significant variation was observed in total dissolved solids, pH, total alkalinity, hardness, dissolved oxygen, free CO_2, nitrate-N, and phosphate-P across treatments. Higher detrital loading under eutrophic and hyper-eutrophic conditions increased nutrient levels and reduced dissolved oxygen, indicating hypoxia. Correlation analysis revealed positive associations of detritus with pH, nitrate-N, and phosphate-P, and negative with dissolved oxygen.

Interpretation: Elevated nutrients accelerate the detrital loading of *E. crassipes* degrading water quality. The study advocates for nutrient control, sustainable biomass utilization, and integrated water quality management to maintain aquatic ecosystem health.

Key words: Detritus dynamics, *Eichhornia crassipes*, Mesocosm, Trophic gradient, Water quality



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Introduction

Eichhornia crassipes (Mart.) Solms, commonly known as water hyacinth is a clonal aquatic plant that has become the most harmful intruders of wetland habitat. Although it originated in South America, presently it has dispersed to more than 50 countries across the world (Gao and Li, 2004). It is included in the world's most invasive species list (Rezania *et al.,* 2015), which can be attributed to its ability to produce vast number of seeds in the aquatic systems (Verma *et al.,* 2003; Pe´rez, *et al.,* 2015; Cronk and Fennesy, 2016) and can remain viable for nearly two decades in the sediment (Wang *et al.,* 2009; Perez *et al.,* 2011) besides its fast growth via daughter plants (Li *et al.,* 2006; Li and Wang, 2011). In addition, the allelochemical properties of this plant prevent the growth of other species nearby (Shanab *et al.,* 2010). All these invasion attributes affect native biodiversity (Bishop *et al.,* 2010; Kominoski *et al.,* 2010) and decrease the efficiency and ecosystem service potentials of aquatic systems leading to a major ecological, economic, and social concerns. Several *in situ* investigations have demonstrated that *E. crassipes* responds strongly to nutrient enrichment (Chen *et al.,* 2010; Li *et al.,* 2012; Gao *et al.,* 2016).

Upon senescence, this invasive aquatic plant contributes substantial detrital biomass, serving as a significant source of organic matter and nutrients within the aquatic ecosystems (Balasubramanian *et al.,* 2012). The bacterial decomposition of this detritus alters both the physical and chemical characteristics of water body, particularly influencing carbon cycling and nutrient dynamics (Masifwa *et al.,* 2004; You *et al.,* 2014; Mwamburi, 2018). Microbial breakdown of plant material has been found to significantly impact the water quality parameters, including dissolved oxygen, pH, electrical conductivity, turbidity, and nutrient concentrations such as nitrates and phosphates (Masifwa *et al.,* 2004; Gamage *et al.,* 2005). Liu *et al.* (2010) observed that elevated levels of atmospheric CO_2 consistently stimulated the growth of *E. crassipes* across different nutrient conditions, indicating its potential for increased infestations in future eutrophic water bodies. In view of the above, it may be mentioned here that although the ecological implications of *E. crassipes* have been widely studied, there remains a substantial gap in understanding how its detrital inputs affect water quality across different nutrient gradients. Addressing this gap, the present study utilizes controlled mesocosm experiments to systematically examine the influence of detrital loadings of *E. crassipes* on water quality parameters under varying nutrient gradients, ranging from mesotrophic to eutrophic to hypereutrophic conditions, each with low and high nutrient loads. This study is crucial for understanding the indirect impacts of detrital loading of *E. crassipes* on water quality across different nutrient gradients, a study that remains underexplored despite extensive spread of this aquatic species.

Materials and Methods

The study was conducted during December 2021 to June 2022 in a greenhouse setup following randomized block design. The set up allowed 70% light intensity and prevented the effect of rain so that the nutrient concentration of water in the experimental tubs remain unaltered. A modified Hoagland solution was prepared following Ghanati *et al.* (2005). Three nutrient regimes like mesotrophic, eutrophic, and hypereutrophic were prepared using the modified Hoagland solution following Burns *et al.* (2000). Each trophic condition was further subdivided into two levels: low and high, resulting in six distinct nutrient gradients: mesotrophic-low, mesotrophic-high, eutrophic-low, eutrophic-high, hypereutrophic-low, and hypereutrophic-high following Burns *et al.* (2000). The control comprised the modified Hoagland solution, where the concentration of N and P was adjusted to oligotrophic concentration following Burns *et al*. (2000). Prior to the experiment, uniform-sized specimens of *Eichhornia crassipes* were collected from water bodies near Assam University, Silchar campus. These plants were acclimatized in the control (modified Hoagland solution) for 15 days following Lin and Li (2016). After acclimation, three individuals of *E. crassipes* were introduced into each experimental tub with a surface area of 0.70 m^2 filled with the respective nutrient gradient solutions.

A total of 252 tubs were maintained throughout the experiment. Water levels in each tub were consistently regulated by replenishing the respective nutrient solutions at regular intervals (Fig. 1, 2, and 3). During the study period, both atmospheric temperature in the greenhouse and water temperature in the experimental tubs were regularly monitored using mercury bulb thermometer. Detrital load and corresponding water samples from each set of experimental tubs (in triplicate) under different trophic conditions were collected at an interval of 15-days. The physico-chemical properties of water in the experimental tubs like water temperature (WT); total suspended solid (TSS); total dissolved solid (TDS); electrical conductivity (EC); pH; total alkalinity (TA); hardness as $CaCO_3$ (H-$CaCO_3$); dissolved oxygen (DO); free carbon di-oxide (CO_2); nitrate-N (NO3-N); phosphate-P (PO_4-P) were analyzed following the method of Trivedi and Goel (1984) and APHA (2017). Every fortnight, large-sized detritus from each experimental tub was manually collected, while smaller particles were retrieved by filtering the tub water through large funnels lined with filter paper. The detrital biomass was noted down by oven drying it for 48 hr at 70°C (Mishra, 1968; Gibbs *et al.,* 2007). Compilation of data and use of various statistics like paired T-test, ANOVA, PCA, linear regression and dendrogram were done using the softwares MS Excel, SPSS version 20, and PAST version 4.13.

Results and Discussion

The perusal of data revealed significant variations in the detrital loadings across different nutrient gradients (F-ratio=219.58; $p<0.01$). Most physico-chemical properties of water like TDS (F-ratio=8.73; $p<0.01$), pH (F-ratio=71.16; $p<0.01$), TA (F-ratio=207.11; $p<0.01$), H-CaCO3 (F-ratio=175.85; $p<0.01$), DO (F-ratio=36.69; $p<0.01$), CO2 (F-ratio=43.60; $p<0.01$); nitrate-N (F-ratio=111.36; $p<0.01$), phosphate-P(F-ratio=29.06; $p<0.01$) varied significantly across different nutrient gradients.

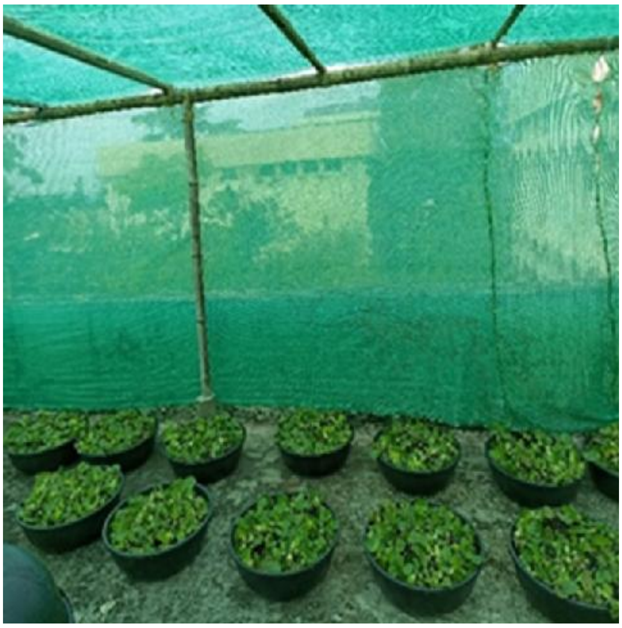

Fig. 1: Experimental setup.

Fig. 2: *E. crassipes* in experimental tub.

Fig. 3: Detritus of *E. crassipes*.

However, WT, TSS, and EC did not vary significantly (Table 1). Further analysis using Tukey's post-hoc test revealed that there were no significant variations in TDS, pH, H-$CaCO_3$, and detrital loading of *E. crassipes* between Control and T1 treatment (Mesotrophic-low) (Table 1), which indicates that mild input of nutrients like Nitrate-N and Phosphate-P in aquatic system does not affect the water properties and detrital loading considerably. However, with further increase in nutrient loading from mesotrophic-high to hypereutrophic-high, significant variations were observed in most of the water properties and the detrital loading of *E. crassipes*. The extent of variations in the physico-chemical properties of water and detrital loadings of *E. crassipes*

Table 1: Variations in water properties and detrital loading of *Eichhornia crassipes* under different nutrient gradients in mesocosm experiments

Parameters	Treatments							F-ratio
	C	T1	T2	T3	T4	T5	T6	
Water temperature (WT; °C)	22.6±0.29^{a}	22.3±0.26^{a}	22.5±0.27^{a}	22.25±0.17^{a}	22.81±0.14^{a}	22.92±0.20^{a}	22.52±0.40^{a}	0.26
Total suspended solid (TSS; mg l^{-1})	0.007±0.005^{a}	0.007±0.002^{a}	0.01±0.002^{a}	0.012±0.004^{a}	0.014±0.03^{a}	0.10±0.001^{a}	0.011±0.002^{a}	0.09
Total dissolved solid (TDS; mg l^{-1})	28.84±0.97^{a}	24.86±1.44^{a}	28.83±0.41^{b}	30.64±0.63^{a}	30.64±0.87^{a}	31.94±0.51^{a}	31.61±0.94^{a}	8.73**
Electrical conductivity (EC; µs cm^{-1})	29.27±0.62^{a}	29.58±0.42^{a}	29.75±0.52^{a}	30.57±0.52^{a}	30.56±0.52^{a}	30.97±0.92^{a}	31.80±0.97^{a}	0.77
pH	7.10±0.07^{a}	7.37±0.04^{a}	7.54±0.04^{b}	7.73±0.04^{c,b}	7.90±0.04^{d}	8.29±0.03^{e}	8.35±0.03^{f,e}	71.16**
Total alkalinity (TA; mg l^{-1})	23.84±0.59^{a}	26.54±0.69^{a}	31.28±1.0^{a}	46.33±0.36^{b}	51.52±1.03^{c}	2.37±0.05^{d}	2.67±0.05^{e,d}	207.11**
Hardness as $CaCO_3$ (H-$CaCO_3$; mg l^{-1})	11.32±0.1^{a}	13.26±0.14^{a}	15.28±0.22^{b}	16.59±0.16^{c}	17.34±0.18^{d,e}	17.78±0.12^{e}	17.92±0.10^{f,d,e}	175.85**
Dissolved oxygen (DO; mg l^{-1})	6.99±0.06^{a}	7.18±0.07^{a}	7.44±0.05^{a}	7.60±0.05^{b,a}	6.71±0.04^{c,b}	6.97±0.05^{d,c}	6.17±0.06^{e,c}	36.69**
Free carbon di-oxide (CO_2; mg l^{-1})	1.68±0.04^{a}	1.75±0.04^{a}	1.78±0.04^{a}	1.81±0.03^{a}	1.79±0.03^{a}	2.37±0.05^{b}	2.67±0.05^{c,b}	43.60**
Nitrate-N (NO_3-N; mg l^{-1})	0.005±0.001^{a}	0.05±0.06^{a}	1.03±0.08^{a}	1.19±0.10^{a}	2.18±0.16^{b,a}	2.19±0.17^{c}	3.34±0.05^{d,c}	111.36**
Phosphate-P (PO_4-P; mg l^{-1})	0.003±0.009^{a}	0.009±0.002^{a}	0.01±0.001^{a}	0.01±0.003^{a}	0.06±0.003^{a}	0.16±0.03^{b,a}	0.48±0.03^{c}	29.06**
Detrital loading (gm m^{2})	4.86±0.21^{a}	5.14±0.22^{a}	5.12±0.21^{b}	5.30±0.22^{c}	5.44±0.24^{d}	5.69±0.22^{e,f}	5.93±0.22^{f,d}	219.58**

Mean ±SE; n=36, For F-ratio df=6; **indicates p<0.01 and * indicates p<0.05; C- Control; T1- Mesotrophic (low); T2- Mesotrophic (high); T3- Eutrophic (low);T4- Eutrophic (high); T5- Hyper-eutrophic (low); T6- Hyper-eutrophic (high); mean value of the respective parameter with similar alphabet (s) are not significantlydifferent from each other whereas mean values of the respective parameters with dissimilar alphabet(s) are significantly different from each other (p<0.01 asper Tukey's post-hoc analyses)

Table 2: T-values indicating the extent of variations in physico-chemical properties of water and detrital loadings of *Eichhornia crassipes* under different nutrient gradients with respect to control in mesocosm experiments

Parameters	C-T1	C-T2	C-T3	C-T4	C-T5	C-T6
Water temperature (°C)	-2.63	-6.03	-6.44	-9.35	-16.43	-19.37
Total suspended solids (mg l^{-1})	-0.24	-1.69	-3.48	-4.84	-3.69	-5.61
Total dissolved solids (mg l^{-1})	2.75	0.19	-3.04**	-4.99**	-1.47**	-3.96**
Electrical conductivity(µs/cm)	-0.38	-0.60	-3.52	-2.21	-2.20	-3.45
pH	-4.25**	-6.56**	-7.29**	-11.67**	-15.60**	-17.67**
Total alkalinity (mg l^{-1})	-8.48**	-11.87**	-23.74**	-35.95**	-36.45**	-51.10**
Hardness as $CaCO_3$ (mg l^{-1})	-14.36**	-15.82**	-24.07**	-24.60**	-56.95**	-38.85**
Dissolved oxygen(mg l^{-1})	-2.63	-6.03**	-6.44**	-9.35**	-16.43**	-19.37**
Free carbon dioxide (mg l^{-1})	-8.65**	-11.64**	-11.15**	-12.43**	-18.44**	-23.53**
Nitrate-N (mg l^{-1})	-7.56**	-16.06**	-12.84**	-12.12**	-22.30**	-24.34**
Phosphate-P (mg l^{-1})	-2.77	-5.90**	-8.61**	-1.85**	-2.90**	-14.34**
Detrital loading	-3.28**	-2.04**	-3.85**	-4.85**	-6.68**	-9.12**

n=36; df=35; **indicates p<0.01 and * indicates p<0.05; C- Control; T1- Mesotrophic (low); T2- Mesotrophic (high); T3- Eutrophic (low); T4- Eutrophic (high); T5- Hyper-eutrophic (low); T6- Hyper-eutrophic (high)

under different nutrient gradients with respect to control (Table 2), were analyzed. It was observed that DO, phosphate-P, did not show significant variations between control and T 1, while TDS did not show significant variations between control and T1, and control and T2. However, pH, TA, H-$CaCO_3$, CO_2, nitrate-N, and detrital loading showed significant variations between control and treatments under different nutrient gradients. These results therefore suggest that nutrient inputs in aquatic systems lead to

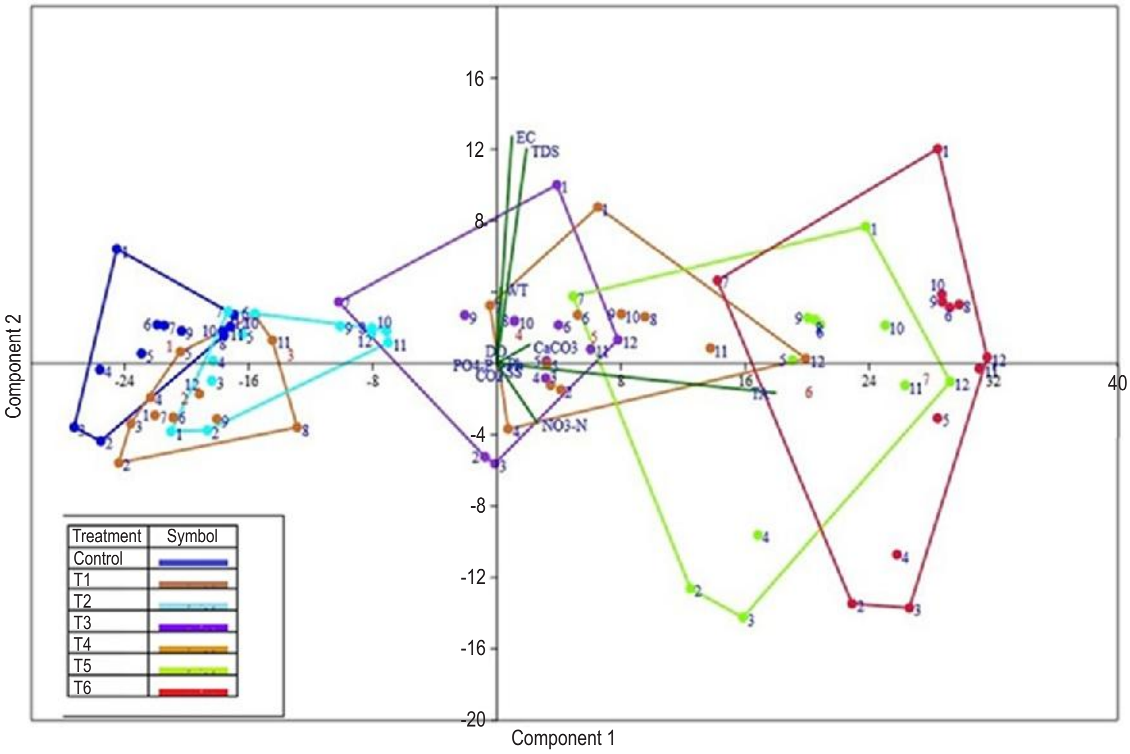

Fig. 4: Group-wise PCA to identify and differentiate different water properties under different nutrients gradients and detrital loadings of *E. crassipes* in mesocosm experiments. Here, the size of the polygon is directly proportional to the overall variability of the water properties, while overlapping regions amongst the polygons show similarity in conditions. C-Control; T1- Mesotrophic (low); T2- Mesotrophic (high); T3- Eutrophic (low); T4- Eutrophic (high); T5- Hyper-eutrophic (low); T6- Hyper-eutrophic (high); WT- Water temperature; TSS- Total suspended solid; TDS- Total dissolved solid; EC- Electrical conductivity; Ph; TA- total alkalinity; $CaCO^3$-Hardness as $CaCO_3$; DO- Dissolved oxygen, CO_2- Free carbon di-oxide; NO_3-N- Nitrate-N; PO_4-P- Phosphate-P.

significant changes in detrital loading, accompanied by alterations in most water properties. Group-wise PCA of water properties under different nutrient gradients and detrital loadings of *E. crassipes* (Fig. 4) showed overlapping of control, T1 and T2, thus indicating that these treatments exhibit similar water property characteristics. Likewise, similar sharing of water property characteristics was observed for T3 and T4 and for T5 and T6. Larger polygons in treatments 3, 4, 5 and 6 indicate more variability in water parameters with increase in nutrient concentration and detrital loading which can be attributed to complex interactions of detritus decomposition, increased nutrient load, and microbial activity.

Comparison of loading scores of variables on principal components for water properties under different nutrient gradients loaded with detritus of *E. crassipes* in mesocosm experiments (Table 3) revealed three significant principal components for Control, T1, T2, T3, T5 and T6, and four components for T4. These components explained 83.40% of the total variance in Control, 72.06% in T1, 72.31% in T2, 70.52% in T3, 74.69% in T4, 68.85% in T5, and 77.82% in T6 (Table 3), respectively. Under control conditions, the water quality was primarily influenced by TSS, WT pH and TDS, indicating a relatively balanced system with minimal nutrient stress. In mesotrophic treatments (T1 and T2), the increasing influence of TDS, EC and TA suggested moderate ionic enrichment and the onset of nutrient accumulation. In eutrophic treatments (T3 and T4), strong loadings of NO_3-N and PO_4-P, along with elevated WT, TSS, EC, and pH, indicate nutrient enrichment and organic matter buildup, significantly altering water chemistry. Under hyper-eutrophic conditions (T5 and T6), the dominance of EC, TDS and TSS, together with shifts in pH, TA, and hardness as $CaCO_3$, highlights a state of advanced eutrophication and degraded water quality. Overall, the PCA results demonstrate a clear nutrient-driven transformation of water quality along the trophic gradient.

As the detrital input from *E. crassipes* increased, the influence of physical (TSS), chemical (TDS, EC, pH, and TA), and nutrient (NO_3-N, PO_4-P) parameters became more pronounced and interrelated. This progression reflects a shift from a stable aquatic environment to one undergoing progressive eutrophication, marked by ionic accumulation, reduced oxygen availability, and nutrient overloading, ultimately indicating a decline in water quality and ecosystem integrity (Abba and Sankarannair, 2024). Linear regression between detrital loading

Table 3: Comparison of loading scores of variables on principal components rotated according to Varimax method for water properties under different nutrient gradients loaded with detritus of *E. crassipes* in mesocosm experiments

Principal components		**Control**			**T1**			**T2**			**T3**			**T4**				**T5**			**T6**		
		VF1	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**	**VF4**	**VF1**	**VF2**	**VF3**	**VF1**	**VF2**	**VF3**
Loading score	WT	0.31	0.75	0.43	0.08	0.82	0.17	0.04	0.05	0.77	0.78	-0.22	-0.07	0.47	-0.81	-0.03	-0.03	0.85	0.37	-0.24	0.62	0.69	0.15
	TSS	0.88	0.27	-0.23	0.74	0.55	0.16	0.40	0.61	0.59	0.83	0.06	0.30	0.70	-0.51	-0.21	0.07	0.19	0.56	0.44	0.85	0.12	0.16
	TDS	0.22	0.85	0.61	-0.09	0.05	0.96	0.41	-0.05	0.65	-0.18	0.81	0.03	0.50	0.59	0.14	-0.18	0.85	-0.06	-0.40	0.20	0.88	0.17
	EC	-0.34	0.25	0.31	0.82	0.11	-0.21	0.81	0.17	0.03	-0.08	0.75	0.09	0.15	0.47	0.67	-0.13	0.88	0.07	-0.33	0.04	0.94	-0.07
	pH	0.71	0.52	0.08	0.58	0.18	-0.13	0.09	0.87	0.03	-0.06	0.11	0.90	0.83	-0.03	-0.08	-0.10	0.20	-0.07	0.53	-0.04	0.01	0.91
	TA	0.67	0.17	-0.24	0.41	0.75	0.17	0.20	0.73	0.50	0.11	0.08	0.85	0.82	-0.14	-0.20	-0.05	0.17	0.10	0.57	0.18	-0.08	0.84
	H-$CaCO_3$	0.22	-0.07	-0.26	-0.03	0.82	-0.12	0.68	0.03	0.37	0.69	0.23	-0.05	0.56	-0.09	0.39	0.36	0.74	0.34	-0.07	0.85	0.23	0.02
	DO	0.67	0.13	-0.28	0.27	0.52	-0.06	0.27	0.46	-0.26	-0.34	-0.58	0.48	0.19	.063	-0.87	0.02	0.45	0.54	-0.02	0.75	0.40	0.03
	CO_2	0.55	0.69	0.31	0.85	0.03	0.01	0.68	0.48	-0.29	0.46	0.43	0.06	0.63	-0.21	0.25	0.13	-0.43	-0.68	0.15	-0.71	-0.03	-0.03
	NO_3-N	-0.90	-0.28	0.20	-0.77	-0.49	-0.07	-0.84	-0.20	-0.34	-0.94	-0.03	0.03	-0.24	0.90	0.01	0.07	-0.02	-0.61	-0.18	-0.39	-0.71	0.17
	PO_4-P	-0.83	-0.28	0.18	-0.92	-0.12	-0.03	-0.88	-0.31	-0.24	-0.93	0.14	0.11	-0.02	0.01	-0.08	0.91	0.08	0.78	0.12	-0.86	-0.23	-0.11
Eigen value		4.35	2.41	2.40	4.02	2.80	1.09	3.55	2.30	2.09	3.94	1.90	1.90	3.19	2.39	1.57	1.05	3.31	2.37	1.88	3.90	2.97	1.68
% of variance		39.57	21.94	21.88	36.55	25.53	9.97	32.30	20.96	19.04	35.84	17.35	17.32	29.07	21.78	14.30	9.54	30.10	21.55	17.12	35.47	27.07	15.27
% of cumulative variance		39.57	21.88	83.40	36.55	62.09	72.06	32.30	53.26	72.31	35.84	53.19	70.52	29.07	50.85	65.15	74.69	30.10	51.65	68.85	35.47	62.54	77.82

VF, Variance factors; Bold values indicate strong loading score; Control; T1- Mesotrophic (low); T2- Mesotrophic (high); T3- Eutrophic (low); T4- Eutrophic (high); T5- Hyper-eutrophic (low); T6- Hyper-eutrophic (high); WT- Water temperature; TSS- Total suspended solid; TDS- Total dissolved solid; EC- Electrical conductivity; Ph; TA- Total alkalinity; H-CO_3- Hardness $CaCO_3$; DO- Dissolved oxygen; CO_2- Free carbon dioxide; NO_3-N- Nitrate-N; PO_4-P- Phosphate-P

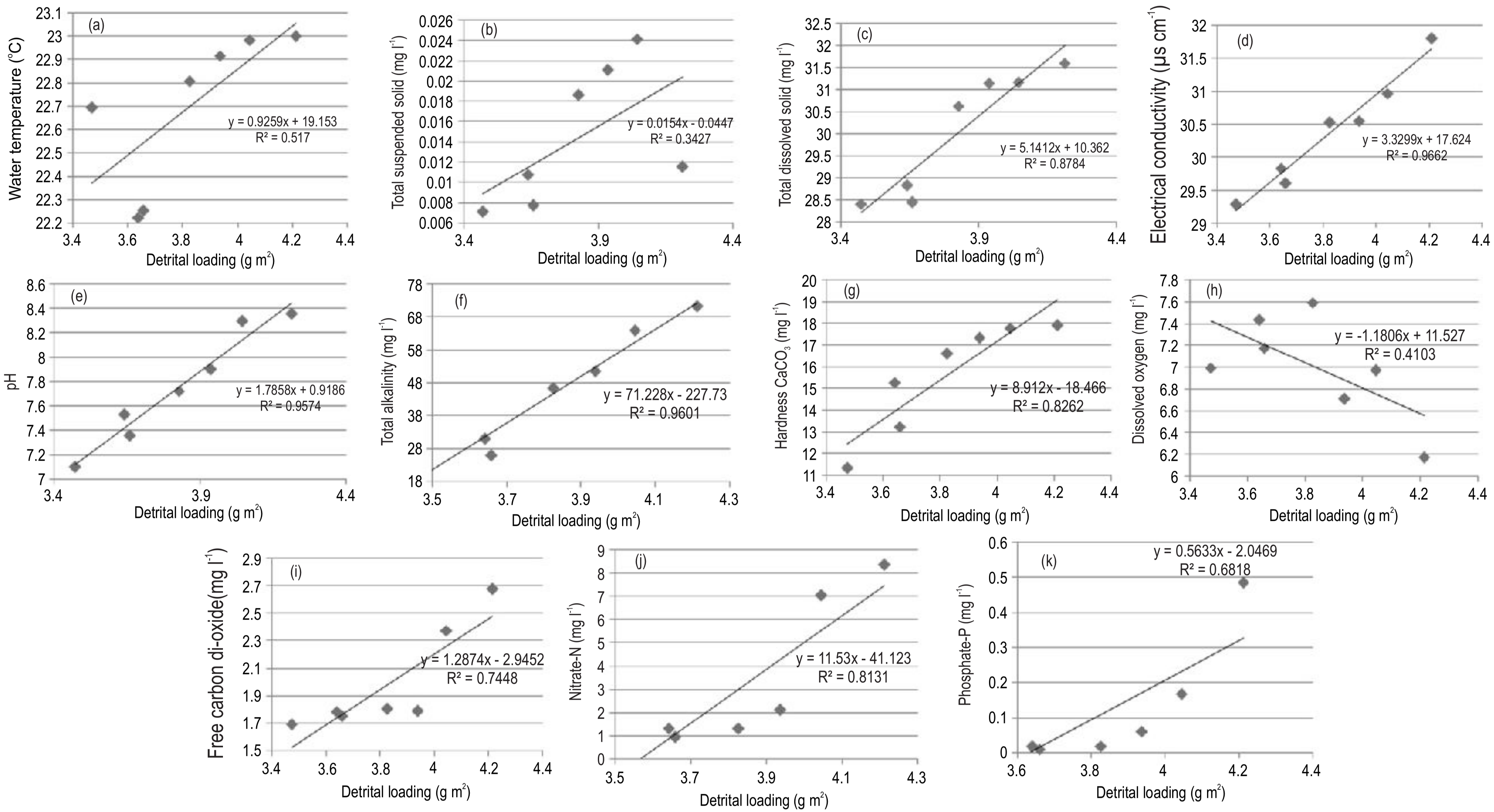

Fig. 5: Linear regression analyses of detrital loading of *E. crassipes* in relation to physico-chemical properties of water under different treatments in mesocosm experiments; A: Detrital loading Vs Water temperature; B: Detrital loading Vs Total suspended solid; C: Detrital loading Vs Total dissolved solid; D: Detrital loading Vs Electrical conductivity; E: Detrital loading Vs pH; F: Detrital loading Vs Total alkalinity; G: Detrital loading Vs Hardness as $CaCO_3$; H: Detrital loading Vs Dissolved oxygen; I: Detrital loading Vs Free carbon-dioxide; J: Detrital loading Vs Nitrate-N; K: Detrital loading Vs Phosphate-P.

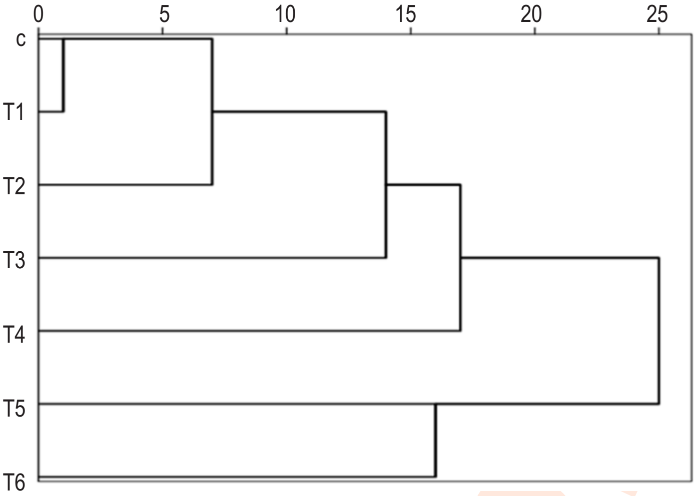

Fig. 6: Dendrogram showing cluster analysis of the detrital loading of *E. crassipes* under different nutrient gradients in mesocosm experiments. C-Control; T1-Mesotrophic-low; T2- Mesotrophic-high; T3-Eutrophic-low; T4-Eutrophic-high;T5-Hypereutrophic-low; T6-Hypereutrophic-high.

of *E. crassipes* and different physico-chemical properties of water under different treatments in mesocosm experiments (Fig. 5) aimed to quantify the degree to which detrital loading affects different physico-chemical properties of water, thereby providing insights into ecosystem changes driven by deposition of detrital matters of *E. crassipes*. The results indicate that detrital loading of *E. crassipes* had a positive relation with WT, TSS, TDS, EC, pH, TA, H-CaCO3, CO_2, NO_3-N, PO_4-P (Fig. 5 A, B, C, D, E, F, G, I, J, K) while a negative relation with DO (Fig. 5 H). However, significant positive relation of detrital loading of *E. crassipes* could be observed for TDS (Fig. 5 C; R^2 =0.8784; p< 0.05), EC (Fig. 5D; R^2 =0.9662; p <0.05), pH (Fig. 5E; R^2=0.9574; p < 0.05), TA (Fig. 5F; R^2 =0.9601; p < 0.05), H-$CaCO_3$ (Fig. 5G; R^2 =0.8262; p <0.05), CO_2 (Fig. 5I; R^2 =0.748; p <0.05) and NO_3-N (Fig. 5 J; R^2 =0.8131; p <0.05) of water in the mesocosm. These results, therefore, indicate that increased nutrient and subsequent detrital loadings and its decomposition in aquatic systems increases the concentration of dissolved ions, thereby elevating TDS (Villamagna and Murphy, 2010; Gezie *et al.,* 2018) and EC (Leitei *et al.,* 2016).

Decomposition of detritus leads to production of CO_2 (Scheffer *et al.,* 2001; Rejmankova and Sirova, 2007;Gao *et al.,* 2017; Pan *et al.,* 2020). In addition, mineralization of organic nitrogen contained in the detrital matters leads to the formation of NO_3-N, contributing to higher nitrate concentrations in water (Lasfar *et al.,* 2007; Singh, 2013; Li, 2023). With increase in nutrient availability, the photosynthetic activity of live plants in the experimental tubs intensifies, leading to greater uptake of dissolved CO_2. This reduces the concentration of carbonic acid and availability of hydrogen ion, thereby causing an increase in water pH (Xie *et al.,* 2004; Masifwa *et al.,* 2004; Li *et al.,* 2012). Cluster analysis of detrital loading of *E. crassipes* under different nutrient gradient (Fig. 6) shows that treatments with similar nutrient levels and detrital characteristics are clustered together, thereby indicating the influence of nutrient gradients on detrital dynamics. It showed clustering of mesotrophic treatments (T1 and T2), indicating similar detrital characteristics under moderate nutrient conditions.Distinct cluster formation of eutrophic and hypereutrophic treatments (T3 to T6), suggests that higher nutrient levels significantly alter detrital properties compared to control or mesotrophic conditions (Ripley *et al.,* 2006). The study therefore reveals that higher nutrient conditions in aquatic systems accelerate detrital loading of *E. crassipes* and its decomposition, releasing additional nutrients and degrading water quality.

Detrital effects are most pronounced in eutrophic and hyper-eutrophic conditions, creating hypoxic environments which is harmful to aquatic life (Rommens *et al.,* 2003). The findings of this study recommends implementation of strategies to control nutrient inputs and mitigate eutrophication of water bodies. This may be possible by mechanical harvesting of *E. crassipes* before its peak decomposition followed by sustainable utilization, such as through vermicomposting (Gajalaxmi *et al.,* 2002) and biogas production (Rathod *et al.,* 2018) to minimize its ecological impact while generating economic benefits. Besides, the findings underline the need for integrated water quality management to mitigate detritus-driven ecosystem degradation due to *E. crassipes* and ensure the sustainability of aquatic habitats. As Integrated water quality management (IWQM) offers a holistic and proactive framework to manage organic pollution of upstream drivers like eutrophication and downstream impacts like detrital loading and habitat loss, the present study also emphasizes the importance of adopting IWQM to address detritus-induced ecosystem degradation caused by *E. crassipes* and to safeguard the long-term sustainability of aquatic habitats.

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