Weed-bed Macro-invertebrate Composition and Abundance in Relation to Water Hyacinth (*Eichhornia crassipes* (Mart) Solms) in the North-Eastern Lake Tana, Ethiopia

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Abstract: *The composition and abundance of weed-bed macro-invertebrates were assessed using data from Lake Tana from September, 2012 to May, 2013. Higher weed-bed macro-invertebrates density (6395ind/m² inaverage) was recorded in the weed-infested sites. Ephemeroptera was the dominant taxa in weed-infested sites while Hemiptera in the non-infested sites. Statistically there were no significant spatial variations in the density of weed-bed macro-invertebrates in the weed infested and non-infested sites except coleopteran. Seasonally, however, Ephemeroptera, Diptera and Coleoptera showed highest peak density during the dry season in the weed-infested site. While, Hemiptera and Basommatophora, during the rainy reason and Diptera during post rainy season showed peak density in the non-infested sites. The results obtained from Hilsenhoff-Family Level Biotic Index H-FBI categorized site Ribas the highest organic and nutrient polluted site while site Debre-Sinaas the least perturbed site. Though, the results of H-FBI did not show clear difference between the weed-infested and non-infested sites, the observed spatial disparity in taxa may be explained by the variation in the density of prey items, interstitial space for refuge, and presence of predators coupled with small variations in physico-chemical factors. Presence of higher density of beetle species of the families Dytiscidae and Hydrophylidae at the leaf and root interface of water hyacinth seemed to have association between them. Therefore, further investigation is recommended to see their effect and interactions with the weed so as to use those beetles as biological agent to control the weed.*

Keywords: Biotic index; niche diversity; organic pollution; tolerance level; weed

1. Introduction

Ecological effects of Invasive Alien Species (IAS) on inland water ecosystems vary significantly depending upon the invading species, the extent of the invasion, and the vulnerability of the ecosystem being invaded (Levine, 2000). Loss and degradation of biodiversity due to IAS can occur at all levels of biological systems, extending from species to ecosystem levels, and may involve major alterations to the physical habitat, water quality, essential resources and ecological processes. These effects can vary in terms of the lapse of time between the initial introduction and subsequent spread of an IAS, the severity of its effect, the likelihood of synergistic interactions with other threatening processes, and the potential for initiation of a cascade of effects ramifying throughout an entire ecosystem (Levine, 2000; Shuvra, 2013).

Aquatic plants are ideal habitats for macro-invertebrate colonization (Arti *et al*., 2015). However, non-native species such as water hyacinth, through restricting the photosynthetic activities of other aquatic macrophytes via shading effect, may seriously alter the ecosystem functions that other macrophytes provide (Luken and Thieret, 1997). Comparative studies on non-native species, water hyacinth and native species show that native macrophytes supported different macro-invertebrate assemblages (Toft *et al*., 2003).

On the other hand, water hyacinth mat at the edge of open water or the presence of few water hyacinth plants support highest density of macro-invertebrates as compared to other rooted emergent vegetation (Barker, 2011). Therefore, this study was aimed to identify the major changes in the composition and abundance of weed-bed macro-invertebrate community in temporal and spatial bases, comparing water hyacinth-infested areas with non-infested areas of the lake and check the degree of perturbation using community characteristics and structure of macro-invertebrates.

2. Materials and Method

2.1. The study area

Lake Tana is found in the Abay basin in the north-western highlands of Ethiopia at an elevation of 1800m which is the largest (3150 km^2) freshwater body (Eshete *et al.,* 2002). It is a shallow lake with a mean depth of 8m and with a volume of 28,000km^3 (Margareta 2015). Its water level depends on the volume of the outflow to Blue Nile River and, the recently constructed Tana-Beles hydropower and irrigation scheme and the volume of inflow from the tributary rivers especially during the main rainy season. The lake has eight permanent inflowing rivers (Gilgel Abay, Rib, Gumara, Dirma, Megech, Gelda, Arno-Garno and Enfranz), which contribute more than 95% of the inflow (Tenalem, 2009). The Lake is meso-oligotrophic, turbid and frequently mixed with short duration of thermocline (Eshete *et al*., 2004). The climatic condition of the lake region is characterized by four seasons: post-rainy season, main rainy seasons, dry season and pre-rainy season (Eshetie, 2003). The rainfall pattern is also uni-modal. Mean annual rainfall varies from 947.9 to 1274.2 mm with a mean value of 1102.1 mm. Long-term rainfall distribution data indicates that most of the rain occurs in July followed by August. The mean annual air temperature of the lake area varies between 19.02^{o}C and 22.68°C. Maximum temperature was occurred in March and April and the minimum in December and January (Wondie, 2013).

2.2. Sampling sites and procedures

Sampling was carried out once during each of the four seasons. Sampling stations were selected on the basis of the extent of invasion by the weed and subsequently categorized as infested and non-infested stations (Table 1 and Figure 1).

Table 1. Description of sampling stations

Sampling sites	Site description	Depth Range (m)	Coordinates	
			Latitude	Longitude
Water hyacinth infested site				
Addisgie-Dingie (Ad)	Close to Megech river mouth	0.42 - 0.62	12° 16' 15.3''N	37° 22' 55.7''E
Achera (Ac)	Close to a farm land	0.56 – 1.21	12° 16' 59.9''N	37°21' 43.5''E
Kerigna (Kr)	Sand beach close to a farm land	0.28 – 1.60	12° 07' 29.4''N	37° 36' 22.1''E
Non-weed infested site				
Rib (Rb)	Close to Rib river mouth	0.15 – 0.60	12° 02' 24.9''N	37° 35' 53.8''E
Dirma (Dr)	Close to Dirma river mouth	0.65 – 1.50	12° 15' 49.6''N	37° 18' 18.5''E
Debresina (Db)	Conserved wetland close to the monastery of Debre-Sina	0.98 – 2.30	12° 14' 33.5''N	37° 18' 01.2''E

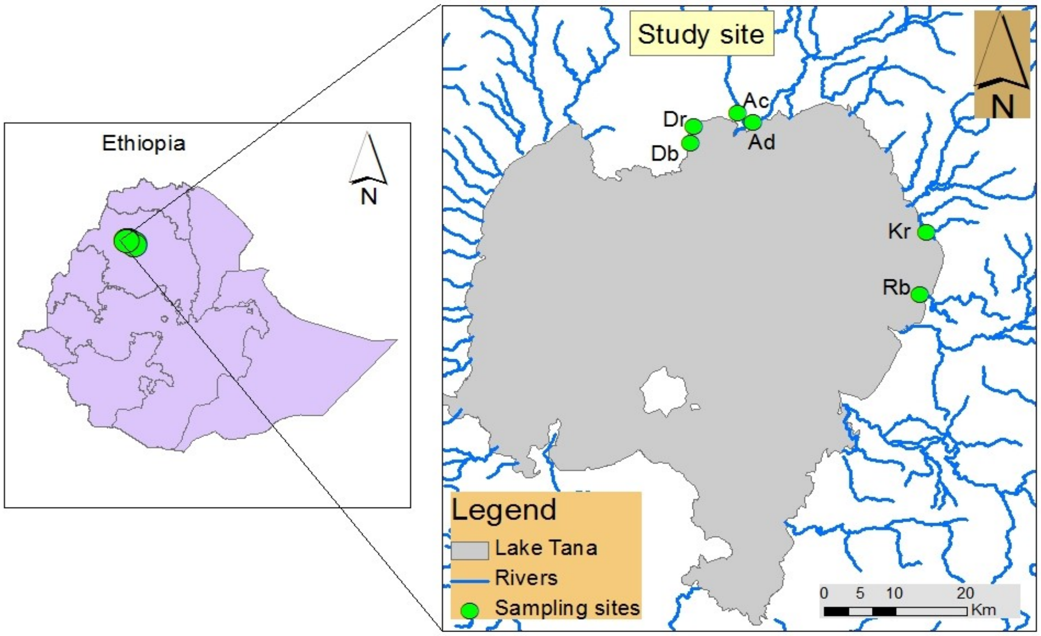

Figure 1. Map of Lake Tana and its catchment areas with sampling sites [Water hyacinth infested sites]

2.2.1. Measurement of physico-chemical parameters

Dissolved Oxygen (DO), pH, specific conductance, Total Dissolved Solid (TDS), salinity and temperature were measured *in situ* using YSI 556 multi-probe system. Transparency of the water was measured by lowering a 30 cm diameter circular disc (Secchi disc) with a calibrated cable into the water column.

Measurements of Ammonia (NH_3-N) were based on an indophenol method, Phosphate (PO_4-P) based on Palintest Phosphate LR method and silica (SiO_2) using Ammonium Molybdate in the form of tablet at 640 nm wave length and Nitrate (NO_3-N) based on Palintest Nitratest method and Total hardness based on a unique colorimetric method using Hardicol No.1 and No.2 tablets at 570 nm wave length and were carried out using a portable water analysis kit (Wagtech International, Palintest transmittance display photometer 5000). Nutrient analyses were made in the shore area immediately after sample collection using water samples filtered through Whatman GF/F.

2.2.2. Weed-bed Macro-invertebrate

Weed-bed Macro-invertebrates were collected using aquatic deep net with an effective area of 0.07065 m^2 and mesh size of 500 µm from the surface of water with Macrophytes (Barbour *et al*., 1999). Samples were collected four times (in September and December 2012, and March and May, 2013) at weed infested and non-infested areas, concurrently the physico-chemical measurements were also done. Triplicate samples were collected from each site within 3 seconds in 3 meter intervals to avoid disturbance. All three samples collected in a station were combined to obtain a composite sample. The samples were, then, preserved in 95% ethyl alcohol and all the dislodged organisms were carried by the water into the net. Then, the net was removed from the water with an upward scooping motion to prevent any of the organisms it contained to wash away; after which the contents of the net were poured into a bucket with water. All debris and organisms were handpicked from the net. The above procedures were then repeated for the collection of the second and third samples within the same station. The macro-invertebrates were carefully separated from the substrate (if present) using forceps in the Bahir Dar Fishery & Other Aquatic Life Research Center. This study was limited to the identification of the aquatic macro-invertebrates to the family level for consistency among samples.

2.3. Statistical analysis

For macro-invertebrate communities, Non-parametric Kruskal–Wallis test was employed to see temporal differences of organisms counted, whereas the Mann–Whitney test was used for pair-wise comparisons when testing spatial variations between the two sites. Hilsonhoff-Family level Biotic Index (H-FBI), which is an average of tolerance values of all the macro-invertebrates families in a sample, was employed. H-FBI was calculated according to Mandaville (2002).The relationship between the abundance of macro-invertebrate taxa with physico-chemical variables was assessed by using a multivariate analysis tool, Redundancy Analysis (RDA), using CANOCO for windows version 4.5 and verified by Pearson's correlations.

3. Results and Discussion

3.1. Weed-bed Macro-invertebrates Composition and Abundance

In this study, a total of 19,218 individuals from the weed-infested and 10,320 individuals from non-infested sites were collected, which belong to 4 classes, 10 orders and 29 families. Ephemeroptera, with two families, was the dominant taxon, which accounted for 55% of the total macro-invertebrate density in the weed-infested sites, followed by Diptera and Coleoptera, with four and five families that accounted for 18% and 12%, respectively. In the non-infested sites, Hemiptera was the dominant taxon, which accounted for 26% of total macro-invertebrate density (Figure 2). In Lake Tana, dominancy of Ephemeroptera and Hemiptera was reported by Dereje (2009) before the infestation of water hyacinth. In this investigation, however, Ephemeroptera was the most dominant in the weed-infested sites, while Hemiptera was prominent in the non-infested sites. Caenidae and Baetidae (Ephemeroptra), Coenagrionidae (Odonata), Dytiscidae and Hydrophilidae (Coleoptera), and Chironomidae (Diptera) had higher density in the weed-infested site than the non-infested sites. On the other hand, Corixidae (Hemiptera) showed higher density in the non-infested sites.

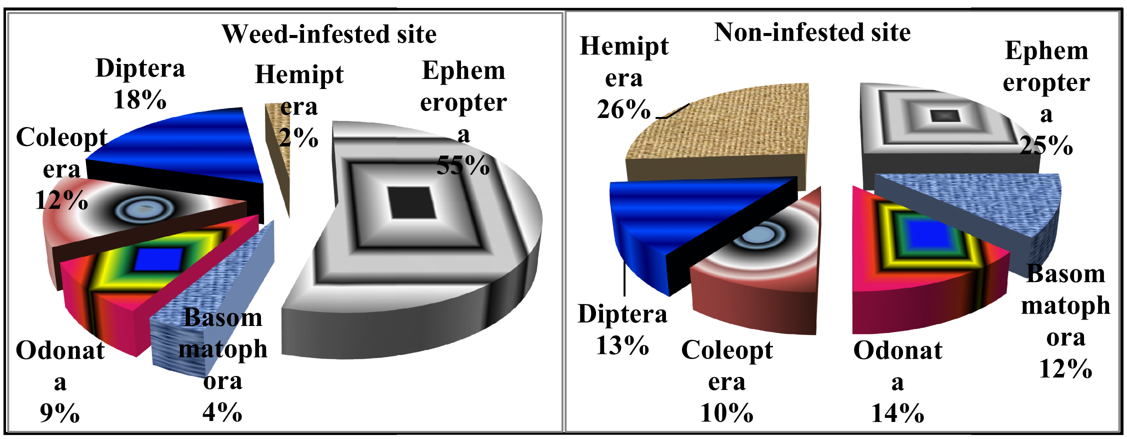

Figure 2. Percentage contribution of different weed-bed macro-invertebrates of the total macro-invertebrate density

No significant spatial variation was observed in the density of weed-bed macro-invertebrates except coleopteran, which exhibited significant differences between the weed-infested and non-infested sites (Mann-Whitney test, $p<0.05$). Seasonally, Ephemeroptera, Diptera and Coleoptera showed the peak density (1853, 704 and 416 ind/m^2, respectively) during the dry season in the weed-infested site. Hemiptera and Basommatophora during the rainy reason and Diptera during the post rainy season showed peak density (651, 293 and 200 ind/m2, respectively) in the non-infested sites (Figure 3). In both sites, density of weed-bed macro-invertebrates was lowest during the pre-rainy season. Ephemeroptra and Coleoptera showed significant seasonal variations in the weed-infested sites (Kruskal Wallis test, $p<0.05$). In this investigation, generally higher abundance of macro-invertebrates was observed in the weed-infested sites. Particularly, higher density of both Caenidae and Baetidae (Ephemeroptera), Dytiscidae and Hydrophylidae (Coleoptera) and Chironomidae (Diptera) was favored by the presence of water hyacinth. The fact that most of their larvae were collected from the complex root structure indicates the fibrous root structure of water hyacinth creates favorable niche diversity. Similar findings were also reported by Villamagna (2009). Floating aquatic plants including water hyacinth support many macro-invertebrates, especially at the edge of the floating mat (Rocha-Ramirez et al., 2007). The positive relationship between surface areas of floating macrophytes and epiphytic macro-invertebrates was also reported by

Brendonck *et al*. (2003) and Rocha-Ramirez *et al*. (2007).

Hilsenhoff (1988) categorized the pollution level of a water body into seven based on scores obtained from the macro-invertebrates density and tolerance value (0 to 10). Based on the scores obtained from weed-bed macro-invertebrates; sites Kr and Db with H-FBI scores of 6.06 and 6.49, respectively, had substantial organic pollution, which signifies fairly poor environmental condition. While sites Ac, Ad and Dr with H-FBI scores of 6.88, 6.50, and 6.65, respectively, had poor environmental condition. However, site Rb with H-FBI score of 7.78 was likely to have suffered from severe organic pollution, which signifies a very poor environmental condition (Table 2.).

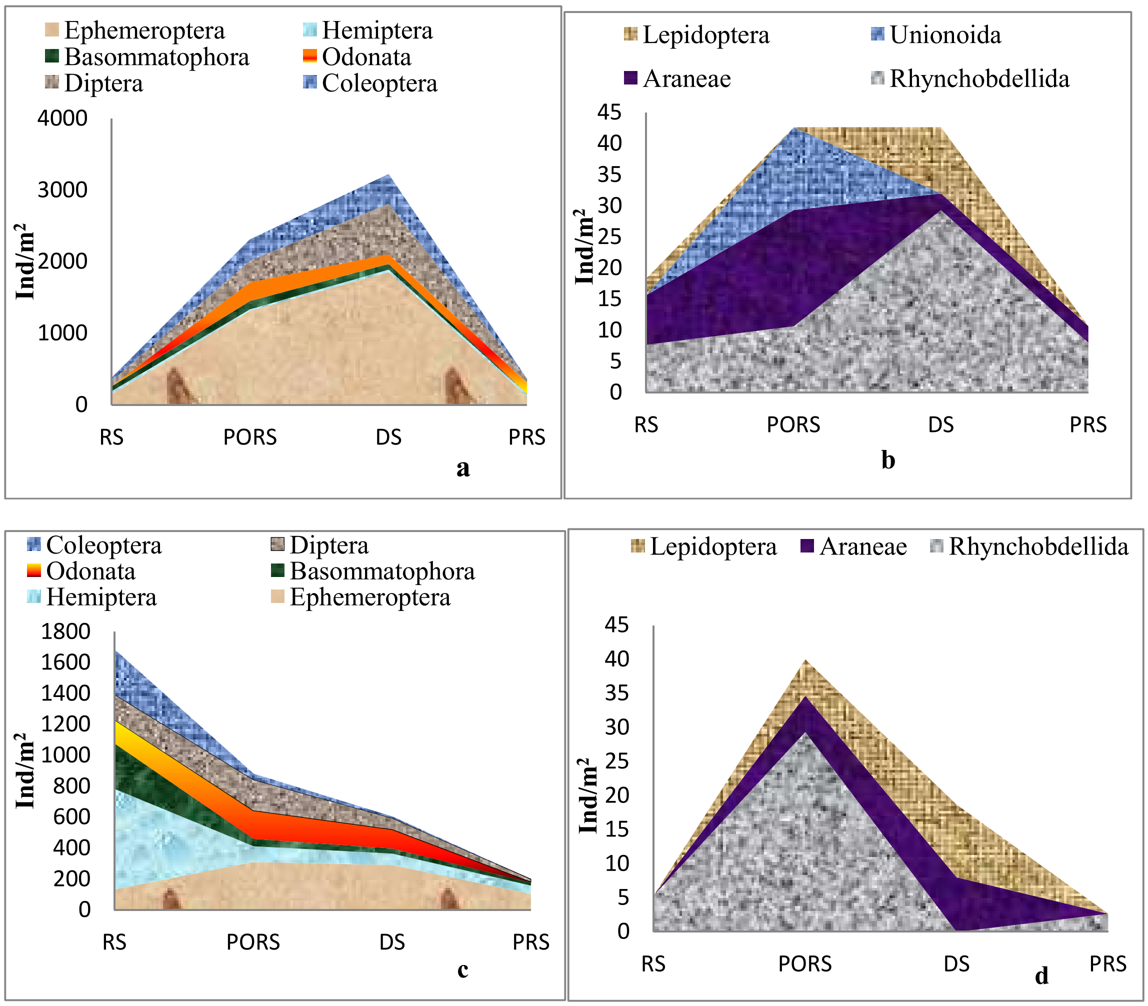

Figure 3. Seasonal trends of weed-bed macro-invertebrates density in the weed infested sites (a & b) and non-infested sites (c & d)

Note: RS = rainy season, PORS = post rainy season, DS = dry season, PRS = pre-rainy season

Nevertheless, the overall results obtained from H-FBI showed that site Rb had the highest organic and nutrient pollution while site Db had the least. The results of this biotic index did not show clear difference between the weed-infested and non-infested sites. However, the observed spatial disparity in taxa may be explained by the variation in the density of prey items, interstitial space for refuge, and presence of predators coupled with small variations in physico-chemical factors (Jonathan, 2001).

Table 2. Composition and abundance of weed-bed macro-invertebrates and their pollution tolerance level and H-FBI scores for the study sites

Order / Family	Tolerance level	Weed-infested sites Abundance (ind./m^2)					Non-infested sites Abundance (ind./m^2)				
		Ac	Ad	Kr	Average	H-FBI	Dr	Db	Rb	Average	H-FBI
Ephemeroptera		**5264**	**2274**	**2744**	**3427**		**464**	**1416**	**640**	**840**	
Caenidae	7	5160	1825	312	2432	2.70	80	928	176	395	0.87
Baetidae	4	104	449	2432	995	0.63	384	488	464	445	0.56
Basommatophora		**272**	**130**	**368**	**257**		**0**	**1064**	**112**	**393**	
Planorbidae	7	200	80	96	125	0.139	0	296	0	99	0.219
Physidae	8	16	40	272	109	0.138	0	424	112	179	0.453
Lymnaeidae	6	56	10	0	22	0.021	0	344	0	115	0.218
Odonata		**352**	**420**	**904**	**559**		**64**	**1208**	**112**	**461**	
Aeshnidae	3	24	1	64	30	0.014	0	360	0	120	0.114
Coenagrionidae	9	328	419	760	502	0.716	64	720	104	296	0.844
Libellulidae	9	0	0	80	27	0.038	0	128	8	45	0.129
Coleoptera		**384**	**395**	**1528**	**770**		**0**	**1000**	**24**	**341**	
Psephenidae	4	0	0	16	5	0.003	0	0	0	0	-
Elmidae	5	0	1	0	1	0.001	0	0	0	0	-
Dytiscidae	5	320	266	584	390	0.309	0	424	0	141	0.224
Hydrophilidae	5	40	120	928	363	0.287	0	552	24	192	0.30
Staphylinidae	-	24	8	0	11	-	0	24	0	8	-
Diptera		**984**	**793**	**1624**	**1134**		**768**	**272**	**336**	**460**	
Chironomidae (Blood-red)	8	320	72	1368	587	0.74	720	216	144	360	0.912
Chironomidae (other)	7	656	718	240	538	0.511	48	8	0	19	0.035
Ceratopogonidae	6	0	0	0	0	-	0	8	0	3	0.005
Culicidae	8	0	3	0	1	0.001	0	32	192	75	0.189
Tabanidae	6	8	0	16	8	0.007	0	8	0	3	0.005
Lepidoptera		**0**	**0**	**8**	**3**	**-**	**0**	**0**	**0**	**0**	**-**

Table 2. Continued

Order / Family	Tolerance score	Weed-infested site Abundance(ind./m^2)					Non-infested site Abundance (ind./m^2)				
		Ac	Ad	Kr	Average	H-FBI	Dr	Db	Rb	Average	H-FBI

Pyralidae	5	0	0	8	3	0.002	0	0	0	0	-
Hemiptera		**88**	**55**	**296**	**148**		**112**	**216**	**2312**	**879**	
Naucoridae	5	56	0	0	19	0.015	8	0	16	8	0.013
Nepidae	8	0	0	32	11	0.013	0	16	8	8	0.02
Gerridae	-	0	8	0	3	-	56	104	40	67	-
Belostomatidae	10	8	0	72	27	0.04	0	48	16	21	0.067
Corixidae	9	0	7	120	42	0.06	0	0	1744	581	1.66
Veliidae	6	0	0	32	11	0.01	48	0	0	16	0.03
Mesoveliidae	-	0	40	8	16	-	0	32	272	101	-
Notonectidae	-	24	0	32	19	-	0	16	216	77	-
Rhynchobdellida		**48**	**15**	**104**	**56**	**-**	**0**	**112**	**0**	**37**	-
Glossiphoniidae	8	48	15	104	56	0.07	0	112	0	37	0.09
Unionoida		**40**	**0**	**0**	**13**		**0**	**0**	**0**	**0**	
Sphaeridae	8	40	0	0	13	0.013	0	0	0	0	-
Araneae		**40**	**8**	**48**	**32**		**16**	**16**	**8**	**13**	
Pisauridae	-	40	8	48	32	-	16	16	8	13	-
Total (mean of three sites)						**6.48**					**6.97**

3.2. Relationship between physico-chemical variables and density of weed-bed Macro-invertebrates

The relationship of physico-chemical variables with weed-bed macro-invertebrate density is shown in Figure 4. In this Redundancy Analysis, the first two axes accounted for 74.4% of the cumulative percentage of variance in species–environment relationship. Axis 1 accounted for 48.7 % of the variation and show strong positive correlation with phosphate, ammonia and temperature and negative correlation with total hardness, silica, TDS, salinity and dissolved oxygen concentration. Similarly, Axis 2, which accounted for 25.7% of variance, was showed positive but weak correlation with Secchi depth, nitrate, phosphate, dissolved oxygen and silica, and negative correlation with total hardness, pH and temperature concentrations.

Density of Hemiptera was strongly correlated with DO and silica (r = 0.99 and 0.96, respectively, at $p<0.01$) and with salinity and TDS (r = 0.91 and 0.90, respectively, at $p< 0.05$), respectively. Lepidoptera showed strong positive correlation with ammonia (r = 0.92, $p<0.01$). Similarly, Araneae showed strong positive correlation with temperature (r = 0.85, $p<0.05$). Odonata, Coleoptera and Rhynchobdellida showed strong but negative correlation with total hardness (r = -0.97, -0.95 and -0.97, respectively, at $p<0.01$).

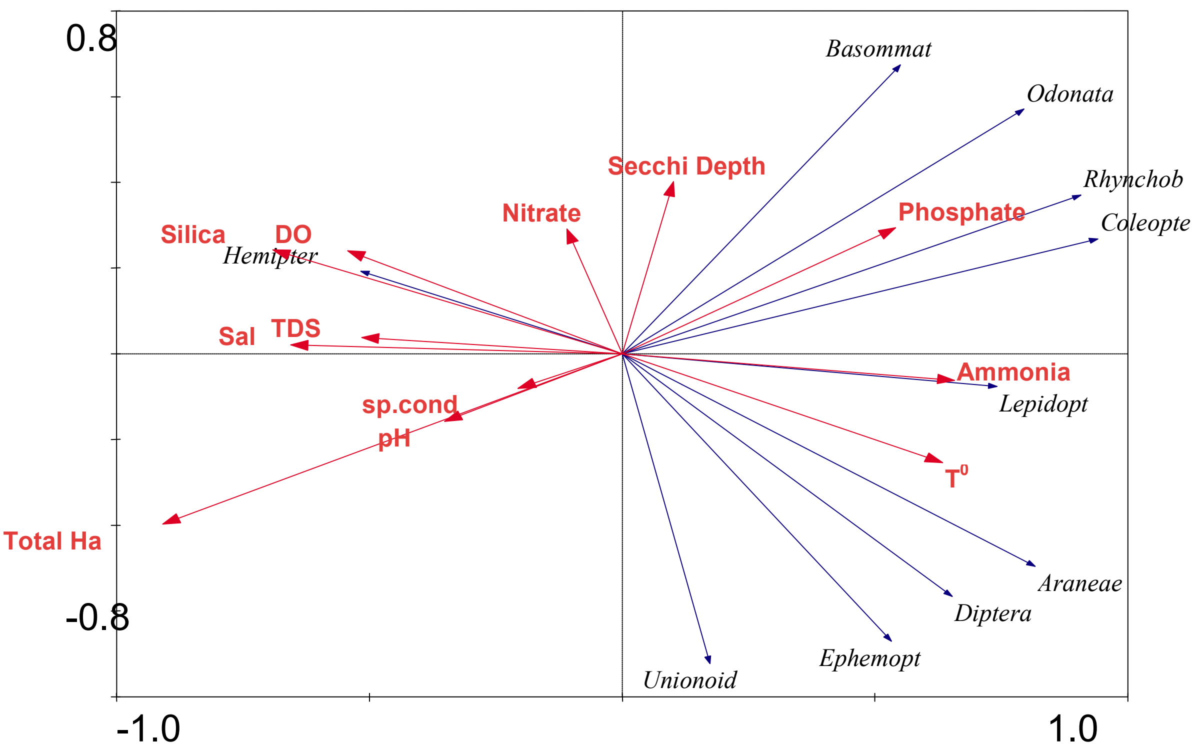

Figure 4. Graph for Redundancy Analysis (RDA) demonstrating the relationship between macro-invertebrate taxa from weed-bed and physico-chemical variables

Note: Ephemopt = Ephemeroptera, Coleopte = Coleoptera, Lepidopt = Lepidoptera, Unionoid = Unionoida, Rhynchob = Rhynchobdellida, Basommata = Basommatophora, T^0 = temperature, TDS = total dissolved solids, sp. cond = specific conductance, sal = salinity and Total Ha = total hardness

4. Conclusion

Though the variation was not statistically significant, higher weed-bed macro-invertebrate diversity and abundance was observed in the weed-infested sites. This may indicate that the presence of water hyacinth mats in the lake did not affect weed-bed macro-invertebrate fauna, which inhabit mainly the uppermost water column. However, the observed density variation between the two sites was due to slight variations in physico-chemical variables together with the availability of abundant food, diverse niche and refuges, which favored their abundance and diversity. In general, the existing water hyacinth biomass did not pose significant effect on lake macro-invertebrates composition and abundance. During this investigation, relatively high density of beetle species of the families Dytiscidae and Hydrophylidae, were observed at the leaf and root interface of water hyacinth. They could be possible biological agents for controlling water hyacinth proliferation. Therefore, further investigation is recommended to see their effect and interactions with the weed.

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