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Distribution Pattern of Aquatic Macrophytic Community and Water Quality Indicators in Upper and Lower Litani River Basins, Lebanon

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Authors' contributions

This work was carried out in collaboration between all authors. Author SB designed the study, developed the protocol and wrote the first draft of the manuscript. Author HI managed the literature searches and analyses of the study. Authors NA and HAH managed the experimental process. Author NAA identified the species of macrophytes. Author MK assisted in the experimental work. All authors read and approved the final manuscript.

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ABSTRACT

In spite of their important role in the structure and function of river ecosystems, aquatic macrophytes of freshwater bodies in Lebanon have so far received very little attention. In the present study, comparative analysis of the composition and spatial distribution of macrophytic communities and water quality indicators were assessed between Upper and Lower Litani River Basins in Lebanon. Five sites distributed along River Basins which are separated by Qaraoun Dam and its reservoirs were investigated during 2013-2014. A total of 35 of both submersed and emergent macrophytes were observed. FCA analysis revealed the presence of a heterogeneous

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spatial distribution pattern of the communities between the Upper and Lower River Basins. Two principle taxa units each characterizing either of the river basins were identified. Corresponding water quality analysis also showed heterogeneous spatial distribution and high levels of eutrophication of the Upper Basin and better quality conditions of the Lower Basin and CCA analysis highlighted the distinctive ecological features of macrophytic associations with respect to water quality parameters and trophic conditions of studied sites. These results clearly indicate the influence of nutrient enrichment in the determination of macrophyte assemblages and role of Qaraoun reservoir in the observed discontinuity of the taxa between the Upper and Lower basins and reducing the eutrophication level in the Lower Basin. Monitoring of macrophytes could, thus, be a reliable means to assess the ecological status of Litani River.

Keywords: Macrophytes; water quality; Litani River; Lebanon.

1. INTRODUCTION

Aquatic macrophytes form a major group of primary producers in many surface water ecosystems. They play a significant role in primary production, nutrient recycling, and providing food and shelter for other aquatic assemblages [1,2]. Macrophytes affect nutrient cycling through transfer of nutrients and chemical elements from sediments to water. Limiting nutrients like phosphorous and nitrogen are released by macrophyes and rapidly used by microalgae and bacteria attached to macrophyte surface and their detritus [3].

With respect to their responsiveness to aquatic ecosystem environmental conditions, increased nutrient loading is recognized to result in a shift from macrophyte dominated clear water state to a turbid, phytoplankton dominated state [4,5]. The composition and distribution of submerged macrophytes is indicated to be influenced by trophic status of water bodies. Worldwide studies have reported the suitability of macrophytes as useful bioindicators in the assessment of the ecological status of rivers and lakes [6-9]. In addition, the spatial distribution of particularly submerged taxa is reported to reflect the concentration gradients of nutrients and heavy metals in water and sediments [10]. Major efforts are recently focused on the role of macrophytes as efficient biofilters for self-purification of eutrophic water bodies. Some species, i.e. *Eicchornia crassipes* and *Hydrilla verticillata* [11], *Potamogeton pectinatus* and *P. malaianus* [12] are indicated for their high capacity to absorb heavy metals.

Being the largest and most important river in Lebanon, Litani River has always been considered the lifeblood of Bekaa Valley and an indispensable resource for community livelihood and economic development. During the last decade, serious concerns regarding the deteriorating water quality of the river has greatly grown across the country. The increasing degradation of water quality mainly of its upper part, is attributed to the increased urbanization pressure, inappropriate agricultural practices, a wide range of industrial activities and absence of effective management policies [13,14]. Excessive amounts of plant nutrients, primarily phosphorus and nitrogen, are delivered to the river resulting in hypertrophic conditions. Numerous studies have been carried in order to define the physiochemical characteristics of river water, particularly of its upper part, whereas little attention has been focused on biological elements as a useful biotypological tool in the assessment of the river ecosystem. Existing knowledge about macrophytes in Lebanese streams and rivers is still limited. Nevertheless, several recent studies on macrophytic community of Upper Litani River and associated water bodies in the basin i.e. Qaraoun Lake and Ghouzail river, have resulted in the identification of several different macrophyte assemblages and the spatio-temporal variations in their diversity and distribution patterns in these water bodies [15-18]. The present study focuses on the comparative analysis of macrophytic communities and water quality between Upper and Lower Litani Basins to develop our knowledge on the structure and distribution of these communities and influence of abiotic parameters of their aquatic habitat.

2. MATERIALS AND METHODS

2.1 Study Sites

Flowing from the vicinity of Baalbek in North Bekaa and totally hosted within the boundaries of the country, Litani River runs in a south- westerly direction through Bekaa valley to meet the Mediterranean Sea (Fig. 1). It extends for nearly 170 km forming a catchment of around 2,000 km^2 area, the equivalent of 20% of Lebanon's area. The construction of the Qaraoun dam and reservoir in 1960s came to store water for Summer irrigation and electricity generation. The Qaraoun reservoir divides the river basin into two sub-basins with the largest being the Upper Basin stretching between its source until the dam at an altitude ranging between 800 to 1000 meters and with an estimated area of approximately 1,500 km^2. As it exits Bekaa, the river forms the Lower Basin of about 500 km^2 and takes a steeper slope sharply dropping within 60 km from an altitude of 800 m to its outlet at sea level. Five sites distributed along both the upper and lower river basins were selected for the study (Fig. 1). Rayak (Site L1, 33°51' 49''; 35° 59' 21''; 905 m), El Marj (Site L2: 33°46' 37''; 35° 53' 31''; 872 m) and Jeb Janine (Site L3: 33°38' 20''; 35° 47' 31''; 861 m) were the sites of Upper Litani Basin. While Dellafi (Site L4: 33°26' 29''; 35° 39' 11''; 534 m), and Khardali (Site L5: 33°20' 33''; 35° 32' 34''; 247 m) were the sites of the Lower Basin. Except Dellafi (presence of repisylve), the selected study sites were characterized by a very good exposition to sun light (no repisylve) and varied in their hydrological and geomorphological features as well as the type and magnitude of anthropogenic pressures and land use. Both Rayak (L1) and El Marj (L2) sites, located on the upper part of Litani, had relatively minimal to moderate water flow, a very strong odor, a dark color and high turbidity. Both sites were characterized by intensive mixed residential, agricultural, industrial and construction works. Sewage and effluents were directly discharged into the river. Jeb Janine (L3) was characterized by mainly agricultural surrounding with a scattered Bedouin settlements and residential activities. The river had minimal to moderate flow and had dark green color due to algal and aquatic plants growth. Site L4 is located in Dellafi (Western Bekaa Valley) had a moderate to high flow and a clear blue green color with some submerged rocks. The site was characterized by some recreational activities and aquaculture farming of trout fish. Located at Khardali, Site L5 was surrounded by a major network of main roads and a bridge and appeared to be a site for picnickers and modest recreational activities.

2.2 Water Quality and Substratum Granulometry

Several seasonal surveys and sampling campaigns of macrophytes and their water habitat were conducted in 2013 and 2014. A spectrum of physiochemical properties of water habitat of macrophytes in all selected sites was assessed. Both on site and laboratory tests were performed. Dissolved oxygen (DO) and temperature (t) were recorded by DO/Temp. Meter (Gondo Ezodo PDO-408, Taiwan) while turbidity was assessed by Turbidity Meter (LT Lutron TU-2016, Taiwan) and Secchi Disk, and pH by 370 pH Meter (JENWAY, E.U). Electrical conductivity (EC), total dissolved solids (TDS) and salinity were measured by TRACER Pocket tester (LaMotte/ code 1749, USA), biological oxygen demand (BOD) by B.O.D System6 – FTC 90 – Refrigerated incubator (VELP - Scientifica, Spain) and chemical oxygen demand (COD) by ECO6 Thermoreactor (VELP, Spain). Phosphate (PO_4^{3-}), nitrate (NO_3^-), nitrite (NO_2^-), sulfates (SO_4^{2-}) and ammonium (NH_4^+) were all determined by colorimetery (La Motte, Model SMART2, USA). With the exception to BOD, all measurements were performed in three replicates. Velocity of river water at each site was measured by using a float crossing a fixed distance of 20 m. The structure of the water quality variability was explored using the Multivariate Analysis of Variance (ANOVA) and Principal Component Analysis (PCA) (PAWAS Statistics 18).

Granulometric composition of substratum of studied sites was performed by a visual evaluation (in %) (fine = lime, silt, sands; coarse = gravels, pebbles and boulders) and sieve analysis, excluding particles of > 2 cm in diameter, to determine the distribution of particle sizes [19]. Triplicates of samples of 500 grams of river sediments of the studied sites were dried and mixed for sieve analysis. The percentage of different particles was computed.

2.3 Macrophytic Communities

Vegetation surveys were carried out over 100 m stretches of the phytolittoral zone of study sites. The identification of macrophytic phanerogames was based on “Nouvelle Flore du Liban et de la Syrie” [20] and “Illustrated Flora of Lebanon” [21] supplemented with Flora Europea [22] while naming was based on the recent accepted names of the Plant List [23]. The identification of the algal taxa followed Rodriguez and Vergon (1996) [24]. Vegetation community compositions were based on the assessment of stretch area of 100 x 1 m^2 [25]. Relative abundance of species was recorded using Braun-Blanquet scale (r = solitary, + < 1%, 1=1-5%, 2=6-25%, 3=26-50%, 4=51-75% and 5=76-100%) [26]. The vegetation data was analyzed using Factorial

Correspondence Analysis (FCA) and Canonical Correspondence Analysis (CCA) to sort the water quality indicators and macrophytes in sampling sites (CANOCO for Windows, Version 4.5, Microcomputer. Power; Ithaca, New York).

Fig. 1. Study sites at upper and lower Litani River basins, Lebanon
Adopted of
https://strikehold.files.wordpress.com/2009/10/bekaa-valley-map.gif

3. RESULTS AND DISCUSSION

3.1 Water Quality and Substratum Characteristics

Table 1 presents the mean values of water quality indicators assessed at studied river sites during the course of study (2013-2014). In this table it can be seen that the sites hosting different macrophytic communities exhibited a wide range of water quality conditions. ANOVA statistical analysis revealed significant spatial differences (at $P < .05$) in all indicators during study duration. A slight to moderate shift towards alkalinity was observed with all pH values (7.6-8.1). This is most certainly attributed to the combined influence of the limestone and dolomite formations of the catchment basin and types of swage, runoffs and effluents driven into the river [27]. Temperature mean values ranging between 19.91±2.83 and 23.35±5.40 were higher than any of the mean values recoded in several sites of the river during the last decade [28-30]. As for the mineralization levels, TDS and EC levels varied between the sites of Upper and Lower river with the former having values around the range of “Slight to Moderate Degree of Restriction on Use” for irrigation set as 450-2000 mg/l and 0.7-3.0 dS/m, respectively. Whereas the values of the Lower River fell within the “None Degree of Restriction on Use” at <450 mg/ml and <0.7 dS/m, respectively [31].

Further reflecting the environmental profile of the river, DO values were all below the critical level for aquatic life (5 mg/L). High values of COD at particularly, Rayak and El Marj in Upper River, indicated the high contamination load and oxidation susceptibility of both organic and inorganic contaminants. Unexpectedly, BOD values of these sites appeared to only moderately exceed the European maximum allowable levels for good aquatic life set at 3.0-6.0 mg/L [32]. A dominance of non-biodegradable matter, low biodegradability and presence of toxic substances affecting microbial activity in these sites may be the underlying cause of these reduced BOD levels. As for the sites of lower river, the values of DO (2.4 mg/L), BOD (1.9-2.5 mg/L) and COD (15.8-21.0 mg/L) indicated better quality conditions.

As indicated in Table 1, nitrate and nitrite contents (6.2-8.1 mg/L and 0.3–0.7 mg/L, respectively) were moderate and falling below the criteria to protect freshwater life (<2.9-3.6 mg NO_3-N/L equivalent to 12.8 to15.9 mg/L NO_3^- and 0.08-0.35 mg NO_2-N/L equivalent to 0.26-1.15 mg/L NO_2^-) recommended by the Canadian Council of Ministers of the Environment [33] and Alonso [34]. On the contrary, the levels of toxic ammonia at the sites of Upper River (9.8-34.3 mg/L) exceeded by many folds the healthy water bodies criteria for short or long term exposure (0.05-0.35 mg NH_3-N/L equivalent to 0.06–0.43 mg/L NH_3 or 0.01-0.02 mg NH_3-N/L equivalent to 0.012-0.024 mg/L NH_3) [35]. These dominant levels of ammonia may be mostly a result of active denitrification process controlling this part of the river under low DO conditions. In spite of the considerable uncertainty in the magnitude and rates of nitrogen cycling at river basin scales, several studies have reported the key role of the cycle in making nitrogen available for aquatic plants or susceptible to denitrification losses and the influences of many natural, geomorphological and anthropogenic factors such as temperature, DO level, pH, dams and other biological and chemical conditions on the levels of N forms in a water body [36,37].

Table 1. Mean values±SD (n=27) of quality indicators analyzed at the five studied sites of Litani River in 2013-2014. Superscript a, b, c indicate homogenous value subsets that significantly differ by ANOVA

Indicator*	Rayak	El Marj	Jeb Janine	Dellafi	Khardali	Standard limits
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
pH	$7.6±0.4^{a}$	$7.7±0.34^{a,b}$	$7.8±0.4^{b}$	$8.0±0.4^{c}$	$8.1±0.3^{c}$	5.0-9.0 [31]
T (℃)	$20.4±5.3^{a}$	$22.7±5.7^{a,b}$	$23.3±5.4^{b}$	$19.9±2.8^{a}$	$21.9±3.3^{a,b}$	10-25
SD (cm)	$14.8±14.8^{a}$	$16.1±14.7^{a}$	$32.2±15.3^{b}$	$>300^{d}$	$130.0±59.3^{c}$	57-60 [33]
EC (µS cm^{-1})	$1,672±676^{d}$	$1,129±255^{c}$	$635±118^{b}$	$342±31^{a}$	$334±29^{a}$	2500 [31]
TDS (mg L^{-1})	$1,167±464^{d}$	$788±178^{c}$	$444±81^{b}$	$231±35^{a}$	$243±25^{a}$	1200 [31]
Sal (mg L^{-1})	$831±337^{d}$	$565±127^{c}$	$318±58^{b}$	$177±21^{a}$	$166±16^{a}$	500-1500 [31]
SO_4^{-2} (mg L^{-1})	$20.6±18.4^{b}$	$18.9±16.4^{b}$	$33.7±19.8^{c}$	$10.6±3.9^{a}$	$10.4±5.1^{a}$	250 [40]
PO_4^{-3} (mg L^{-1})	$16.2±11.2^{c}$	$9.3±5.4^{b}$	$7.6±9.5^{b}$	$0.6±0.6^{a}$	$0.4±0.5^{a}$	0.1 [35]
NO_2^- (mg L^{-1})	$0.4±0.3^{a}$	$0.4±0.2^{a}$	$0.7±0.4^{b}$	$0.3±0.1^{a}$	$0.3±0.2^{a}$	0.26-1.15 [35]
NO_3^- (mg L^{-1})	$7.0±3.2^{a,b}$	$6.2±2.6^{a}$	$7.8±3.3^{a,b}$	$8.1±2.5^{b}$	$6.9±3.4^{a,b}$	12.8-15.9 [35]
NH_3 (mg L^{-1})	$34.3±18.4^{c}$	$33.9±17.9^{c}$	$9.8±4.6^{b}$	$0.2±0.2^{a}$	$0.2±0.1^{a}$	0.012-0.43 [35]
Tur (ntu)	$65.6±35.1^{d}$	$48.3±25.7^{c}$	$25.2±14.3^{b}$	$1.7±1.5^{a}$	$4.2±2.9^{a}$	8 [33]
Vel (m s^{-1})	$0.4±0.4^{b}$	$0.1±0.1^{a}$	$0.3±0.4^{b}$	$0.1±0.03^{a}$	$1.3±0.3^{c}$	-
DO (mg L^{-1})	$0.8±1.1^{a}$	$0.8±0.9^{a}$	$1.3±1.1^{a}$	$2.4±2.3^{b}$	$2.4±2.3^{b}$	>5 [32]
BOD (mg L^{-1})	$11.1±9.5^{b}$	$8.2±8.3^{b}$	$3.7±3.3^{a}$	$1.9±3.9^{a}$	$2.5±3.4^{a}$	<30 [32]
COD (mg L^{-1})	$484.5±284.2^{c}$	$306.3±199.8^{b}$	$74.7±64.1^{a}$	$21.0±24.1^{a}$	$15.8±23.6^{a}$	<250 [32]

Consequently, it is more desirable that total nitrogen (organic and inorganic N) is considered when estimating N in streams and rivers [38,39]. As for phosphates, the values at both Upper Basin and Lower Basin sites were evidently far above the recommend criterion for healthy water bodies set below 0.1 mg/L by USGS 1996-1998 [40].

PCA plots in Fig. 2 highlight the ecological features of studied sites with respect to 15 quality indicators. Axis 1 (66.1%) put Rayak (L1) and El Marj (L2) of Upper Litani Basin characterized with high level of eutrophication and high mineralization in opposition to L4 and L5 (Lower Litani Basin) characterized by higher water current velocity, SD, DO and pH. Whereas axis 2 (18.4%) individualized Jib Janine (L3) at Upper Litani Basin characterized by temperature, SO_4^{-2} and NO_2^- level (Fig. 2). These results clearly indicate an important role of Qaraoun dam in the reduction of the level of eutrophication and mineralization of Upper Litani Basin and don't describe the upstream-downstream gradient of eutrophication classically mentioned in the literature [41]. They are, rather, in line with the reports of Ismail and co-investigators [16]. The responses of river ecosystems to dams are multiple, varied and complex. Water storage in reservoir induces physical, chemical and biological changes in the stored water. As a result, the chemical composition of water released from reservoirs can be different to that of inflows. Reservoir acts as nutrient sinks, thermal regulators and play a role in nitrogen cycling, sediment storage, increased evaporation and release of greenhouse gases [37,42,43]. Thus, the changes caused by Qaraoun dam on Litani River regime can directly and indirectly influence a wide range of dynamic factors that affect the ecological integrity of the river ecosystem.

Granulometry analysis of substratum of the various sites showed that the major constituted constituents were gravel at Jeb Janine (65.4 ±6.5%) and fine at both Dellafi and Khardali each forming 55.0±3.6% and 87.8±0.5% of substratum (Table 2). The visual evaluation of substrate granulometry showed that the substratum was finer at L2, L3 and L5 (fine = 90%, coarse = 10%) than L1 (fine = 65%, coarse = 35%) and L4 (fine = 45%; coarse = 55%) which, together with the high level of physical and chemical variables favored the development of plants specially macro algae and phanerogams at all sites and bryophytes only in L4, while benefiting from presence of coarse substratum in this site.

3.2 Macrophyte Species Composition and Spatial Distribution

A total of 35 taxa of both submersed (17 taxa: 5 algae; 2 bryophytes and 10 phanerogames) and emergent macrophytes (18 taxa of phanerogames) forming different associations and communities were observed across the different sites of the river (Table 3). The overall community cover area during the maximum growth period (May to August) reached its highest at Jib Janine with the formation of a very dense cover of relatively numerous species of aquatic plants colonizing most of the river bed. Large area covers were also observed at Dellafi and Khardali with each occupying around 75% and 60%, respectively, of surveyed phytolittoral area (100 m^2). Much smaller area cover was noted at the sites of El Marj (5%) and Rayak (20%) both experiencing serious anthropogenic pressure indicated by the observed number of point sources of pollution (sewage pipes) from industrial and municipal activities directly delivered into the river (data not shown).

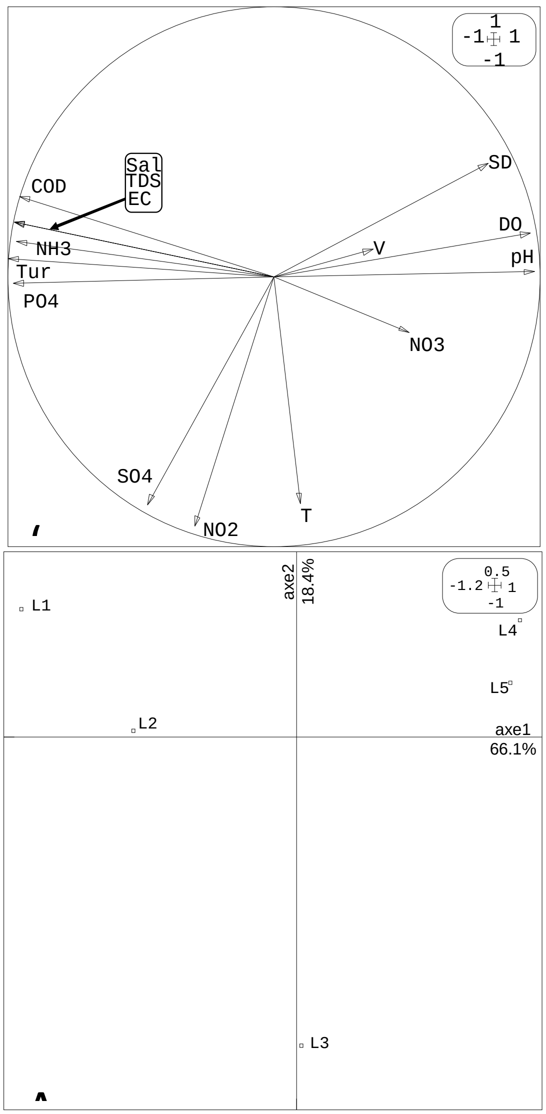

Fig. 2. PCA applied on the 15 water quality indicator (average for the quantitative statement) in Rayak (L1), El Marj (L2), Jeb Janine (L3), Dellafi (L4) and Khardali (L5); a) Projection of study sites and b) water quality indicators

Additionally, diffuse sources of pollution arising mostly from runoffs containing agricultural agrochemicals, oil and gasoline storage, drainage from livestock farms and poultry factories were also visually observed.

The analysis of taxonomic richness and the composition of macrophytic communities show a spatial variability according to sites. The sites of Jeb Janine and Dallafi hosted the highest richness each hosting 22 and 21 different taxa, respectively, whereas, the sites of El Marj and Rayak exhibited only four taxa in the former and seven taxa in the later. The richness in Khardali stood at 15 taxa. Whilst Jib Janine appeared to host nearly all the identified submersed phynerogams and the largest populations of *Butomus umbellatus*, *Potamogeton trichoides* and *Phragmites australis*, Dallefi was the only site observed to host both recorded bryophytes (*Amblystegium* sp. and *Cinclitods* sp.) and the largest community of *Potamogeton crispus.* The presence of bryophytes in this site is in direct relation to the type of substratum (coarse) and the degree of light exposure which support their development. El Khardali was characterized by the largest population of *Typha angustifolia*. *Phragmite australis* was the only common and most abundant taxon among all studied sites. However, the dominance of phanerogams (hydrophytes and helophytes) in all stations is a result of the silty substrate granulometry and increase in sunlight exposure as well as the increase in water flow [16].

According to both abiotic and biotic results, it seems that water quality and the level of nutrients in each site have influenced the taxonomic composition of the macrophytic stands. As reported in bibliography that fairly disturbed and eutrophicated stretches of rivers carry a more developed vegetation than the modestly disturbed and highly disturbed stretches [43,44,16]. This may explain the higher taxonomic richness observed in L3, L4 and L5 (less polluted station) as compared to L1 and L2 (more polluted station).

FCA analysis (axis 1 inertia 39.6%; axis 2 inertia 31.4%), taking into account the total taxa detected at the five studied sites and treating the presence or absence of taxa, revealed two principal units of taxa (I and II) characterizing the taxa of Upper Litani River (I) and Lower Litani River (II) (Fig. 3). In group Ia of submersed phanerogams characterized the site of Jeb Janine (L3). In group of IIa, the green algae *spirogyra*, 2 bryophytes and 3 emergent phanerogams characterized Dellafi (L4); group IIb represented by 4 emergent phanerogams characterized Khardali (L5) and IIc represented by 2 algal taxa and 2 emergent phanerogams common to both L4 and L5. Unit III was represented by a mixture of submersed (2 taxa) and emergent phanerogams (7 taxa) common to Upper and Lower Basins. Unit IV constituted of the green algae (*Cladophora* sp.) and the emergent phanerogam *Phragmites australis* was present in all sites. The absence of *Butomus umbellatus* (ButU) in L4 individualized this site.

Table 2. Mean values±SD (n=3) of substratum granulometry of study sites at Litani River

Site	Gravel%	Coarse Sand%	Medium Sand%	Fine Sand%	Fines%
	Mean±SD	**Mean±SD**	**Mean±SD**	**Mean±SD**	**Mean±SD**
Rayak	35.9±3.3	19.3±2.0	11.5±1.6	1.8±0.3	31.5±2.9
El Marj	NA	NA	NA	NA	NA
Jeb Janine	65.4±6.5	12.3±1	6.8±1	1.4±0.6	16.6±5.5
Dellafi	32.2±1.2	7.6±1.0	4.2±1.1	1.0±0.3	55±3.6
Khardali	1.9±0.2	2.7±0.4	4.4±0.5	3.2±0.4	87.8±0.5

NA=Not available

Table 3. Macrophyte species and cover area as a percentage of stretch/belt area studied (100 m2) and noted as a measure of 1 to 5 (R = solitary, + < 1%, 1= 1-5%, 2= 5-25%, 3= 26-50%, 4= 51-75% and 5= 76-100%) [26]

Macrophytes	Species code	Rayak	El Marj	Jeb Janine	Dellafi	Khardali
Submersed species						
Alg. *Chara* sp.	Char				1	1
Alg. *Cladophora* sp.	Clad	1	1	1	1	1
Alg. *Rhizoclonium* sp.	Rhiz				1	1
Alg. *Spirogyra* sp.	Spir			R	1	R
Alg. *Vaucheria* sp.	Vauc	1	1	1		
Bry. *Amblystegium* sp.	Ambl				1	
Bry. *Cinclitods* sp.	Cinc				1	
Phy. *Ceratophyllum demersum* L.	CerD			+		
Phy. *Lemna gibba* L.	LemG			R		
Phy. *Lemna minor* L.	LemM			1		
Phy. *Myriophyllum spicatum* L.	MyrS			1	1	
Phy. *Potamogeton crispus* L.	PotC			1	4	
Phy. *Potamogeton pectinatus* L.	PotP			1		
Phy. *Potamogeton trichoides* Cham. & Schltdl.	PotT			2		
Phy. *Ranunculus fluitans* Lam.	RanF			1		
Phy. *Ranunculus aquatilis* L.	RanA			1		
Phy. *Ranunculus trichophyllus* Chaix ex Vill.	RanT			1		
Emergent species						
Phy. *Apium nodiflorum* (L.) Lag.	ApiN			1	1	
Phy. *Butomus umbellatus* L.	ButU	1	1	3		2
Phy. *Carex divisa* Huds.	CarD				+	1
Phy. *Cyperus longus* L.	CypL					2
Phy. *Epilobium hirsutum* L..	EpiH				1	
Phy. *Eupatorium cannabinum* L.	EupC				1	1
Phy. *Glyceria plicata* (Fr.) Fr.	GlyP					+
Phy. *Lycopus europaeus* L.	LycE			1	1	2
Phy. *Nasturtium officinale* R. Br.	NasO				1	
Phy. *Mentha aquatica* L.	MenA	1		1	1	
Phy. *Phalaris arundinacea* L.	PhaA	1		3	2	2
Phy. *Phragmites australis* (Cav.) Trin. Ex Steud.	PhrA	2	1	3	2	2
Phy. *Polygonum persicaria* L.	PolP	R		1	1	1
Phy. *Sparganium emersum* Rhemann	SpaE					+
Phy. *Sparganium neglectum* Beeby	SpaN			+	+	
Phy. *Sparganium angustifolium* Michx.	SpaA			1	1	1
Phy. *Typha angustifolia* L.	TypA					2
Phy. *Veronica anagallis-aquatica* L.	VeAa				1	
Total species		**7**	**4**	**22**	**21**	**16**

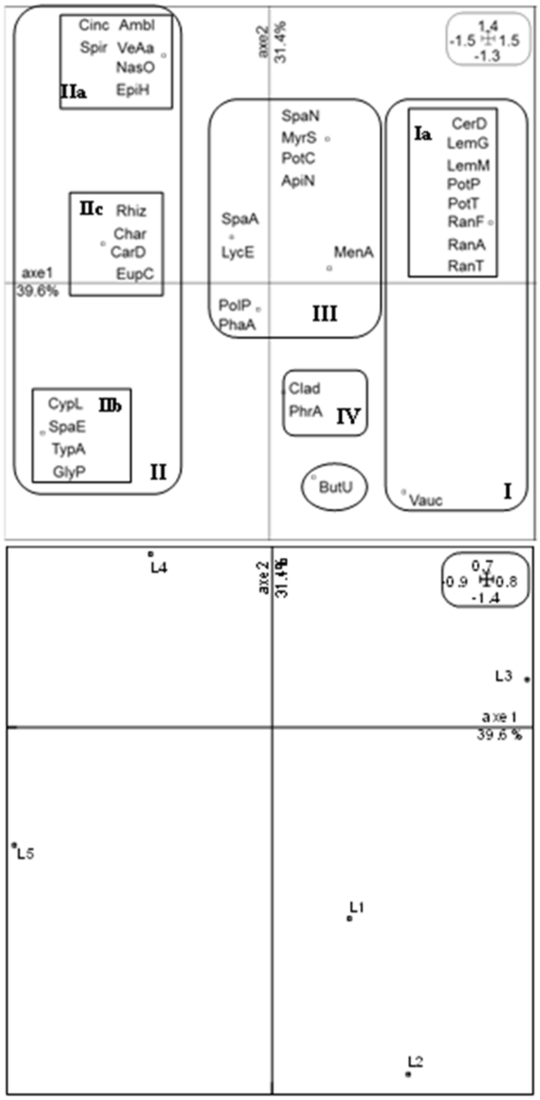

Fig. 3. FCA applied on the 35 macrophytic taxa (presence -absence for the qualitative statements) in Rayak (L1), El Marj (L2), Jeb Janine (L3), Dellafi (L4) and Khardali (L5); a) Projection of study sites and b) macrophytic taxa (Submersed macrophytes: Char, Clad, Rhiz, Spir, Vauc, Ambl, Cinc, CerD, LemG, LemM, MyrS, PotC, PotP, PotT, RanF, RanA, RanT; Emergent macrophytes: ApiN, ButU, CarD, CypL, EpiH, EupC, GlyP, LycE, NasO, MenA, PhaA, PhrA, PolP, SpaE, SpaN, SpaA, TypA, VeAa

This heterogeneous spatial distribution of macrophytes across the studied sites is in accordance with the observed characterization of water quality at Upper Litani Basin exhibiting high levels of eutrophication and mineralization and at Lower Basin having higher water current velocity, SD, DO and pH. This may clearly indicate that nutrient levels in Litani River play a key role in structuring macrophyte communities. In Upper Litani Basin, whilst the levels of nutrient enrichments in Jib Janine resulted in high area cover and species richness, they instigated limited levels of growth and richness at Rayak and El Marj. Increased nutrient input has been reported by many ecologists to lead to increases in macrophyte biomass and species richness until the enrichment reaches a threshold where competitive exclusion of nutrient-sensitive species occurs [45]. A comparative analysis with previously assessed macrophyte communities of these sites at Upper Litani Basin in 2005-2006 revealed similar evolution patterns accompanying the observed elevations in mineralization and nutrient levels [16].

In addition, the role of water movement and substratum in determining macrophyte composition has already been confirmed by other studies. These factors are well recognized to directly and indirectly affect macrophytes as in a complex way [46]. Demars and Harper [47] underlined the difficulty in illustrating the specific effect of nutrients because of synergistic effect of a number of physical factors.

To underline the relationship between physico-chemical parameters and macrophyte richness and coverage, a CCA analysis has been conducted. This analysis took into account 50 quantitative parameters, 35 of which correspond to cover percentages of macrophytes, and 15 correspond to the values of the abiotic descriptors. This CCA highlighted the distinctive ecological features of macrophytes with respect to some environmental parameters. It also made it possible to establish macrophytic associations which exist in several sectors of Litani River and to distinguish between the stations by their floristic characteristics. On the map of the CCA (axis 1 inertia 48.2%; axis 2 inertia 21.4%) (Fig. 4), L4 is separated from L1, L2, L3 and L5 by axis 1 and L1, L2 and L3 are separated from L5 by axis 2. In addition, axis 2 (41% inertia) describes mineralization and eutrophication gradients at its negative part and an oxygenation gradient at its positive part. Thus, the degree of pollution effect is strongly increased along axis 2 displaying a clear ecological distinction between a sector of strongly polluted sites at Upper Litani Basin (L1, L2, L3) and a sector of lightly polluted sites at Lower Litani Basin (L4, L5). On one hand, we can individualize between Lower Litani

Basin characterized by depth, velocity and well oxygenated water and on the other hand, the sites of Upper Litani Basin characterized by a high conductivity, TDS, Turbidity, COD, NO_2^-, SO_4^{2-} and PO_4^{3-} concentrations. Accordingly, 3 groups can be distinguished: Group (G1) positively correlates with the depth and dissolved oxygen. It is primarily made up by hydrophytes which colonize mesotrophic to eutrophic medium such as the filamentous algae *Rizoclonium* sp. (epiphytism on bryophytes), *Spirogyra* sp. and *Chara* sp. characteristic of mesotrophic to moderately eutrophic media [48,49]. The phanerogams hydrophytes *Potamogeton crispus* and helophytes *Nasturtium officinale* colonizing this sector are characteristic of mesotrophic media [50]. The presence of both bryophytes *Amblystegium* sp. and *Cinclidotus* sp. demonstrates the presence of a sector with coarse substrate at L4. Group (G2) includes phanerogams generally announced on the river banks *Cyperus longus, Lycopus eurapeus* [44]. This group is characterized by a strong representation of helophytes growing at oligotrophic ecosystem (*Glyceria plicata*) [51] and mesotrophic to eutrophic system (*Typha angustifolia, Sparganum emersum* and *Lycopus europaeus*) [16,52]. Group (G3) characterized by the absence of bryophyte and the presence of phanerogams (hydrophyte and helophyte) and algae inhabiting eutrophic zone with low velocity and sandy substratum. Beside the filamentous algae such as *Cladophora* sp. and *Vaucheria* sp. [53], this group is made up by helophytes phanerogams usually described in the rhithral of small eutrophized rivers with a very good light exposure and a low flow (*Butomus umbellatus, Phragmites australis, Phalaris arundinacea,, Sparganium angustifolium)* associated with hydrophyte phanerogams of both small and large eutrophized river (*Lemna gibba, Lemna minor, Potamogeton pectinatu*s, Potamogeton *trichoides* C*eratophyllum demersum*) [16,50,54,55].

As reported by Ismail and co-investigators [16], this mixture of helophytes, hydrophytes groups (algae, bryophyte and phanerogams) describes the various types of disturbances (organic and mineral pollution, low water level) which influence the river's ecosystem and determine its macrophytic composition. Contrarily to previous studies [41,44], these results translate the positive effect of Qaraoun reservoir on Litani River's water quality [15] and an improvement according to upstream-downstream gradient confirming the role of dams in the improvement of rivers' water quality [16].

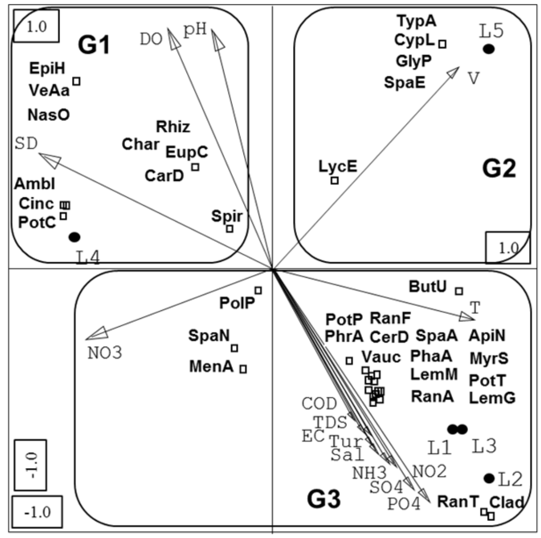

Fig. 4. CCA applied on the 15 abiotic and 35 biotic variables (average for the quantitative statements) in L1, L2, L3, L4, L5. Projections of the abiotic and biotic variable points and the stations points. Hydophyte: Char, Clad, Rhiz, Spir, Vau, LemG, LemM, Ambl, Cinc, CerD, MyrS, PotC, PotP, PotT, RanA, RanF, RanT. Helophyte: Apin, ButU, CarD, CypL, GyP, EpiH, EupC, LycE, MenA, NasO, PhaA, PhrA, PolP, SpaA, SpaE, SpaN, TypA, VeAa

4. CONCLUSION

In Litani River, heterogeneous spatial variations are indicated in both water quality and macrophytic communities with the Upper Litani River characterized by eutrophication and mineralization and the Lower Litani River having better water quality indication the role of Qaraoun Dam in reducing the eutrophication level in the Lower Basin. Distinctive ecological features of the macrophytic associations with respect to water quality parameters and trophic conditions of river are revealed. The considerable changes noted during the last decade in macrophyte community structure in Upper Litani Basin confirm the influence of nutrient input by the heavy anthropogenic pressure observed in this region. Excessive pressure has the potential to push functionally freshwater ecosystems beyond the bounds of resilience and sustainability, threatening their ability to provide important services on both short and long time scales. The effects of enrichment and mineralization on macrophytes can be complex and difficult to separate from other physical and hydrological conditions as well as climatic and geomorphogical factors. More comprehensive investigations are necessary to better understand the interactive relationships between macrophyte assemblages and environmental conditions of Litani River ecosystems. The understanding of macrophytes can provide scientifically sound tools for the development of appropriate management strategies of this important water resource. Furthermore, it is important to address the composition and richness of macrophytes as a key tool in the performance of ecosystem function and restoration of water bodies. A better understanding of species specificity and importance of vegetation diversity will both advance our knowledge of macrophytes role in freshwater bodies and lead to a better guidance of restoration efforts of the river.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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