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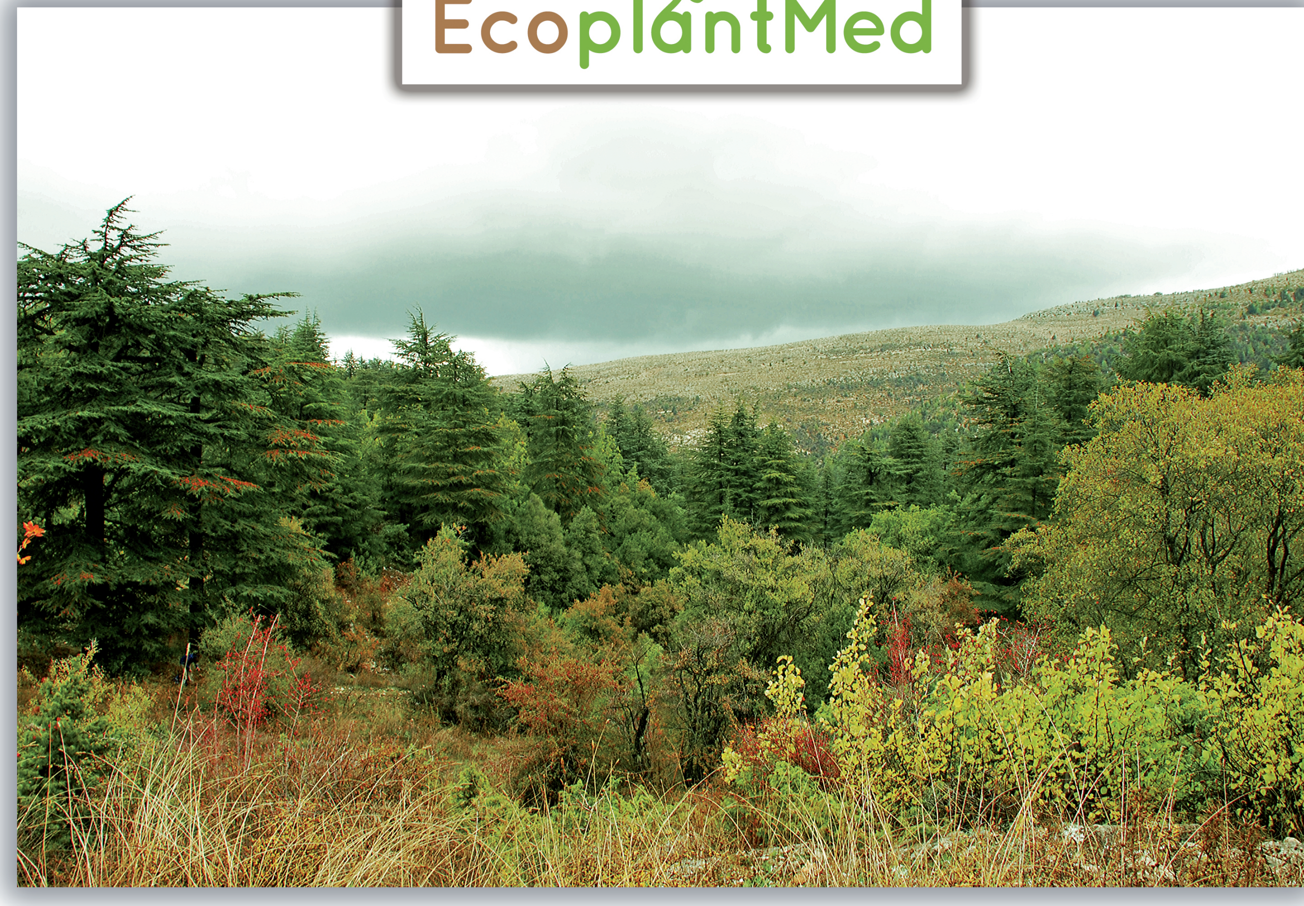

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Riparian woody vegetation distribution along ecological gradients in an East Mediterranean stream

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Abstract
Few studies addressed the distribution of riparian trees and shrubs, and the factors affecting their distribution and structure in Lebanon. The objective of this investigation is to identify the riparian tree and shrub species around Nahr Ibrahim River. We selected 21 sites covering all altitudinal range from sea level up to 1766 m as well as a cross section gradient from river bed. Results showed that biodiversity indices are affected by bioclimatic conditions (vegetation stages) and river flow regime. A moderate dry period of less than 3 months seems to have a positive effect on species richness and composition (trees vs shrubs). A regulated flow would increase the number of tree individuals and reduce biodiversity. *Salix acmophylla* Boiss., *Salix alba* L. and *Platanus orientalis* L. are obligate riparian (phreatophytes) and *Salix libani* Bornm., *Ostrya carpinifolia* Scop., *Juglans regia* L., *Crataegus monogyna* Jacq. are classified as facultative riparian (facultative phreatophytes). Further we were able to classify riparian species according to gradients related to altitude, slope, distance from river bed and number of dry months.

Key words: East Mediterranean, ecological gradient, Lebanon, riparian, woody vegetation.

Introduction

The riparian zone is defined as "a complex assemblage of plants and other organisms in an environment adjacent to and near flowing water" (Klapproth, 1999), which is rich in biodiversity and plays an important role as a natural corridor for species with disjoined areas of distribution (Fischer & Fischenich, 2000). Without definitive boundaries, it may include stream banks, floodplains, and wetlands as well as sub-irrigated sites forming a transitional zone between upland and aquatic ecosystems. Riparian areas combine aquatic and terrestrial characteristics. Easily accessible water and productive soils support a greater plant biomass than what is usually found in upland areas, in addition to the presence of a wide variety of species and complex vertical structures in forests (Larue *et al*., 1995). The natural, structural and functional characteristics of the riparian ecosystem are the key links to maintaining ecological integrity, yet they are affected by numerous topographic influences varying between longitudinal, lateral, vertical, and temporal dimensions (Eubanks & Meadows, 2003; Magdaleno *et al*., 2014). Since the influence of the river varies gradually depending on the distance of the riparian areas of the stream, the farthest are the least influenced, the borders remain uncertain. Moreover, some natural factors create changes in areas that are not normally in the riparian zone: unexpected rainfall, flooding new areas, erosion, and changes in hydrological regimes create environments for new primary succession, which can extend the riparian zone (Stewart, 2007). Based on stream flow characteristics, rivers are grouped into permanent, intermittent and ephemeral rivers (Zaimes, 2007). Johnson *et al*. (1984) classified riparian species according to their frequency of occurrence into obligate, preferential, facultative riparian and non-riparian. Another classification of riparian vegetation is based on their tolerance to drought. The majority of riparian trees species are phreatophytic, they rely on the groundwater above the water table to survive and grow, once they are formed (Smith *et al*., 1998). These classifications do not necessarily take into account the combined effect of river flow characteristics, slope and the distance of vegetation from the river bank or the phreatic table. Friedman *et al*. (2006) classified species within the riparian zone according to a transversal hydrologic gradient as affected by floods frequency and intensity, sediment particle size, nutrient and light availability. On the other hand, longitudinal zonation is crucial in defining riparian distribution at altitudinal scale (De Bano & Baker, 1999; Thorp *et al*., 2006). Water is a limiting factor in semi-arid region, which keeps Mediterranean rivers amongst the most impounded in the World (Grantham *et al*., 2010). Therefore, Mediterranean riparian ecosystems have seldom been included in systematic conservation planning (Nel *et al*., 2009). Accordingly, there is an increasing demand for scientific data related to these areas, their alterations, and their sustainable management. The impact of hydrological processes on the vegetation varies between species. Information about the species is hence essential to evaluate the risks of hydrological alterations (Berajano *et al*., 2012). Lebanon has a typical Mediterranean climate with four

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dry months. The country has 17 perennial rivers and about 23 seasonal streams. Riparian areas represent crucial ecosystems frequently threatened by anthropogenic activities. However, the ecological status of most rivers in Lebanon remains unstudied (Abboud *et al*., 2012). Abi Saleh *et al*. (1996) described riparian vegetation in Lebanon and categorized them based on vegetation levels and geological formations. Nonetheless, the authors did not define the riparian species based on river flow regime, nor their distribution according to a list of environmental factors. The objective of this investigation is to identify the riparian tree and shrub species around Nahr Ibrahim River. The study will allow us to better understand the distribution of the defined riparian tree and shrub species according to the different environmental abiotic factors. Nahr Ibrahim runs from the western slopes of Mount Lebanon to the Mediterranean Sea and represents an important permanent water resource with a basin surface of 330 Km^2, a length of 30 Km, and a flow of 508 MM3/ year (Korfali & Davis, 2004). It is surrounded by a canyon with dense vegetation, resulting in a typical wet environment. The basin is generally composed by karstic landscape with limestone and localized basaltic or sandstone protrusions. The riparian zone of the river constitutes an important ecological corridor.

Material And Methods

Field assessment is generally an interdisciplinary approach, examining abiotic factors, soil parameters, hydrology, and vegetation of the area. It also establishes interrelationships with the vegetation in order to predict the ecological responses to hydrologic events and changes over time and space (Leonard *et al*., 1992).

We selected 21 sites covering all altitudinal range from sea level up to 1766 m (Tab. 2). Sites cover all bioclimatic zones, and a wide range of slope, soil and rock types, and different flow regimes. In addition to the main stream 4 effluents were selected. Plot size was 40 m along the river with a width of 10m from each side of the stream. Physical environment characteristics were recorded through multiple visits between April and September. In each plot we inventoried and measured the distance from the river bank for all trees. For shrubs and canes, the land cover percentage was estimated.

Since not all the effluents are perennial, the phreatic table level is also affected by the Number of Dry Months (NDM). In order to assess whether the species root system requires a contact with the phreatic table or not and classify them according to water availability, we calculated a parameter (R) related to the presence of soil moisture combining both NDM and height of the tree collar above the water surface in the stream (h). Where:

$$R = NDM \times h$$

NDM was assessed on the field through repetitive observations in each site, while (h) was calculated using a Pythagorean equation of the slope angle (α) and distance from stream (d) measurements, in order to take into consideration the measured slope on each bank:

$$h = \sqrt{\frac{TAN^2\alpha + d^2}{TAN^2\alpha + 1}}$$

For species present in more than one site, we classified inventoried tree species whether obligate riparian, preferential or facultative riparian (phreatophyte), non-riparian (mesophyte), or strictly xerophytes based on R, NDM, d and h values. Since we could not measure the distance between the riverbank for shrub and cane species in most sites, we considered riparian, species that are mentioned in the literature as riparian (Abi Saleh *et al*., 1996; Tohme & Tohme, 2014).

To investigate the results at site level, we used exact Chi square test in SPSS to study the effect of altitude and flow regime on canopy cover as well as the distribution of species according to soil types as recorded during the survey (A: Limestone; B: Sandstone; C: Basalt; D: Alluvial; E: mixed A+B; F: marl: G: mixed A+B+C). At species level, we conducted a one way ANOVA (Duncan test) to classify riparian species based on (R) and study the distribution of the identified riparian species according to slope, altitude, and dry period gradients.

Results

Based on the number of dry months, we were able to classify the sites according to their water flow regime. Ten sites out of twenty-one cross a perennial stream, 5 cross an intermittent stream, and 6 are located on ephemeral streams. The sites were distributed as follows, according to the vegetation levels that are characteristics of certain altitudinal range: 4 located in the Thermomediterranean level, 5 in the Mesomediterranean, 6 in the Supramediterranean, and 5 in the Montane Mediterranean (results not shown here).

Chi-square tests showed that canopy cover is significantly affected by vegetation level (Tab. 1): open and discontinued canopy cover with less than 10% is observed in Mediterranean Montane sites, while those within the Thermomediterranean level have a significantly higher canopy cover (>70%). Canopy cover is not significantly affected by river flow regime, even if the frequency of sites with close canopy is higher in sites near permanent streams (Tab. 1).

Figure 1 illustrates that the maximum richness is reached in plots with 1-3 dry months (a total of 8 trees and 7 shrub species respectively), while the minimum

Tab. 1 - Canopy cover variation as affected by vegetation level and river flow.

		Canopy cover				Exact P	Chi Square
		<10%	10-40%	40-70%	>70%		
Vegetation Level	Thermomed	0	0	0	5	0.000***	37.333
	Mesomed	0	1	4	0		
	Supramed	0	1	4	1		
	Montanemed	5	0	0	0		
River Flow	Perennial	0	1	4	5	0.072	9.923
	Intermittent	2	1	1	1		
	Ephemeral	3	0	3	0		

*** Highly significant on a degree of confidence of 95%.

Tab. 2 - Tree species classification based on the number of dry months (NDM), height of the root system from river surface (h) and the derived parameter R (One-way ANOVA Duncan test).

Species	N	Frequency in sites (%)	NDM	h	R
Acer syriacum	9	9.5	0.4	6.7	3.09[ab]
Cercis siliquastrum	19	28.6	2.8	4.5	13.94
Crateagus monogyna	3	14.3	2.8	1.7	2.41[ab]
Ficus carica	37	47.6	0.8	1.3	0.59[a]
Juglans regia	16	19.0	2.4	2.2	4.76[ab]
Juniperus excelsa	4	9.5	2.3	4.8	11.6[de]
Laurus nobilis	22	23.8	2.3	5.4	13.61[e]
Ostrya carpinifolia	2	9.5	4	1.2	4.86[ab]
Pistacia palaestina	34	28.6	2.6	3.6	9.53[cd]
Platanus orientalis	365	71.4	1.65	1.4	1.26[a]
Prunus ursina	32	23.8	2.8	2.8	7.89[bcd]
Quercus calliprinos	53	42.9	2.2	5.7	13.18[e]
Quercus infectoria	4	19.0	3	3.7	10.27[de]
Rhamnus alaternus	3	9.5	3.2	1.3	3.97[ab]
Salix acmophylla	54	14.3	0	1.8	0[a]
Salix alba	248	47.6	0.2	1.4	0.14[a]
Salix libani	76	23.8	2.6	1.6	4.23[ab]

Different letters within the same column indicate significant differences at a degree of confidence of 95%.

richness (1 tree and 1 shrub species) is observed in sites with long dry period. Figure 2 proves that the abundance of individuals in inventoried sites is highly correlated to drought: 480 trees were counted in 10 sites with perennial stream, while only 50 are inventoried in the 6 sites with ephemeral stream. The results show a negative linear regression between the number of trees (y) and the NDM (x), while a moderate drought (up to 2 months) has a positive effect on shrub abundance.

Twenty-six (26) tree species were listed along the river (1116 trees were inventoried). Table 2 illustrates the results related to inventoried species in more than one site (frequency above 5%). According to their frequency in the plots and their numbers, *Platanus orientalis* L. and *Salix alba* L. are the dominant trees

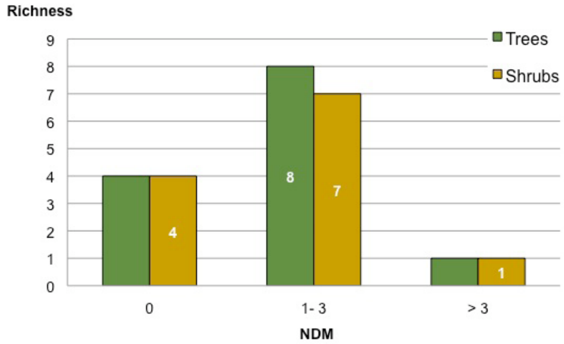

Fig. 1 - Richness variation of riparian woody species according to NDM.

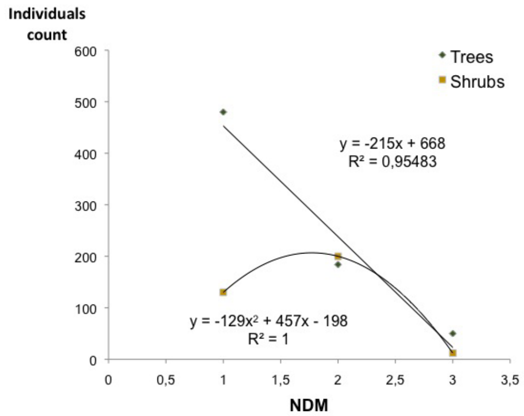

Fig. 2 - Abundance variation of riparian woody species according to the number of dry months.

along the river; followed by *Salix acmophylla* Boiss. and *Salix libani* Bornm. Table 2 shows a gradient of tolerance to moisture for tree species found in riparian zones. *Salix acmophylla* and *Salix alba* have the lowest R values (0 and 0.14 respectively), followed by *Ficus carica* L. and *Platanus orientalis* (0.59 and 1.26 respectively). *Populus nigra* L. is planted in one site, and therefore was not included in this classification due to its low frequency.

To compare the resistance of species to drought, we analyzed the variance of the NDM in their respective area of distribution, and discriminated them with Duncan test, as shown in Table 3. The results show that *Salix libani* is the most tolerant to extended NDM (2.45 up to 3 months), followed by *Populus nigra* and *Rhododendron ponticum* L. var. *brachycarpum* Boiss. (2 months) while the other two *Salix* species are obligate riparian, as described previously they are more frequent on perennial streams (NDM <1). Analysis of variance using Duncan test for discrimination between species for altitude and slope showed that species can be classified into four significantly different categories according to altitudinal gradient, and into two signifi-

Tab. 3 - Riparian species tolerance to extended dry periods (One-way ANOVA - Duncan test).

Species	N	Average NDM
Salix acmophylla	54	0.00^{a} +/- 0
Tamarix smyrnensis	23	0.09^{a} +/- 0.42
Salix alba	248	0.13^{a} +/- 0.46
Arundo donax	38	0.16^{a} +/- 0.54
Rubus hedycarpus	212	1.03^{b} +/- 1.22
Platanus orientalis	365	1.42^{bc} +/- 1.63
Rhododendron ponticum	80	2.00^{cd} +/- 0
Populus nigra	3	2.00^{cd} +/- 0
Salix libani	76	2.45^{d} +/- 0.64

Different letters indicate significant differences at a degree of confidence of 95%.

cant groups according to slope (Tab. 4). Species tolerant to high slopes (>30%) are significantly different from other species: *Rhododendron ponticum* var. *brachycarpum* (35%), *Salix libani* (33.62%) and *Platanus orientalis* (31.38%); where *Platanus orientalis* is the only tree included.

The exact Chi square test showed that there is a significant difference in species distribution according to soil type (Tab. 5). *Salix acmophylla* highly alluvial soils (90% of individuals) and can grow on limestone. *Salix libani* individuals are found on sandstone (80%) and limestone (20% of individuals). *Rhododendron ponticum* is exclusively found on sandstone, the remaining species are indifferent to soil type.

Discussion

At site level, canopy cover next to streams decreases with altitude as the river are narrower, with higher frequency of ephemeral streams bordered by shrubs in the Montane Mediterranean level. This is also sustained by the decrease of the abundance of trees with increased number of dry months. If an intermittent drought has a certain positive effect on tree and shrub richness as well as shrub abundance; obligate phreatophytes are resistant and the facultative phreatophytes are resilient which explains the maximum richness obtained in intermittent streams (Bond *et al*., 2008), which illustrate higher diversity in hydorgeomorphological characteristics, converging with the results of Cliff and Rinaldi (2007). Shrubs benefit from the sharp decrease in tree abundance, and consequently a reduced competition for light and moisture. Their intermediate size, explains their persistence on sites with longer recurrence of inundation and their inability to form root sprouts limits their presence on frequently and disturbed flooded sites (Friedman *et al*., 2006). The number of individuals sharply decreases (riparian trees number is reduced by 6 folds) with extended dry period to avoid competition over scarce water, and the riparian woody species are replaced by mesophytic and xerophytic plants as shown in Table 2.

At the species level, the classification of riparian species based on the frequency of occurrence as suggested by Johnson *et al*. (1984), is not adequate for streams enduring drought. Therefore, the width of the riparian zone is reduced and non-riparian species are captured within the inventoried sites. Another reason could be the restricted range in altitude or in soil for some riparian species, which reduced their frequency of occurrence (in Tabs. 3 and 4 the standard deviation of both *Populus nigra* and *Rhododendron ponticum* is nil due to their presence in single sites). The elaboration of a factor (R) for soil moisture combining NDM and h, allows to better illustrate riparian species. We considered species with an average R values below 2 (Duncan subset group "a" in Tab. 2) as obligate riparian those between 2 and 5 (subset "ab") are facultative riparian.

Tab. 4 - Riparian species distribution (average and standard deviation) according to altitude and slope (One way ANOVA-Duncan test).

Species	N	Altitude (m)	Slope (%)
Arundo donax	38	131.79a +/- 331.263	10.18a +/- 1.557
Platanus orientalis	365	850.47b +/- 377.846	31.38b +/- 19.28
Populus nigra	3	1245 c +/- 0.000	15.00a +/- 0.000
Rhododendron ponticum	80	1506d +/- 0.000	35.00b +/- 0.000
Rubus hedycarpus	212	944.55b +/- 426.183	18.75a +/- 12.972
Salix acmophylla	54	772.46b +/- 54.088	14.91a +/- 14.714
Salix alba	248	892.31b +/- 237.707	15.57a +/- 7.119
Salix libani	76	1535.2d +/- 170.017	33.62b +/- 8.509
Tamarix smyrnensis	23	777.26b +/- 101.964	10.22a +/- 1.043

Different letters within the same column indicate significant differences at a degree of confidence of 95%.

Tab. 5 - Species distribution according to soil type (Chi square test). A: Limestone; B: Sandstone; C: Basalt; D: Alluvial; E: A+B; F: marl: G: A+B+C.

	A	B	C	D	E	F	G	Exact P	Chi square
Platanus orientalis	66	2	92	51	63	62	29		
Salix alba	9	4	2	117	10	68	38		
Salix acmophylla	4	0	0	47	0	0	3		
Salix libani	9	36	0	0	0	2	29		
Tamarix smyrnensis	0	1	0	22	0	0	0	0.000*	1510.68
Rubus hedycarpus	31	21	16	33	12	99	0		
Rhododendron ponticum	0	80	0	0	0	0	0		
Populus nigra	0	3	0	0	0	0	0		
Arundo donax	35	3	0	0	0	0	0		

* Highly significant difference at a degree of confidence of 95%

Species with values between 5 and 10 are mesophytic and those above 10 are xerophytic.

As a result, *Salix acmophylla*, *Salix alba* and *Platanus orientalis* are obligate riparian (phreatophytes) and *Salix libani*, *Ostrya carpinifolia* Scop., *Juglans regia* L., *Crataegus monogyna* Jacq. are classified as facultative riparian (facultative phreatophytes). *Ficus carica* which is a Mediterranean cultivated crop has been also assessed for its unusual capacity to invade riparian zones (Holmes *et al*., 2014). Based on this, and excluding fig tree, but adding the inventoried riparian shrub species, we were able to define an ascending gradient to different environmental factors summarized as follows:

- Altitude: *Arundo donax*, *Salix acmophylla*, *Tamarix smyrnensis*, *Platanus orientalis*, *Salix alba*, *Rubus hedycarpus*, *Populus nigra*, *Rhododendron ponticum*, and *Salix libani*.
- Drought: *Salix acmophylla*, *Salix alba*, *Arundo donax*, *Tamarix smyrnensis*, *Rubus hedycarpus*, *Platanus orientalis*, *Rhododendron ponticum*, *Populus nigra*, and *Salix libani*.
- Slope: all species then *Platanus orientalis*, *Salix libani*, and *Rhododendron ponticum*.
- Distance from river bank: *Salix acmophylla*, *Salix alba*, *Platanus orientalis*, *Rubus hedycarpus* and *Tamarix smyrnensis*.

On an altitudinal gradient, *Platanus orientalis* thrives between sea level and 1200 m while *Rhododendron ponticum* and *Salix libani* grow at high altitudes in the Montane Mediterranean vegetation level which converges with Mouterde (1966) and Abi Saleh *et al*. (1996). *Salix acmophylla* and *Tamarix smyrnensis* are strictly found on lower altitudes. This could be related to their tropical and subtropical origin (Lansdown, 2013; Hassler, 2016).

If in altitudinal range *Salix alba* shows a high plasticity, *Platanus orientalis* has the uppermost elasticity amongst riparian tree species when it comes to drought tolerance, and the species can be classified as preferential riparian according to Johnson *et al*. (1984). The results converge with those of Glenn & Nagler (2005) and Magdaleno *et al*. (2014) and explain the shifts from *Salicaceae* to *Tamarix* species with drought occurrence (Gonzalez *et al*., 2012). Over a slope gradient, *Platanus orientalis* is a preferential riparian species with developed root system providing water from unsaturated soil layers as well as from the groundwater, which explains its tolerance to high slopes (Smith *et al*., 1998; Singer *et al*., 2012). The distribution of species according to soil type converge with those of Abi Saleh *et al*. (1996) regarding the distribution of *Rhododendron*. *Salix alba* and *Salix acmophylla* seem to prefer alluvial soils. Willows are resilient to flood and debris flow which make them pioneer species, this also explain their preference to alluvial soil where fresh deposits of sediments are ideal (Naiman *et al*., 1998).

This study is a first look on the Lebanese riparian tree and shrub species and their distribution as affected by the physical environment. Further investigation is foreseen to upscale the inventory to different river basins in order to reach an accurate range for rarely encountered species and encompass the effect of anthropogenic factors on the hydrogeomorpholoy of rivers and riparian habitat (Gumiero *et al*., 2015), in order to better understand species resilience to these factors and consequently suggest appropriate conservation measures for these important ecosystems.

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