Biologia **66**/1: 76—87, 2011
Section Botany
DOI: 10.2478/s11756-010-0127-2

Relationships between environmental variables and vegetation across mountain wetland sites, N. Iran

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Abstract: The mountain wetlands studied represent a unique habitat on the southern slopes of the Alborz mountain range, the second largest range in Iran. In comparison with other parts of this range the western section is ecologically and botanically unknown. Floristic and vegetation variation were assessed using diverse environmental variables along a broad altitudinal span (350 m to 3200 m a.s.l.). Using both statistical and ordination analyses floristic variation was assessed on three defined altitudinal belts which were delimited based on Alborz macro-climatic boundaries. The distribution of individual wetland plant species, of phytogeographic elements and of life-forms all differ among altitudinal belts. This result is also shown in both direct and indirect analyses of ordinations. The proportion of geophytes significantly increases with altitude and geophytes are very well represented in the upper altitudinal belt. The number of species of a narrow phytogeographical distribution (e.g. endemics) increases with altitude, soil pH and EC declined with altitude. The first axis of DCA ordination with passively projected environmental variables indicates that, organic matter and concentration of Fe^{2+} are increased toward higher altitude. The second axis of ordination is related to both soil texture and slope inclination. The distribution of species in the CCA species plot is also close to the distribution of those in the DCA ordination. This study indicates that altitude and slope together with other dependent environmental variables (pH, EC, $Ca^{2+}$and soil texture) are the main ecological factors controlling species distribution across the Western Alborz wetland sites.

Key words: altitudinal gradient; dry mountain wetlands; life form; vegetation ordination; Western Alborz mountain range; Iran

Abbreviations: CCA, canonical correspondence analysis; DCA, detrended correspondence analysis; EC, electrical conductivity; OM, organic matter; PE, phytogeographic element

Introduction

The Mountain wetlands of the southern slopes of Alborz are from the floristic and environmental viewpoint sharply differentiated from the adjacent steppe ecosystems. Despite being relatively small and scattered areas, they are extremely important contributors to species-richness within the dry steppe southern slopes of the Alborz mountain range. The occurrence of the large number of these verdant ecosystems not has been anticipated because the dry climate of the southern steppe slopes of Alborz which differs from the wet climate of the northern slopes (Klein 2001; Tregubov & Mobayen 1970; Zohary 1973). Similar ecosystems have also been studied in other mountainous areas in both the Irano-Turanian and Euro-Siberian regions. Studies relating to altitude and other ecological factors for example slope inclination, soil properties and vegetation have been carried out in many mountain wetland habitats (Miserere et al. 2003; Rolon & Maltchik 2006; Hájek et al. 2008). The effects of environmental variables such as soil on different plant communities have been the subject of many ecological studies in recent years (Bowles et al. 2005; Bragazza et al. 2005; Lyon & Gross 2005; Pinto et al. 2006).

Most studies on the flora and vegetation of the Alborz mountain range have been concentrated in the central and eastern sections (Zohary 1973; Klein 1984, 2001; Klein & Lacoste 1995; Nazarian et al. 2004; Jafari & Akhani 2008; Naqinezhad et al. 2009). Therefore, detailed ecological and floristic characteristics remain very

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scarce, particularly for the wetland sites in the western section.

The primary aim is to acquire more insight into how plant species are distributed along environmental gradients and to determine which variables control species composition of wetland vegetation. The next stage of this work was to determine the interrelationships between life-forms, phytogeographic elements, physical and chemical properties of soil, slope and their variation in relation to altitude.

Study area

The study area corresponds to the western sector of the Alborz mountain range between the Karaj–Chalus road in the east and the Qazvin-Rasht road (Sefidrud dam) in the west. This section covers area, 250 km long and 70 km wide rises to 4175 m high on the mount of Siahlan. This area is located between 49°24′ and 51°19′ E and between 35°56′ and 36°45′ N.

Eocene volcanic and volcaniclastic rocks form the most prominent geological feature of the southern section of the Alborz mountains range. However, in the northern section of the Alborz, Middle Jurassic to Upper Cretaceous limestone formations become much more important and form some very high rock cliffs along the east-west directed thrust fault zones (Stöcklin 1974).

The study area exhibit temperate and continental climates in the low and high altitudes respectively. The climatic data show that the higher altitudes of the Alborz mountains range are affected by the north westerly flow of polar air masses (Khalili 1973). Unfortunately there is no meteorological data from higher elevations in the western section of the Alborz mountains range. At the 1300 m a.s.l. (Qazvin station), the mean annual temperature is 13 °C, that of January –0.6 °C and that of August 26 °C. Mean annual rainfall is 370 mm y^{-1}, that of September 130 mm y^{-1} and that of March 480 mm y^{-1}.

There are five major wetland habitats, mire, wet meadow, spring, lake and riverside in the study area (Naqinezhad et al. in preparation). The two primary categories, aquatic and telmatic wetlands were recognized using the studied relevés. Aquatic wetlands mainly consist of perennial hydrophytes or emergent plants (lakeside and riverside habitats). Telmatic wetlands are defined as wet, semi-terrestrial wetlands and are not aquatic wetlands or temporary wetlands (Wheeler & Proctor 2000; Wheeler & Shaw 2000) include three major types of wetland vegetation, i.e. springs, mires and wet meadows. The mire and wet meadow habitats mainly dominated by species such as *Carex orbicularis*, *Blysmus compressus*, *Dactylorhiza umbrosa, Eleocharis uniglumis, Mentha longifolia* and *Primula auriculata* in the higher altitudes. The spring habitat contains vegetation around high mountain cold springs and in the small flowing rivulets originating from them. They are characterized by *Ligularia persica, Lythrum salicaria, Plantago lanceolata* and *Veronica biloba.* The lake habitats are composed by mainly of hydrophytic species such as *Batrachium trichophyllum, Zannichellia palustris* and some helophytes such as *Alisma lanceolata*, *Schoenoplectus lacustris,* and *Typha caspica.* The riversides are main habitats for the helophytic species such as *Bolboschoenus affinis, Juncus inflexus, Typha laxamannii* and *T. minima.* The riverside and lakeside mainly located at lower altitudes.

Material and methods

Collecting of vegetation and floristic data

Ninety wetland study sites on the southern slopes of the western Alborz mountains range were selected within the study area (Table 1, Fig. 1).The study was carried out within the period of 2005 to 2007 and sites were situated between 350 up to 3200 m a.s.l. and varied in area from 200 m^2 to 10 ha (86.49 ha in total). The vascular flora of the wetland sites was recorded in 430 relevés across the 90 study sites and then they were identified in the central herbarium of Tehran University (TUH). Nomenclature for vascular plants was based on Flora Iranica (Rechinger 1963–2005) and Flora of Iran (Assadi et al. 1988–2008).

The collection of relevés followed the Braun–Blanquet approach (Braun–Blanquet 1964; Muller–Dombois & Ellenberg 1974). The sample area for most relevés was 1 m^2. The number of relevés and their size were related to site area and to ensure that all vegetation types were sampled, relevés were recorded from different parts of each site.

Measuring of species characters

Studied variables are classified into two groups, including both, species-related variables group (life-form, phytogeographical information) and environmental variables group (altitude, slope, physical and chemical soil properties). Following Raunkiaer life-forms (Raunkiaer 1934) were separated: chamaephyte, geophyte, helophyte, hemicryptophyte, hydrophyte, phanerophyte and therophyte. The geographical distribution of each species was assessed based on data obtained from monographs and distributional data in the floras, particularly Flora Iranica (Rechinger 1963–2005). The terminology and delimitation of the main phytogeographic areas (i.e. Euro-Siberian (ES), Irano-Turanian (IT), Mediterranean (M) and Pontic province within Euro-Siberian region (PON)) relates to standard reference works, particularly those of Zohary (1973) and Takhtajan (1986). The classification of phytogeographical elements into four categories was also used in the current work to provide summary data with appropriately-sized groupings for statistical analysis. For this study, a PE is a group of plant taxa that share similar centers and limits to the total geographical distribution: PE_1 'broadly pluriregional' (wide-ranging taxa associated with more than three phytogeographics region); PE_2 'narrowly pluriregional' (plants found in two or three phytogeographics region, i.e. Euro-Siberian, Irano-Turanian (ES-IT) and Euro-Siberian, Irano-Turanian, Mediterranean (ES-IT-M) etc. PE_3 'Irano-Turanian' (includes both Irano-Turanian *sensu stricto* (IT) and Irano-Turanian-Pontic (IT-PON) floristic elements); PE_4 'endemic' (includes endemic species or subendemic species). Strictly, PE_4 is a component of PE_3.

Measuring of site attributes

Soil cores (five replicates per site) were collected at random to a depth of 10 cm. Soil samples were mixed to reduce heterogeneity and air-dried prior to analysis. They were subsequently crushed and sieved through a 2 mm mesh. Measured soil variables include physical and chemical properties. Soil texture (the proportions of sand, silt and clay) was determined by the hydrometer method (Bouyoucus 1951). Soil pH in a suspension of 1:5 soil: water ratio at 20 °C and electrical conductivity (EC) in a saturation extract at 20 °C were determined by pH meter glass electrode and EC meter respectively. Organic matter (OM) was estimated by the Walkley and Black method (Nelson & Sommers 1996) and the proportion of $CaCO_3$ was measured by

Table 1. Location of wetland study sites in the western Alborz mountains range. (See Fig. 1 for the location of each study site).

Site No.	Latitude (N)	Longitude (E)	Area (m^2)	Altitude (m a.s.l.)	Site No.	Latitude (N)	Longitude (E)	Area (m^2)	Altitude (m a.s.l.)
1	36° 19′ 09.7″	50° 14′ 51.4″	500	1700	46	35° 56′ 47.7″	50° 56′ 35.0″	1000	1750
2	36° 00′ 02.0″	50° 22′ 00.2″	2000	1200	47	35° 56′ 36.1″	50° 57′ 24.8″	3000	1800
3	36° 02′ 47.2″	50° 22′ 12.3″	1000	1200	48	36° 27′ 13.8″	50° 21′ 49.9″	10000	1200
4	36° 18′ 45.7″	50° 04′ 33.3″	500	1400	49	36° 22′ 32.2″	50° 15′ 40.1″	2500	2200
5	36° 18′ 27.9″	50° 04′ 33.3″	15000	1500	50	36° 23′ 52.0″	50° 19′ 09.5″	1500	1500
6	36° 24′ 52.8″	49° 59′ 17.6″	1000	1800	51	36° 28′ 58.2″	50° 26′ 44.5″	70000	1800
7	36° 26′ 11.0″	50° 07′ 53.5″	10000	2150	52	36° 23′ 50.4″	50° 30′ 18.9″	10000	1300
8	36° 26′ 06.2″	50° 07′ 33.7″	8000	2140	53	36° 22′ 25.8″	50° 12′ 52.4″	2500	2200
9	36° 25′ 48.6″	50° 07′ 24.6″	3000	2150	54	36° 21′ 37.6″	50° 34′ 50.2″	1500	1800
10	36° 03′ 24.1″	50° 21′ 15.1″	2000	1200	55	36° 21′ 08.0″	50° 36′ 48.0″	500	2200
11	36° 04′ 13.7″	50° 19′ 57.2″	2500	1200	56	36° 45′ 41.0″	49° 53′ 56.0″	3500	2020
12	36° 04′ 27.8″	50° 19′ 31.4″	2500	1200	57	36° 45′ 41.4″	49° 54′ 01.9″	5000	2000
13	36° 23′ 21.9″	49° 47′ 45.0″	10000	1555	58	36° 42′ 47.8″	49° 55′ 14.4″	1500	1550
14	36° 29′ 16.6″	49° 50′ 05.8″	10000	2000	59	36° 45′ 33.5″	49° 54′ 12.9″	6000	2050
15	36° 24′ 15.1″	49° 47′ 50.8″	15000	1600	60	36° 37′ 47.1″	49° 29′ 51.8″	100000	350
16	36° 27′ 18.3″	49° 52′ 47.4″	2500	1800	61	36° 26′ 54.9″	49° 24′ 58.4″	500	1500
17	36° 28′ 29.4″	49° 55′ 13.2″	500	2000	62	36° 25′ 47.7″	49° 25′ 55.0″	500	1600
18	36° 30′ 57.4″	49° 59′ 17.3″	4000	2150	63	36° 25′ 10.9″	49° 25′ 51.7″	3000	1700
19	36° 31′ 10.5″	49° 58′ 12.8″	3000	1950	64	36° 27′ 57.3″	49° 42′ 45.1″	1000	2000
20	36° 23′ 51.2″	50° 13′ 03.4″	500	2200	65	36° 25′ 23.4″	50° 36′ 35.0″	8000	2100
21	36° 32′ 30.0″	50° 11′ 01.7″	80000	900	66	36° 25′ 33.9″	50° 36′ 23.8″	10000	1800
22	36° 22′ 39.1″	50° 13′ 02.9″	600	2200	67	36° 24′ 07.6″	50° 46′ 36.9″	500	2800
23	36° 29′ 20.4″	50° 15′ 20.5″	90000	950	68	36° 24′ 09.4″	50° 46′ 46.3″	3500	2800
24	36° 06′ 24.9″	50° 30′ 23.7″	80000	1500	69	36° 24′ 17.4″	50° 46′ 40.8″	5000	2800
25	36° 27′ 48.1″	50° 05′ 56.5″	10000	2400	70	36° 24′ 04.4″	50° 47′ 02.2″	15000	2800
26	36° 26′ 02.1″	50° 07′ 04.3″	40000	2100	71	36° 24′ 11.3″	50° 47′ 05.3″	3500	2850
27	36° 25′ 54.2″	50° 06′ 46.5″	4000	2050	72	36° 24′ 19.4″	50° 47′ 47.8″	60000	2900
28	36° 26′ 17.7″	50° 07′ 47.0″	200	2150	73	36° 23′ 56.8″	50° 46′ 07.5″	3000	2700
29	36° 26′ 15.6″	50° 07′ 27.7″	5000	2120	74	36° 29′ 28.9″	50° 26′ 42.1″	3000	1800
30	36° 26′ 29.6″	49° 36′ 41.0″	6000	1800	75	36° 29′ 26.7″	50° 26′ 54.0″	1500	1850
31	36° 09′ 45.5″	50° 31′ 56.8″	4000	2100	76	36° 24′ 06.0″	50° 31′ 23.2″	2000	1300
32	36° 10′ 55.9″	50° 33′ 12.2″	5000	2450	77	36° 09′ 43.1″	51° 17′ 53.5″	10000	3100
33	36° 10′ 59.6″	50° 34′ 06.3″	6000	2550	78	36° 07′ 56.4″	51° 16′ 00.2″	3000	2600
34	36° 08′ 48.4″	50° 36′ 29.7″	300	2050	79	36° 08′ 46.9″	51° 12′ 45.6″	1000	3000
35	36° 08′ 00.1″	50° 40′ 34.6″	400	2300	80	36° 08′ 13.4″	51° 14′ 14.9″	5000	2650
36	36° 09′ 56.4″	50° 42′ 35.6″	5000	1900	81	36° 07′ 46.3″	51° 11′ 18.7″	6000	3200
37	36° 11′ 47.4″	50° 35′ 47.4″	4000	1900	82	36° 08′ 37.2″	51° 11′ 19.9″	7000	3000
38	36° 12′ 12.9″	50° 37′ 18.2″	2500	1900	83	36° 10′ 19.2″	51° 10′ 00.7″	2000	3200
39	36° 12′ 14.5″	50° 43′ 31.9″	9000	2100	84	36° 09′ 08.2″	51° 10′ 04.4″	1000	2900
40	36° 13′ 54.6″	50° 46′ 17.6″	400	2300	85	36° 09′ 50.0″	51° 08′ 32.5″	3000	2700
41	36° 14′ 38.6″	50° 56′ 03.0″	8000	2600	86	36° 09′ 32.9″	51° 17′ 28.0″	5000	3100
42	36° 14′ 34.0″	50° 55′ 51.0″	2000	2700	87	36° 07′ 51.5″	51° 19′ 31.4″	500	2500
43	36° 11′ 33.6″	50° 56′ 21.1″	500	2550	88	36° 11′ 42.0″	51° 05′ 04.2″	8000	2700
44	36° 07′ 24.8″	50° 54′ 11.9″	10000	2900	89	36° 34′ 21.8″	50° 21′ 52.1″	3500	2700
45	36° 08′ 39.9″	50° 52′ 38.2″	2000	2500	90	36° 37′ 13.7″	50° 18′ 22.6″	3000	2400

the Calcimeter method (Allison & Moode 1965). The measurements of extractable cations of Potassium (K^+), Calcium (Ca^{2+}), Sodium (Na^+) extracted with Ammonium acetate (NH_4OAc) and Iron (Fe^{2+}) extracted with DTPA (diethylenetriaminepentaacetic acid) (Page 1982) were determined using ICP-emission spectroscopy (GBC Integra XL) (Dahlquist & Knoll 1978). The inclination of slope of the ground was subjectively assessed in the field. Altitude and coordinates were measured by GPS (Garmin 76CSx).

Data analysis

Two data matrices were constructed. The species matrix includes data on the presence or absence species data (0, 1) extracted from the original relevés from each site, and the variables matrix includes altitude, degree of slope, percentages of each life-form and phytogeographic elements, sand, silt, clay, OM, $CaCO_3$ and pH, EC, Na^+, K^+, Ca^{2+}, Fe^{2+} for each site.

Canoco 4.5 for Windows (ter Braak & Šmilauer 2002) was used for ordination analyses. An unconstrained ordination analysis (detrended correspondence analysis, DCA) was applied to find the axes with maximum variation in floristic composition of studied sites and thus describe the general pattern in species distribution along the gradients (ter Braak 1987; Lepš & Šmilauer 2003). The DCA diagram was subsequently passively projected with all variables to show their variation across the species data. Constrained ordination (canonical correspondence analysis, CCA) was applied to assess the variation explained by the most significant measured environmental variables (ter Braak 1987; Lepš & Šmilauer 2003). The effect of these variables on species composition in the CCA ordination was tested using the Monte-Carlo permutation test with 499 permutations. In both ordination techniques, rare species were down-weighted.

The Kolmogorov-Smirnov test was used to approve the normal distribution of parametric variables. It was found necessary to square-transform of all studied variables except altitude, percentages of silt, sand, geophyte, hemicryptophyte, PE_1 and PE_3. The Pearson correlation coefficient

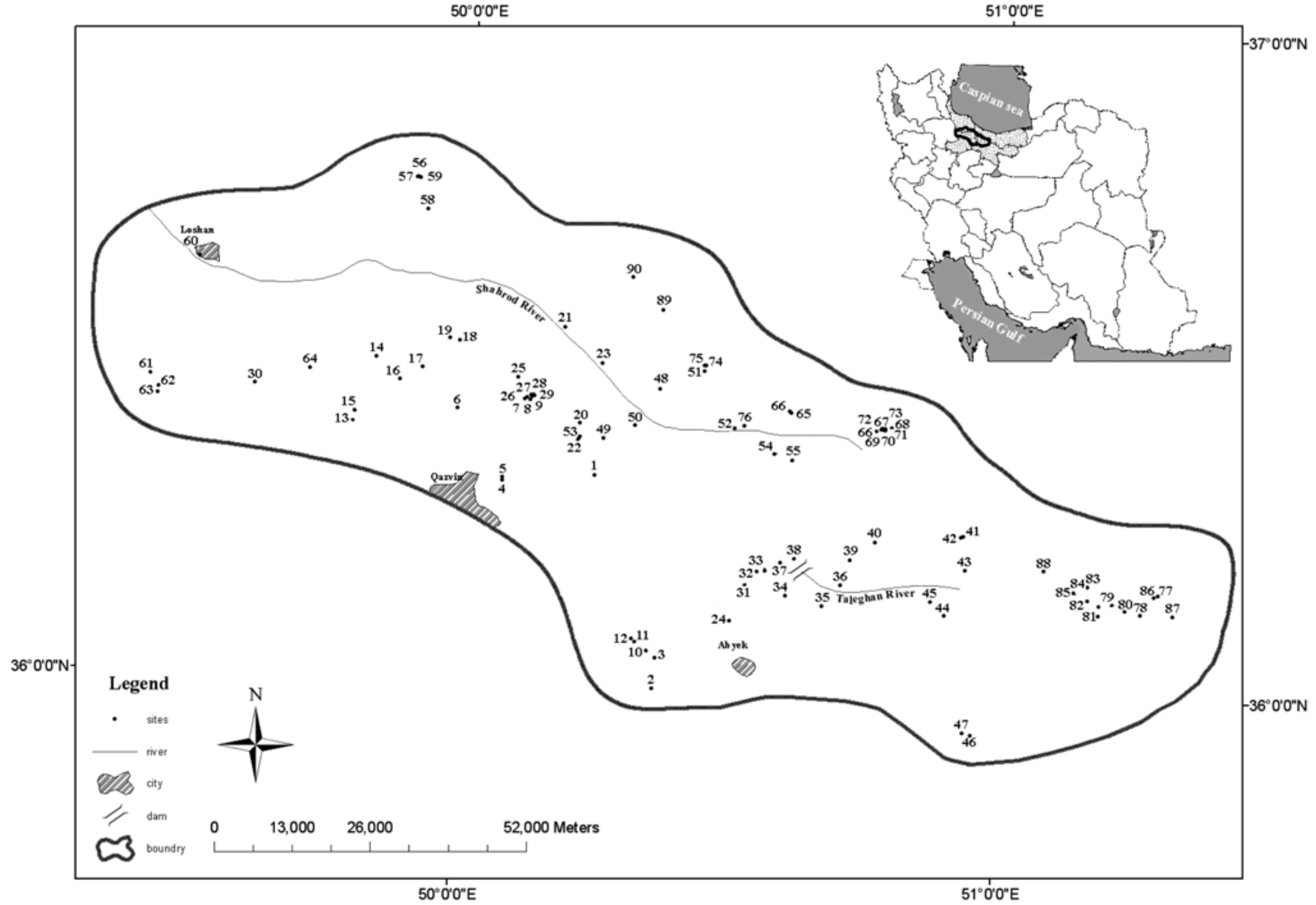

Fig. 1. Location of the study wetland sites in the western Alborz mountains range. (Iran). The numbers on the map correspond to the wetland sites listed in Table 1.

was used to examine relationships between ordination scores for sites and the distribution of species and habitat variables.

To check whether altitudinal belts separated for steppe communities were also relevant for wetlands (see Klein & Lacoste 1998), three altitudinal classes, lower belt (350–1800 m a.s.l.), middle belt (1801–2500 m a.s.l.) and upper belt (2501–3200 m a.s.l.), were also separated and differences in the distribution of species and habitat variables between these three altitudinal belts were assessed using one-way ANOVA with differences between subsets assessed by *post-hoc* Tukey tests. The delimitation of these three belts is according to both macro-climatic boundaries in the Alborz mountains range and a variation in related Irano-Turanian steppic vegetation across the belts (Sabeti 1969; Klein & Lacoste 1998; Klein 2001; Naqinezhad et al. 2009). Statistical tests were performed using SPSS for Windows^{TM} (Version 16.0).

Results

A total of 368 plant taxa were determined across 90 wetland patchy sites. A gradient of floristic change is observed using indirect (unconstrained) gradient analysis (DCA) on species and sample data (Figs. 2–3). The first and second axes are very well correlated with the studied variables ($r = 0.95$ for the first and $r = 0.87$ for the second axis). The first axis of the DCA ordination is highly correlated ($P < 0.001$) with altitude, slope, Ca^{2+}, Fe^{2+}, pH and the percentages of geophyte, PE_1 ('broadly pluriregional'), PE_3 ('Irano-Turanian') and PE_4 (endemic) species, sand, clay, OM and $CaCO_3$. The second axis seems to be connected to moisture and is highly correlated ($P < 0.001$) with slope and the percentages of hydrophytes, hemicrptophytes, sand and clay (Fig. 2). Many of the variables correlated with these two DCA axes are also highly significantly correlated with each other (Table 2).

According to the DCA plot of species data, species such as *Alopecurus myosoroides, Bolboschoenus affinis, B. maritimus, Eleocharis mitracarpa, Galium aparine, Inula thapsoides, Phragmites australis, Polygonum persicum, Rumex chalepensis, Schoneoplectus lacustris, Typha caspica* and *T. minima* mostly occurred in the lower altitudinal belt (350–1800 m a.s.l.). Species such as *Carex melanostachya, C. songorica, Eleocharis uniglumis, Juncus articulatus, Lemna minor, Lotus corniculatus* subsp. *corniculatus* var. *corniculatus*, *Mentha longifolia* var. *kotschyana*, *Poa pratensis* and *Scrophularia umbrosa* are mainly found in the middle altitudes (1801–2500 m a.s.l.). *Carex pseudofoetida* subsp. *acrifolia, Cirsium rhizocephalum, Epilobium frigidum, Euphrasia pectinata, Gypsophila elegans, Ligularia persica, Myosotis lithospermifolia, Primula auriculata, Ranunculus bulbosus, Swertia longifolia* and *Trichopho-*

Table 2. Pearson correlation matrix for variables measured in each of the 90 studied sites. The following abbreviations are used: Alt = Altitude (m a.s.l.), Ch = chamaephyte (% species), Ge = geophyte (%), Hl = helophyte (%), Hm = hemicryptophyte (%), Hy = hydrophyte (%),Ph = Phanerophyte (%), Th = Therophyte (%), OM = organic matter (%), PE_{1-4} (%) relates to the four phytogeographic categories ('broadly pluriregional', 'narrowly pluriregional', 'Irano-Turanian' and 'endemic', respectively) described in Material and methods. Here and in other tables *, ** and *** identify $p < 0.05$, <0.01 and <0.001, respectively.

Alt	Alt																							
Slope	0.46***	Slope																						
Silt	−0.23*	−0.37**	Silt																					
Sand	0.33**	0.40***	−0.73***	Sand																				
Clay	−0.32**	−0.33**	0.38***	−0.90***	Clay																			
OM	0.40***	0.19	0.13	−0.13	0.11	OM																		
$CaCO_3$	−0.56***	−0.29**	0.31**	−0.40***	0.34**	−0.22*	$CaCO_3$																	
K^+	−0.13	−0.28**	0.34**	−0.41***	0.34**	−0.05	0.15	K^+																
Na^+	−0.37***	−0.27*	0.18	−0.24*	0.22*	−0.01	0.29**	0.34**	Na^+															
Ca^{2+}	−0.42***	−0.24*	0.44***	−0.56***	0.50***	0.09	0.55***	0.36 ***	0.46***	Ca^{2+}														
Fe^{2+}	0.42***	0.12	−0.02	0.13	−0.12	0.62***	−0.33**	−0.11	0.11	−0.13	Fe^{2+}													
EC	−0.33**	−0.12	0.15	−0.15	0.12	−0.06	0.29**	0.05	0.44***	0.63***	−0.06	EC												
pH	−0.60**	−0.28**	0.18	−0.30**	0.31**	−0.43***	0.54***	0.21*	0.25*	0.40***	−0.69***	0.07	pH											
Ch	−0.23*	−0.12	0.18	−0.09	0.02	−0.18	0.29**	0.09	0.17	0.06	−0.22*	0.14	0.22*	Ch										
Ge	0.49***	0.31**	−0.10	0.18	−0.16	0.38***	−0.33**	−0.08	−0.09	−0.22*	0.28**	−0.22**	−0.34***	−0.17	Ge									
Hl	−0.54***	−0.36***	0.17	−0.30**	0.29**	−0.13	0.46***	0.19	0 .29**	0.33**	−0.15	0.15	0.29**	0.16	−0.39***	Hl								
Hm	0.17	0.30**	−0.07	0.22	−0.24	0.01	−0.15	−0.21	−0.25*	−0.16	0.03	−0.08	0.03	0.01	−0.24*	−0.43**	Hm							
Hy	−0.02	−0.29**	0.13	−0.19	0.14	−0.09	0.02	0.32**	0.00	0.09	−0.08	−0.06	0.10	−0.03	−0.23*	0.06	−0.16	Hy						
Ph	−0.21*	0.58	−0.08	0.18	−0.19	−0.29**	0.05	0.28**	0.23*	0.23*	−0.28**	0.27**	0.26*	0.28**	−0.19	0.09	0.06	0.07	Ph					
Th	−0.07	0.89	−0.08	−0.02	0.06	−0.13	−0.01	−0.21	0.01	0.00	−0.04	0.17	−0.05	−0.14	−0.40***	−0.15	−0.02	−0.15	−0.08	Th				
PE_1	−0.59***	−0.33**	0.26*	−0.22*	0.13	−0.17	0.44***	0.21*	0.14	0.19	−0.17	0.07	0.33**	0.15	−0.41***	0.50***	−0.12	0.1	0.03	0.01	PE_1			
PE_2	−0.28**	−0.53	−0.01	−0.01	0.02	−0.12	0.00	−0.06	0.09	0.08	−0.10	0.11	0.21*	0.15	−0.05	0.14	0.04	−0.04	0.10	−0.13	−0.19	PE_2		
PE_3	0.71***	0.39***	−0.18	0.23*	−0.19	0.24*	−0.41***	−0.13	−0.27*	−0.33**	0.22*	−0.19	−0.46***	−0.18	0.43***	−0.48***	0.09	−0.03	−0.06	−0.03	−0.59***	−0.53***	PE_3	
PE_4	0.49***	0.22*	−0.15	0.12	−0.08	0.24*	−0.21	−0.12	−0.1 7	−0.02	0.18	−0.12	−0.29**	−0.30**	0.23*	−0.41**	−0.04	−0.13	−0.17	0.13	−0.45***	−0.49***	0.46***	PE_4

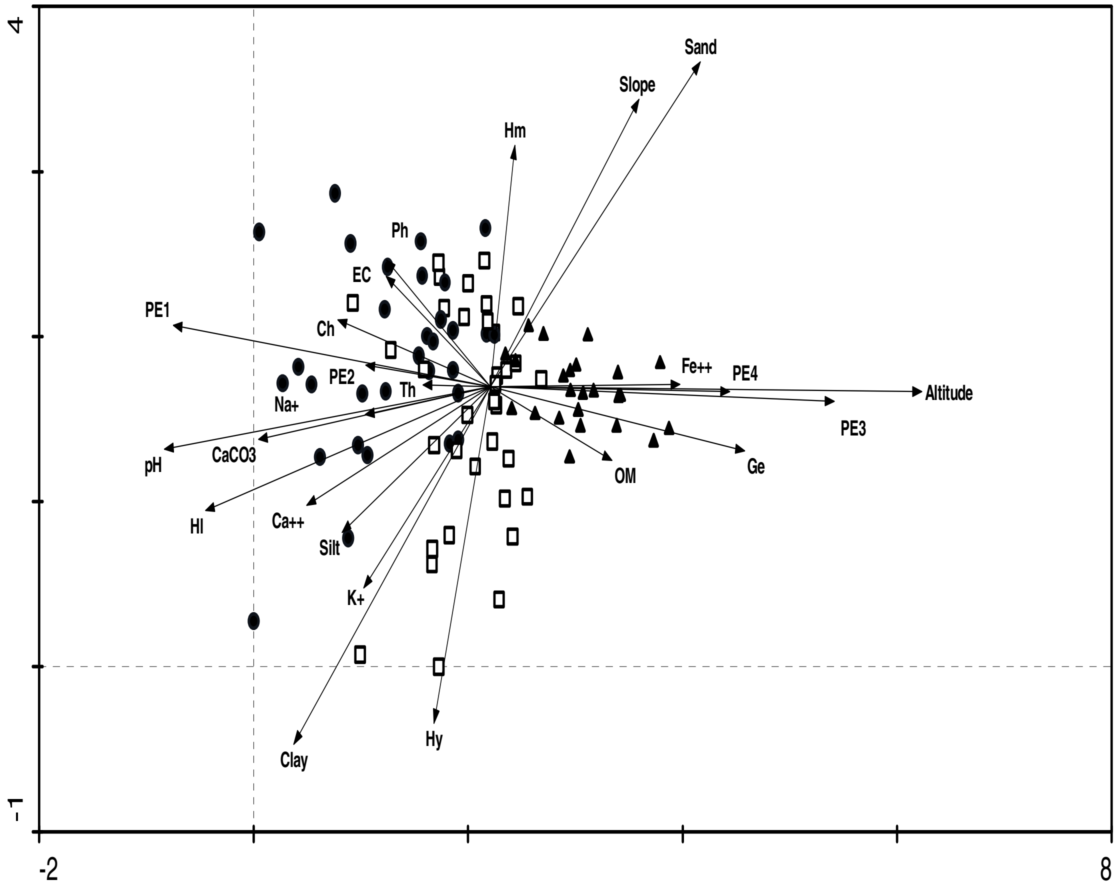

Fig. 2. DCA ordination biplot of the western Alborz wetland sites. The eigenvalues of 0.38 and 0.22 for two first axes respectively explaining 10.3 % of total species inertia. Environmental variables, phytogeographic and life-form data are passively projected onto the ordination diagram. Lower belt sites with altitudes 350–1800 m a.s.l. (●); middle belt sites with altitudes between 1801–2500 m a.s.l. (□); upper belt sites with altitudes between 2501–3200 m a.s.l. (▲). Ch = chamaephyte; Ge = geophyte; Hl = helophyte; Hm = hemicryptophyte; Hy = hydrophyte; OM = organic matter; Ph = phanerophyte; Th = therophyte. PE$_{1-4}$ relates to the four phytogeographic categories (‘broadly pluriregional’, ‘narrowly pluriregional’, ‘Irano-Turanian’ and ‘endemic’, respectively) described in Material and methods.

rum pumilum occur at the highest altitudes recorded in this study (2501–3200 m a.s.l.). The result indicates variation of floristic composition within studied sites across the altitudinal range (Fig. 3).

The longest gradient length in the DCA analysis (3.87 SD) suggests a CCA analysis on the current data (Lepš & Šmilauer 2003). At first all environmental variables investigated in this study were incorporated in the CCA analysis. Global Monte-Carlo test on all these variables together were highly significant, both on the first canonical axis and all canonical axes ($P = 0.002$). Nevertheless, forward selection was applied to include the highest correlated variable into the model and test residual variation. This procedure was repeated until newly included variables no longer contribute significantly to the model. The results of forward selection indicate that the effects of altitude, slope inclination and percentage of clay are highly significant ($P = 0.002$) on the CCA ordination. Moreover, the effects of EC ($P = 0.03$), pH ($P = 0.03$) and $CaCO_3$ ($P = 0.04$) are also significant in further steps of forward selection. The six latter variables explain 0.828 from 1.246 of the total explainable inertia (i.e. almost 66% of the total variation explainable by the all the 13 variables included in the CCA analysis).

Using the highest significant variables (altitude, slope and percentage of clay), CCA analysis demonstrated quite similar relationships to DCA analysis with 7.8 percent of variation in species composition explained by two first axes of the CCA ordination (eigenvaules 0.31 and 0.15 for two first axes respectively) (Fig. 4). Moreover, 84% of total species-environment relationship is explained by two first axes. The effects of altitude and slope on the floristic variation are significant on both the first and second axes. CCA ordination shows that the first axis is correlated well with altitude and second axis is much affected by soil texture and slope inclination (Fig. 4). The distribution of species on the CCA species plot is also close to distribution of those on the DCA ordination (Fig. 4).

The main difference between CCA and DCA is that CCA reduces the arch effect of redundancy information and summarises the best variables used in the main gradients. The quite close species inertia both in the DCA and CCA (10.3 and 7.8% respectively) suggests that the selected environmental variables in the CCA analysis are those responsible for the observed variation in

Fig. 3. DCA plot of species in the western Alborz wetland sites. Species weight (2%) was used for the selection of the species in the plot. The species included in the diagram here and CCA species plot abbreviated to the first three letters of the genus and the first four of the specific epithet are as follows:*Alchemilla rigida, Alisma lanceolatum, Allium subvineale, Alopecurus arundinaceus* var. *arundinaceus*, *A. myosoroides, Barbarea plantaginea*, *Batrachium trichophyllum, Belevalia cyanopoda, Blysmus compressus* subsp. *compressus*, *Bolboschoenus affinis, B. maritimus, Bromus scoparius, Calamagrostis glauca, C. pseudophragmites, Campanula glomerata*, *Carex diluta, C. divisa, C. melanostachya, C. orbicularis* subsp. *kotschyana, C. pseudofoetida* subsp. *acrifolia, C. songorica, Cardamine uliginosa, Cichorium intybus, Cirsium arvense* var. *arvense, Cirsium obvallatum, C. turkestanica, Dactylis glomerata* subsp. *glomerata, Dactylorhiza umbrosa, Deschampsia flexuosa, Eleocharis mitracarpa*, *E. palustris* subsp. *palustris, E. quinqueflora, E. uniglumis, Epilobium hirsutum, E. roseum, Epipactis latifolia, Equisetum palustris, E. ramosissimum*, *Euphrasia pectinata*, *Festuca pratensis, Galium aparine, Gentiana septemfida, Glyceria plicata, Gypsophila elegans, Heracleum persicum*, *Hordeum violaceum, Hypericum perforatum, Inula thapsoides, Juncus articulatus, J. gerardi* , *J. inflexus, Lactuca scarioloides, Lemna minor, Lepidium draba, Ligularia persica, Lolium perenne, Lotus corniculatus* subsp. *corniculatus* var. *corniculatus, Lythrum salicaria, Medicago lupulina, M. sativa, Melilotus officinalis, Mentha longifolia* subsp. *kotschyana, Myosotis caespitosa, M. lithospermifolia, M. palustris, Nastortium officinale, Ononis spinosa, Orchis anatolica, Pedicularis sibthorpii, Phalaris arundinacea, Phragmites australis* var. *australis*, *Plantago lanceolata, P. major, Poa bulbosa, P. pratensis, P. trivialis, Polygonum persicum, Potentilla reptans, P. szovitsii, Primula auriculata, Prunella vulgaris*, *Ranunculus arvensis, R. bulbosus, R. polyanthemos, Rumex chalepensis, R. crispus, R. elborsensis, R. secutatus, Sanguisorba minor* subsp. *muricata, Schoenoplectus lacustris, Scirpoides holoschoenus* subsp. *australis, Scorzonera parviflora, Scrophularia umbrosa, Sequigera varia* subsp. *varia, Siline vulgaris, Sium sisaroideum, Stachys setifera* subsp. *Setifera, Swertia longifolia, Tanacetum balsamita* subsp. *balsamotoides, T. parthenium, Taraxacum* sp. , *Trifolium repens* var. *repens, Triglochin maritima, T. palustris, Typha caspica, T. minima, Urtica dioica* subsp. *kurdistanica, Veronica anagalis-aquatica, V. anagalloides, V. gentianoides.*

species composition. Although the second axis of ordination analysis is affected by a soil texture, altitude is still an effective factor controlling many variables including soil texture (Table 2).

Using one-way ANOVA, all variables that are significantly correlated with altitude (in Table 2) except

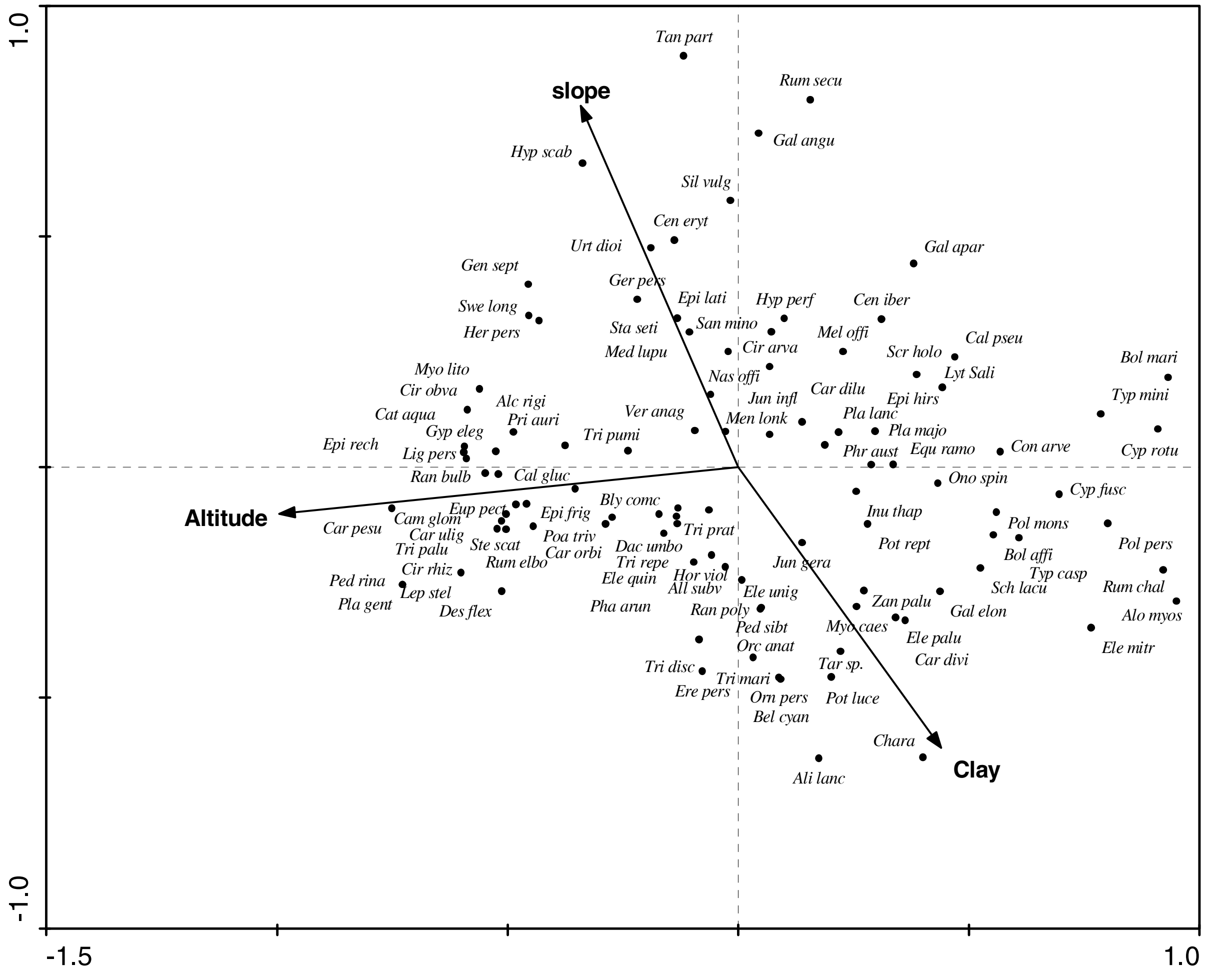

Fig. 4. CCA plot of species in western Alborz wetland sites. Species weight (2%) and species fit (4%) was used for the selection of the species in the plot. *Alchemilla rigida, Alisma lanceolatum, Allium subvineale, Alopecurus myosoroides, Belevalia cyanopoda, Blysmus compressus* subsp. *compressus, Bolboschoenus affinis, B. maritimus, Calamagrostis glauca, C. pseudophragmites, Campanula glomerata, Carex diluta, C. divisa, C. orbicularis* subsp. *kotschyana, C. pseudofoetida* subsp. *acrifolia, Cardamine uliginosa, Catabrosa aquatic, Centaurea iberica, Chara* sp. , *Centaurium erythraea, Cirsium arvense* var. *arvense, C. obvallatum, C. rhizocephalum, Cyperus fuscus, C. rotundus, Dactylorhiza umbrosa, Deschampsia flexuosa, Eleocharis mitracarpa, E. palustris* subsp. *palustris, E. quinqueflora, E. uniglumis, Epilobium hirsutum, E. frigidum, Epipactis latifolia, Equisetum ramosissimum, Eremopoa persica, Euphrasia pectinata, Galium anguineum, G. aparine, G. elongatum, Gentiana septemfida, Gypsophila elegans, Heracleum persicum, Hordeum violaceum, Hypericum perforatum, H. scabrum, Inula thapsoides, Juncus gerardi, J. inflexus, Ligularia persica, Lythrum salicaria, Medicago lupulina, Melilotus officinalis, Mentha longifolia* subsp. *kotschyana, Myosotis caespitosa, M. lithospermifolia, Nasturtium officinale, Ononis spinosa, Orchis anatolica, Ornithogalum persicum, Pedicularis rhinanthoides* subsp. *rotundata, P. sibthorpii, Phalaris arundinacea, Phragmites australis* var. *australis, Plantago gentianoides, P. lanceolata, P. major, Poa trivialis, Polygonum persicum, Polypogon monspeliensis, Potamogeton lucens, Potentilla reptans, Primula auriculata, Ranunculus bulbosus, R. polyanthemos, Rumex chalepensis, R. elborsensis, R. secutatus, Sanguisorba minor* subsp. *muricata, Schoenoplectus lacustris, Scirpoides holoschoenus* subsp. *australis, Siline vulgaris, Stachys setifera* subsp. *setifera, Stellaria scaturiginella, Swertia longifolia, Tanacetum parthenium, Taraxacum* sp., *Trichophorum pumilum, Trifolium pretense, T. repens* var. *repens, Triglochin maritima, T. palustris, Tripleurospermum disciforme, Typha caspica, T. minima, Urtica dioica* subsp. *kurdistanica, Veronica anagalis-aquatica, Zannichellia palustris.*

percentage of silt and phanerophytes are also significant in the ANOVA that compares values from each of the three altitudinal belts (Table 3).

Discussion

Variation of species-related characters

The altitudinal maximum record for the flowering plants is 3200 m a.s.l. and is held by species such as *Carex pseudofoetida* subsp. *acrifolia, Deschampsia flexuosa, Ligularia persica* and *Gypsophila elegans* which are more cryophilic and acidophilic species than the rest. The flora of lowland sites includes *Phragmites australis*, *Salicornia europea Schoenoplectus lacustris* and *Tamarix ramosissima*, all of which frequently occur in saline habitats.

The proportion of phytogeographical categories used here (PE_1–PE_4) changes significantly across the altitudinal belts. More phytogeographically widespread species are confined mainly to lower altitudes while wetland sites at higher altitudes, (with higher soil organic matter content), contain more endemic and other geographically-restricted taxa. The increase in endemism with increasing altitude is consistent with

Table 3. Relationships between ordination axes, altitudinal gradient, environmental and floristic variables. Pearson correlation coefficients between each variable and the first two DCA axes are followed by summary statistics (mean ± standard error and [Range]) and F-ratio from ANOVA of studied variables in each altitudinal belt within the Alborz mountains range. Altitudinal belts with the same letters are not statistically significantly different from each other at $p < 0.05$ in *post-hoc* tests (Tukey).

	DCA (axis 1)	DCA (axis 2)	Lower belt (350–1800 m; $n = 31$) Mean ± SE [range]	Middle belt (1801–2500 m; $n = 35$) Mean± SE [range]	Upper belt (2501–3200 m; $n = 24$) Mean ± SE [range]	F
Environmental variables						
Altitude	0.89***	−0.97				
Slop inclination	0.47***	0.39***	7.4 ± 2.4^{a} [0.0–50.0]	15.3 ± 3.3^{b} [0.0–70.0]	16.5 ± 2.9^{b} [0.0–60.0]	27.1**
Silt %	−0.31**	−0.89	24.8 ± 2.2^{a} [3.0–53.0]	25.2 ± 1.1^{a} [9.0–38.0]	21.0 ± 1.5^{a} [9.0–35.0]	1.7
Sand %	0.41***	0.43***	41.5 ± 3.9^{a} [0.0–80.0]	35.6 ± 2.9^{a} [9.0–73.0]	54.1 ± 2.9^{b} [30.0–77.0]	7.5**
Clay %	−0.36***	0.51***	33.5 ± 2.6^{a} [15.0–71.0]	39.0 ± 2.3^{a} [17.0–63.0]	24.4 ± 2.0^{b} [13.0–52.0]	9.3***
OM %	0.43***	−0.13	2.5 ± 0.4^{a} [0.0–9.3]	6.2 ± 1.2^{b} [1.0–41.0]	7.0 ± 1.6^{b} [0.8–36.0]	9.7***
$CaCO_3$ %	−0.58***	−0.07	9.7 ± 1.2^{a} [0.4–25.4]	7.4 ± 1.1^{a} [0.2–23.4]	2.5 ± 1.1^{b} [0.0–25.8]	14.6***
K^{+} ppm	−0.24*	−0.23	917.8 ± 117.4^{a} [261.0–4022.5]	1016.0 ± 106.0^{a} [292.0–3398.0]	785.8 ± 62.2^{a} [275.0 -1317.0]	0.3
Na^{+} ppm	−0.29**	−0.01	630.5 ± 136.9^{a} [98.5–4019.2]	$290.9\pm 28.5\ ^{b}$ [147.8–912.7]	241.3 ± 24.0^{b} [124.0–684.7]	8.4***
Ca^{2+} ppm	−0.41***	−0.13	$9393.0\pm 1197.7\ ^{a}$ [3202.0–43520]	8239.0 ± 512.7^{a} [3260.0–14704.0]	6035.0 ± 549.1^{b} [2564.0–12168.0]	5.7**
Fe^{2+} ppm	0.48***	−0.66	67.1 ± 15.6^{a} [6.0–319.0]	74.4 ± 12.1^{a} [13.0–302.0]	$170.4 \pm 32.4\ ^{b}$ [26.0–772.0]	10.4***
EC mmhos/cm	−0.29**	0.23	4.0 ± 1.8^{a} [0.4–58.0]	1.3 ± 0.1^{b} [0.5–3.2]	1.1 ± 0.1^{b} [0.4–2.7]	5.3**
pH	−0.66***	−0.06	7.2 ± 0.1^{a} [5.6–8.0]	7.0 ± 0.1^{a} [5.8 -7.6]	6.3 ± 0.1^{b} [4.7–7.3]	18.4***
Life-form						
Chamaephyte (%)	−0.67 *	0.07	1.5 ± 0.6^{a} [0.0–11.1]	0.6 ± 0.3^{b} [0.0–5.9]	00.0 ± 0.0^{ab} [0.0–0.0]	3.5*
Geophyte (%)	0.59***	−0.03	30.0 ± 1.9^{a} [7.1–52.6]	42.9 ± 2.1^{b} [15.4–64.7]	43.8 ± 1.4^{b} [30.3–56.5]	15.2***
Helophyte (%)	−0.56	−0.15	24.4 ± 1.7^{a} [6.3–47.6]	17.3 ± 1.5^{b} [6.3–50.0]	$12.7 \pm 0.9\ ^{b}$ [4.4–19.0]	15.9***
Hemicryptophyte (%)	0.06	0.28**	29.0 ± 1.7^{a} [11.1–50.0]	$28.0\pm 1.8\ ^{a}$ [0.0–50.0]	31.8 ± 1.6^{a} [21.7–44.9]	1.1
Hydrophyte (%)	−0.11	−0.43***	1.3 ± 0.5^{a} [0.0–9.4]	3.7 ± 1.1^{a} [0.0–25.0]	1.5 ± 0.9^{a} [0.0 15.8]	1.6
Phanerophyte (%)	0.24*	−0.27**	1.2 ± 0.5^{a} [0.0–10.0]	0.3 ± 0.2^{a} [0.0–5.9]	0.1 ± 0.1^{a} [0.0–3.0]	2.8
Therophyte (%)	0.71	0.01	12.4 ± 2.0^{a} [0.0–35.7]	7.1 ± 1.1^{a} [0.0–23.1]	9.8 ± 1.0^{a} [0.0–20.4]	2.0
Phytogeographic elements						
PE_1 “Broadly pluriregional” (%)	−0.68***	0.19	50.6 ± 1.8^{a} [30.4–71.4]	42.5 ± 1.3^{b} [28.6–64.7]	36.6 ± 1.3^{c} [26.1–47.8]	19.9***
PE_2 “Narrowly pluriregional” (%)	−0.21	−0.41	$35.5 \pm 1.6\ ^{a}$ [21.4–60.0]	31.4 ± 1.5^{ab} [16.7–52.9]	27.8 ± 1.5^{b} [13.3–44.4]	6.0**
PE_3 “Irano-Turanian” (%)	0.72***	−0.25	10.2 ± 1.1^{a} [0.0–21.4]	20.7 ± 1.4^{b} [0.0–38.1]	27.9 ± 1.5^{c} [17.4–43.5]	42.2***
PE_4 “Endemic” (%)	0.49***	−0.11	1.3 ± 0.6^{a} [0.0–14.3]	3.3 ± 0.5^{b} [0.0–13.3]	6.4 ± 0.9^{c} [0.0–18.2]	17.5***

other wetland or terrestrial studies (Kessler 2000; Vetaas & Grytnes 2002; Hájek et al. 2008; Noroozi et al. 2008; Naqinezhad et al. 2009). Many of wetland species, ca. 28 %, including 23% endemics have a narrow Irano-Turanian distribution. Moreover, some of these endemics (e.g. *Ligularia persica*, *Ranunculus amblyolobus, Rumex kandavanicus* and *Swertia longifolia*) are restricted to wetland habitats. Those almost can consider as indicator species in wetlands (Assadi et al. 1988–2008; Noorozi et al. 2008; Rechinger 1963–2005).

The relationship between the occurrence of different life forms, altitude and other environmental variables is well-known (Campbell & Werger 1988; Floret et al. 1990; Montana & Valientebanuet 1998; Kessler 2000; Pavón et al. 2000; Noy-Meir & Oron 2001; Klimeš 2003; Odland 2009). Hemicryptophytes have been found to be more frequent at higher altitudes in many mountain systems (Raunkiaer 1934; Wang et al. 2002; Klimeš 2003; Noroozi et al. 2008). However, they were fairly constant in South Central Norway (Odland 2009). Here, we found no difference in distribution of hemicryptophytes, but instead, a highly significant positive correlation between the number of geophytes and altitude in the study area. The distribution of geophytes across an altitudinal gradient in dry habitats has been reported both as a constant trend (Wang et al. 2002; Klimeš 2003) and as a decreasing one (Odland 2009). It is possible that the distribution of geophytes in wetland ecosystems shows different trends with respect to altitude than in drier ecosystems as this life form is more adapted to mesic habitats than to dry habitats (Danin & Orshan 1990). These inconsistent results have demonstrated that life-form spectrum is an ambiguous interpretative tool because it may relate to climate, other environmental factors or both (Kessler 2000; Klimeš 2003). A significant correlation between hemicryptophytes and slope inclination has also been reported elsewhere (Odland 2009). The low numbers of helophytes and hydrophytes found at upper altitudes may be explained by the steep topography and the lack of lakes.

Influence of ecological variables on vegetation composition and habitats

As deduced from the uni- and multi dimensional analyses, the variation in species composition of wetland vegetation in the Alborz mountains range was mostly associated with altitudinal gradient. The influence of altitude on plant composition of wetland sites has been reported previously (Sterling 1996).

Soil pH, which ranged between 4.7 and 8.0 in this study, was shown to be another important factor in affecting species distribution and is considered to be the major determinant of vegetation diversity in many habitats (Chytrý et al. 2003; Petraglia & Tomaselli 2003; Nekola 2004; Zelink & Čarni 2008).

Since the degradation of soil OM is microbially mediated, the temperature at which this process occurs is likely to control of soil OM content. Therefore, microbial activities are very slow at higher altitudes (because annual mean temperature is low) such that mineralization processes are reduced in these habitats. Thereby percentage of OM (especially organic acids) increased and soil pH decreased. In contrast, conversion of OM into minerals was possibly responsible for pH increase during their decomposition (Zhi-An et al. 2008). The relationship between soil OM and altitude has been investigated and positive correlations were reported (Sims & Nielsen 1986; Tate 1992; Hontoria et al. 1999; Ganuza & Almendros 2003; Lemenih & Itanna 2004; Dai & Huang 2006). Also the relationship between OM, temperature and microbial activity has also been investigated (Grisi et al. 1997; Grandy et al. 2009). A significant negative correlation between soil pH and accumulation of OM in the soil has also been documented elsewhere (Huang 1994; Vitt 2000). Likewise, a positive correlation between soil pH and EC is well known from many large-scale studies in wet ecosystems (Malmer 1986). Soil pH is highly correlated with $CaCO_3$ deposition in soil as found by some other authors in mire habitats (Boyer & Wheeler 1989; Bootsma & Wassen 1996).

There is a gradient from coarse-textured soil to fine-textured soil (with a high proportion of silt and clay) on the second DCA axis. Fine-textured soils are associated with richness of some elements such as Ca^{2+} and K^{+}. The poor-rich gradient described in many wetland habitats (Waughmann 1980; Wheeler & Shaw 1995) can be seen in the first axis of the DCA ordination (Fig. 2). Nevertheless, there is no significant correlation between the accumulation of OM and concentration of base cations in the soils of the Alborz wetlands. It seems that the variation of OM and base cations contents in the wetland soils are affected by two different biological and non-biological processes respectively. Further investigations should be carried out to indicate clear relationships between these variables. The high positive correlation between Ca^{2+}, Na^{+} and EC found in this study has also been recorded elsewhere (Bragazza & Gerdol 1999). Also, the pH and Ca^{2+} ion concentration have been shown to be positively correlated with each other in wetland systems (Kutnar & Martinčič 2003). The main reason for these relationships here is the calcareous substratum of the sites studied in the Alborz mountains range, where input of cation from mineral sources causes the pH to rise (Ross 1995). This relationship is very loose, especially in areas with non-calcareous geochemistry (Sjors & Gunnarsson 2002; Tahvanainen et al. 2002). The positive relationships between the K^{+} concentration and proportion of clay and silt in the soil was also known, since fine-textured soils can prevent K^{+} leaching from the soil (Mengel 1982).

Organically-bound Fe is one of the major forms in all the soils (Norrström 1995). A high positive correlation between Fe^{+2} and OM indicates the importance of OM for retention of Fe^{+2}, which is consistent with other studies (Henrot & Wieder 1990; Tarutis et al. 1992; Grybos et al. 2007). In an investigation of Welsh wet meadow soils, the concentration of Fe^{2+} and OM were positively correlated with acidity in the soil (Blackstock et al. 1998).

In conclusion we can state that altitude is the most important factor in vegetation differentiation. The supplementary physic-chemical properties of soil, species life-form and phytogeographic measurements are also correlated with altitude. They, however, provide an adequate explanation of the ecological processes that maintain the altitudinal gradient in vegetation types and species composition.

Also, this paper clearly shows that many wetlands of high value in terms of floristic biodiversity, and scientific importance occur in southern slope of the Alborz mountains range. In the current study we have attempted to acquire more insights into primary recognition about mountain and steppic wetlands of Iran especially extensive type of those as telmatic wetlands. The wetlands in arid or semiarid mountains (even deserts) are from conservational importance in biodiversity, endemic species and floristic-environmental interactions.

Acknowledgements

During the preparation of this paper, Prof. Ahamad Ghahreman Iranian famous scientist in botany, passed away. In last 50 years, he played an essential, role in plant taxonomy studies, 27 Vols. of Flora of Iran with beautiful colorful photos which covers about 3375 species description will remain a major legacy of him for next generations to come.

This project was supported by the Research Institute of Forest and Rangelands, Tehran and Shahed Universities, Tehran. The authors are indebted to Prof. J. MacGuire for clarifying this paper, to Dr. S. Zarre, Dr. M. Zarrei, B. Hamzeh'ee and Dr. Y. Ajani for the identifying of some plant specimens and to Y. Filizadeh for providing GIS map of study wetland sites.

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Received September 2, 2009
Accepted March 18, 2010