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Plant Distribution in Arid Ecosystems of Eastern Alborz Ranges at 36° Latitude

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Abstract

Iranian natural ecosystems have aesthetic, conservation and genetics values and provide many functions and services, but have become vulnerable. This investigation aimed to (1) survey flora of an arid-steppe montain ecosystem, (2) analyze the ecological characteristics of the vegetation in relation to altitude and soil properties and (3) elaborate on ecophysiological processes. Samples of soil and plants were collected randomly in three altitudes at about 36° latitude in Parvar Protected Area (PPA), Iran. Plant species were identified, ecologic and floristic data were collected and statistical analyses were performed using Excel and SPSS. Physiognomy of the region is steppe. The type of soil is sandy-loam, and it becomes loamy with increasing altitude. Majority (45.5%) of species are cryptophytes and belong to Irano-Turani region followed by chameophytes (36.4%) and therophyte (18.1%). *Artemisia aucheri, Eremopyrum elengutum* and *Stachys aucheri* dominated at the upper (2338 m), middle (2009m) and lower (1783 m) elevations above sea level, respectively. *Onobrychis cornuta and Astragalus ochrochlorous* were also common to all stations. Ecological indices showed reducing trend with hike in altitude except dominance index which increased. *Artemisia aucheri* was the overall dominant plant and in need of ecological management. Ecophysiological interaction of plant species with environmental parameters at local level undoubtedly determines their community structure, scale and pattern of distribution. Since plant species in semi-arid regions have developed specific adaptation strategies to cope with environmental changes, it is useful to link local adaptation strategies (for example, avoidance, tolerance, resistance) and physiological processes to global changes. In this way, knowledge on morphology, physiology, life-history, phenology and behavior gained from ecological studies based on individuals, communities and ecosystems can be analyzed in ecological and evolutionary context and thus, afford the tool of predicting responses and simulating ecosystem models to environmental changes in future.

Keywords: altitude, ecophysiological, Parvar Protected Area, steppe, vegetation survey

1. Introduction

The Alborz Mountain Ranges (AMR), with the tallest peak in Iran, extends from west to east alongside of Caspian Sea coast and as such creates two main northern and southern watershed basins and many different ecosystems (Klein, 2001). The northern watershed which is very moist and inhabits rich and relic Hyrcanian forests of *Fagus* (beech), *Acer* (maple) and *Quercus* (oak) drains into the Caspian Sea while the southern watershed is mainly semi-arid and contains mostly elements of the steppe vegetation of the Irano-Turanian region (Zohary, 1973), and drains into the Dasht-e-Kavir desert. Kamrani et al. (2011) reported extensively on the wetland vegetation of the southern AMR and sporadic reports on arid and Irano-Touranian vegetation are available (Karimi et al., 2003; Asadi, 1988-2008). Roodi (2009) studied the plant species richness of the N. Semnan province, Iran and documented that species of Asteraceae (12.2%), Poaceae (8.8%), Apiaceae (6.7%), Papilionaceae (6.21%), Chenopodiaceae، Brassicaceae and Labiatae (5.8%), Caryophyllaceae (5%), Rosaceae (4.2%) and Boraginaceae (4.2) were more frequent and expanding in different altitudes. Despite such reports, flora and ecophysiological aspects of vegetation of a huge area in the region still needs to be explored further.

Plant growth is a physiological process dependant on the environmental conditions, life history of the species and exposure time to environmental variables (Aikman & Scaife, 1993). Distribution of plant species and community development is related to topographic factors such as elevation, aspect and slope (Naghinejad et al., 2012, 2013) as well as soil type, precipitation (Hemavani & Thippeswamy,2013) and their ecophysiological plasticity and interaction with soil microorganisms, for example vesicular arbascular mycorrhizal fungi (Khara & Zare-maivan, 2003; Karimi et al., 2004).There has been a general principal that topography and in particular elevation from sea level affects distribution of plant species and many plant species are adapted for particular habitats within each biome or vegetation zone (Walter,1983). However, recent findings advocate the microhabitats and micro-conditions of the root zone and canopy ambiance as determining factors in establishing of plant populations, their persistence and perseverance (Stockwell, 1997; Vinton & Burke, 2001; Chkhubianishvili et al., 2011; Kialashaki & Shabani, 2011; Naghinezhad et al., 2013, 2014) and might influence the evolutionary and ecological processes of populations in the environment (Nagajyoti et al., 2008; Umadevi & Avudainayagam, 2013). Zare-maivan (2013) elaborated on the role of heavy metal toxicity on mycorrhizal and non-mycorrhizal plants in selected ecosystems of northern AMR (Hyrcanian forests). Ecophysiological responses of plant species in relation to altitude have been studied by Lotfifard and Zare-maivan (2015). They observed that distantly (10 to 30 Km) apart individual plants of the same species occurring at the same altitude, had similar physiologic characteristics. Many researchers have shown the relative ecophysiological effects of altitude, temperature, precipitation, host community and soil nutrient concentrations on species richness and community composition in many forest ecosystems (Comstock & Ehleringer,1992; Cook & Irwin,1992; Griffiths et al., 1996; Iravani,1998; Kadmon & Danin,1999; Burke,2001; Villers-Ruiz et al., 2003; Vafadar & Zare-maivan, 2003, 2006; Khademolhosseini et al., 2007; Bahram et al., 2012; Naghinezhad et al., 2013, 2014; Bazdid Vahdati, 2014). However, less attention has been paid to arid ecosystems and commonly, effects of soil and biological, chemical and physical aspects of rhizosphere have been overlooked.

Although, ecological surveys increase our understanding of the interactions of man and environment and equip environmental managers and stakeholders with up-to-date data, it is the ecophysiological knowledge of functioning plant communities that elucidates ecological processes (Rosado et al., 2013), such as plant species distribution (Borchert, 1994), functional convergence (Grime, 1977; Wright et al., 2002), species interactions, symbiosis and coexistence (Markesteijn et al., 2011; Zare-maivan, 2013), environmental filtering (Grime, 1977; Borchert, 1994), ecosystem functions and services (Wardle et al., 1998) and ecosystem conservation (Wikelski & Cooke, 2006). However, despite many sporadic ecological studies on Irano-Tourani vegetation of Iran in the past, recent human development activities have damaged vegetation cover in many, already fragile, semi-arid mountainous ecosystems. Previous research has shown that dominant plant species in semi-arid ecosystems produce chemicals with strong anti-oxidant properties (Zare-maivan et al., 2014; Noori et al., 2012) but, overall ecological analysis is scarce; Therefore, this investigation aimed to (1) survey flora of a selected protected area of an arid-steppe montain ecosystem and elaborate on ecological characteristics of the vegetation in relation to altitude and soil properties..

2. Materials and Methods

2.1 Description of the Study Site

Parvar Protected Area (PPA) is a unique conserved ecosystem in N. Semnan highlands and located between lush Hyrcanian forests to the north and arid and desert plant communities to the south. Middle Jurassic to upper Cretaceous limestone formations are dominant and form some very high rock cliffs along the East-West directed thrust fault zones. The study area has temperate and continental climate in the low and high altitudes, respectively. Annual precipitation varies between 140 - 450 mm and mean temperature of 10-15 ºC, making its climate regime categorized as cold steppe as it is affected by the north-westerly flow of polar air masses (Khalili, 1973). The summer is arid, warm and sunny with intensive radiation most of the time. During the arid season, water is supplied mainly by the melting snow and springs. Annual temperature amplitudes can be high. At 1500 m, the mean annual temperature is 13 °C, in January it is 0.6 °C and in August is 26 °C (Kamrani et al., 2011). Much of annual rainfall is in winter and early spring lessening towards warmer seasons and extending towards lower altitudes and desert lowlands.

2.2 Sampling

Soil and plant sampling and collecting ecological field data were done in 4 quadrates (5 x 5m) 150 m apart (in the direction of SW to E) in 3 altitudes above sea level (ASL) at about 36 ° latitude line on the southern slopes of Alborz mountains in Semnan province (Table1) in a completely randomized design (Barbour et al., 1998) in late May, 2012.

The plants were identified and authenticated and a voucher specimen was deposited at the Herbarium of the Tarbiat Modares University, Tehran-Iran. Plant species were identified using reliable identification sources, for example, Rechinger (1963-2005); Ghahreman (1984-1998); Asadi (1988-2008); Mozafarian (2003); Mobayen (1979-1999); Masoumi (1985-2005); Ezodin (1999); Alayha (2003) and Roodi (2009). Approach of Raunkiaer (1934) was followed to determine plant species life forms (Archibold, 1995).

Table 1. Geographical coordinates and other properties of lower (L), middle (M) and upper (U) sampling stations in PPA, Iran during 2014

Station	Altitude (m)	Geographical Coordinates	Distance between stations (m)	Slope (percent)
U	2338	N:35,59,55.2	L- M	L-M
		E:53,35,46.5	6,566	3.33
M	2009	N:35,58,41.3	M- U	M-U
		E:53,29,0.97	10,053	3.27
L	1783	N:36,02,16.6	L- U	L-U
		E:53,24,48.9	16,619	2.55

2.3 Ecological Characteristics Data Collection

Method of Bonham (1989) was used to collect quantitative ecological characteristics data, such as abundance, frequency, density, percentage of coverage and height, of all plant species in each quadrate in all stations. Data of vegetation was statistically analyzed and Simpson index of dominance (D) (Simpson, 1949), Shannon-Weaver (H') index of Diversity as well as Importance Value and Association Index were calculated

$$D = \sum_{i=1}^{s}(Pi)^{2} \qquad Pi = \frac{ni}{N} \qquad H' = -\sum_{i=1}^{s} Pi\ ln\ (Pi)$$

Where **ni** is abundance of each species, N total abundances and **pi** relative abundance of each species.

2.4 Soil Analysis

Soil samples were air dried for 72 hours. Soil subsamples (3g of 2mm mesh) were power pressed and analyzed via WD-XRF method using XRF Phillips 2404. Soil texture was determined using a hydrometer after soaking 200 g of soil for 24 h. Soil pH was determined using potentiometry method and EC was measured using an EC meter (Page et al., 1982; Dewis et al., 1984). Statistical analysis was performed using SPSS and Excel programs.

3. Results

Statistical analysis of soil samples showed that the type of soil is sandy-loam and it becomes loamy with increasing altitude (Table 2). Silt content was lesser in the lowest altitude. pH and EC did not differ ($p \leq 0.05$) amongst stations. Soil samples were slightly alkaline saline. Soil analysis showed the presence of silicon, aluminum, magnesium, sodium, potassium and phosphorus oxides in upper altitudes. Calcium was present in greater content in the lowest altitude. Oxide of silicone (SiO_2) occurred in greater quantities in all stations. Such a trend was not observed for iron and sulfur.

Table 2. Comparison of Soil Physical Factors Sampled at Three Altitudes in Parvar Protected Area, Iran. Data show means ±SD

	Stations		
Soil Characteristics	Lower Location (L)	Middle Location (M)	Upper Location (U)
Sand%	$76.4^{a}\pm1.6^{*}$	$70.4^{c}\pm1.4$	$72.4^{b}\pm1.6$
Clay%	$5.6^{a}\pm0.1$	$7.3^{a}\pm0.5$	$5.6^{a}\pm0.1^{a}$
Silt%	$18^{a}\pm1.6$	$22.2^{b}\pm1.2$	$22^{b}\pm1.63$
pH	$8.08^{a}\pm0.03$	$8.05^{a}\pm0.05$	$8.13^{a}\pm0.07$
EC(Ds/m)	$1.18^{a}\pm0.063$	$1.17^{a}\pm0.05$	$1.10^{a}\pm0.08$

*Different letters in each row indicate significant difference by Duncan's Test at 5% Probability.

Twenty two plant species were identified which based upon their dominance values are ordered as follows: *Artemisia aucheri, Eremopyrum elongatum, Onobrychis cornuta, Stachys aucheri, Convolvulus pseudocantabrica, Thymus caucasicus, Astragalus ochrochlorus, A. grammocalyx, Sisymbrium sp., Acanthophyllum glandulosum, Myosotis olympica, Tanacetum sp., Stachys inflate, Teucrium polium, Verbascum cheiranthifolium, Galium verum, Taraxacum sp., Marrubium parviflorum, Tragopogon gramini, Helichrysum sp.,Verbascum cheiranthifolium* and *Ziziphora clinopodioides* Lam (Table 3).

Statistical analysis of abundance data indicated where species occurred in all elevations, there were no significant differences between means of species, for example between *A. aucheri*, *E. elongatum* and *S. aucheri*. Three species, *A. aucheri*, *E. elongatum* and *S. aucheri* were significantly more abundant than other species in general and within each station. With a hike in altitude, the abundance of *A. aucheri* increased and *E. elongatum* and *S. aucheri* lowered (Table 3).

Majority of identified species were cryptophytes (45.5%) followed by chameophytes (36.4%) and therophytes (18.1%). Phytogeographically, 10 genera occurred in 1 station, 8 genera in 2 stations and only *A. aucheri*, *E. elongatum, O. cornuta and A. ochrochlorus* were common to all stations (Table 3). In addition, *A. glandulusum, C. pseudocantabrica, Sisymbrium sp.* and *V. cheiranthifolium* were recorded from stations located at 2009 m (M) and 2338 m (U) ASL.

Abundance and density of species varied in different altitudes. In average, there were 6 plants per 1m^2 with an average canopy cover of 24.2%. *A. aucheri* covered in average about 10% of the sampled area followed by *O. cornuta* (5%), *E. elongatum* **(**3%**),** *Thymus caucasicus* (1.2%) and *Stachys aucheri* (1%) and the remaining species covered the other 5% (Table 4). Plant species that showed the highest coverage area in all altitudes, i. e. *A. aucheri*, *O. cornuta* and *E. elongatum,* also had the highest density, as many as 150, 117 and 38 plants per 100 m^2, respectively. These species also showed the highest cumulative importance value and greater assimilation index (Table 5), *S. aucheri* and *C. pseudocantabrica,* although not present in all stations, showed higher density as well, the former at L and the latter at M stations (Table 5). There were few species that occurred only in one altitude. For example, *Astragalus* sp., *G. verum, Helichrysum* sp., *Myosotis olympica*, *Tanacetum* sp., and *Z. clinopodioides* occurred in L altitude, *S. inflate* and *M. parviflorum* in M altitude and *Taraxacum* sp. and *T. graminiflorum* in U altitude.

Table 3. Comparison of Abundance Means and Standard Deviation of Plant Species at Three Altitudes in Parvar Protected Area, Iran, 2012

Species	L	M	U
Acanthophyllum glandulosum	-	3±0.5^a	2±0.2 ^{b}
Artemisia aucheri	32±2.0 ^{c*}	36±2.5^b	44 ±2.0^a
Astragalus grammocalyx	13±0.8^b	16±0.6^a	-
Astragalus ochrochlorus	4±0.1^b	3 ±0.2^b	7±0.6^a
Astragalus sp.	18±1.2^a	-	-
Convolvulus pseudocantabrica	-	24±1.5^a	13±0.3^b
Eremopyrum elongatum	62±3^a	38±0.9^b	6±0.1^c
Galium verum L.	3±1.7^a	-	-
Helichrysum sp.	2±0.1^a	-	-
Marrubium parviflorum	-	1±0.1^a	-
Myosotis olympica Boiss.	27±2.6^a	-	-
Onobrychis cornuta (L) Desv.	10±0.5^a	5±0.2^b	9±0.1^a
Sisymbrium sp.	-	2±0.2^b	8±0.5^a
Stachys aucheri Benth.	92±3.5^a	5±0.1^b	-
Stachys inflate	-	4±0.2^a	-
Tanacetum sp.	18±1^a	-	-
Taraxacum sp.	-	-	3±0.1^a
Teucrium polium	10±0.3^a	-	9±0.2^b
Thymus caucasicus	9.66±0.3^a	-	11±0.1^{ab}
Tragopogon graminifolius	-	-	1±0.1^a
Verbascum cheiranthifolium	-	1±0.1^a	1±0.2^a
Ziziphora clinopodioides Lam.	10±0.6^a	-	-

*Different letters on the same row indicate significant difference by Duncan's test at 5% probability level.

Table 4. Density and Percentage Coverage area of Plant Species at Three altitudes in the Parvar Protected Area, Iran, 2012

	Density(n/100m^2)			Coverage (%)		
Species	**L**	**M**	**U**	**L**	**M**	**U**
Acanthophyllum glandulosum	-	9	3	-	0.3	0.4
Artemisia aucheri	128	145	177	3.87	9.41	17
Astragalus grammocalyx	40	49	0	0.93	0.2	-
Astragalus ochrochlorus	7	10	14	0.74	0.24	1.8
Astragalus sp.	18	-	-	0.09	-	-
Convolvulus pseudocantabrica	-	98	13	-	2.17	0.4
Eremopyrum elongatum	187	154	11	3.15	4.96	0.5
Galium verum L.	9	-	-	0.41	-	-
Helichrysum sp.	2	-	-	0.01	-	-
Marrubium parviflorum	-	1	-	-	0.03	-
Myosotis olympica Boiss.	80	-	-	0.05	-	-
Onobrychis cornuta (L) Desv.	39	10	26	7.6	0.75	5.8
Sisymbrium sp.	-	4	15	-	0.04	1.7
Stachys aucheri Benth.	367	10	-	2.44	0.68	-
Stachys inflate	-	14	-	-	0.51	-
Tanacetum sp.	55	-	-	1.06	-	-
Taraxacum sp.	-	-	3	-	-	-
Teucrium polium	19	-	9	0.6	-	0.5
Thymus caucasicus	29	-	32	1.37	-	2.1
Tragopogon gramini folius.	-	-	1	-	-	-
Verbascum cheiranthifolium	-	2	1	-	0.07	0.1
Ziziphora clinopodioides Lam	10	-	-	0.95	-	-
Total	990	506	305	23.3	19.5	30

Table 5. Ecological characteristics of Parvar Protected Area vegetation, Iran, 2015

Species	Importance value	Diversity index	Assimilation index
Acanthophyllum glandulosum	2.7	0.04	0.014
Artemisia aucheri	92.04	0.36	0.117
Astragalus grammocalyx	10.94	0.12	0.039
Astragalus ochrochlorus	8.8	0.103	0.033
Astragalus sp.	3.9	0.059	0.02
Convolvulus pseudocantabrica	19.2	0.17	0.156
Eremopyrum elongatum	50.6	0.30	0.097
Galium verum L.	1.44	0.025	0.008
Helichrysum sp.	0.43	0.009	0.003
Marrubium parviflorum	0.31	0.007	0.002
Myosotis olympica Boiss.	8.7	0.103	0.033
Onobrychis cornuta (L) Desv.	27.8	0.22	0.07
Sisymbrium sp.	5.46	0.07	0.023
Stachys aucheri Benth.	33.5	0.24	0.08
Stachys inflate	2.6	0.04	0.013
Tanacetum sp.	7.17	0.09	0.028
Taraxacum sp.	0.8	0.01	0.005
Teucrium polium	6.18	0.08	0.026
Thymus caucasicus	12.47	0.13	0.042
Tragopogon graminifolius	0.27	0.006	0.002
Verbascum cheiranthifolium	0.86	0.01	0.005
Ziziphora clinopodioides Lam.	3.35	0.05	0.016

4. Discussion

Determining life forms of plant species has enabled ecologists and environmental mangers to advocate proper decisions for conservation; For example, prevalence of hemicryptophytes and chameophytes can indicate cold alpine climate with severe minimum temperatures during part of the year (Archibold, 1995). In the present paper, study area is located on the southern side of the Alborz mountain ranges and as such, primarily devoid of moisture. Conversely, moisture from Caspian Sea has caused Hyrcanian (Caspian) forests to flourish into the oldest and richest Eurasian temperate forests in north of Iran for so long (Marvie Mohadjer, 2006). Plant communities usually are diverse and distribute along gradients in the mountains and plains because of spatial variations (Jackson and Caldwell, 1993; Fu et al., 2004; Kialashaki & Shabani, 2011) and climate regime (Grytnes & Vetaas, 2002; Coroi et al., 2004**)**.

Results of this study showed that altitude reduces abundance, frequency, density and diversity assimilation indices. As to changes in dominance index of plants, although *Artemisia aucheri* was the overall dominant plant in all stations, data from a greater number of plots is required to offset the number of species for btaining larger dominance values (Table 4); Here.. dominance values are not presented due to very small fractions for so many plant species, making argument meaningless.Whether altitude by itself is sole determining factor for restricting plant species distribution needs to be investigated per species because, adaptive ability of species are depended on many factors. For example, Zare-maivan et al. (2014) indicated that although, altitude might affect plant species distribution as well as their biochemical responses to environmental conditions, it is mostly the soil chemical characteristics and texture that affects plant species distribution and function in cold arid and steppe environments and subsequently, shapes physiological responses of plants to elements of environmental stress as indicated by Naginezhad et al. (2013; 2014; Bazdid-vahdati et al., 2014). As such, it is realized that with hike in altitude, abundance and density of *A. aucheri* increased, while *E. elengutum and S.aucheri* showed lower abundances and densities (Table 4).

Plant genome responds to biotic (symbiosis) and abiotic (stresses) factors via biosynthesis of polyphenol compounds, such as flavonoids and lignin, all of which play strategic role in enabling plants to confront environmental stresses. For example, many plant species avoid harmful effects of UV radiation in open and higher altitudes via production of strong antioxidants (Rice-Evans, 2004; Soon et al., 1997), e.g., Phenylpropanes (p-coumaric acid) and increasing their anthocyanine pigments as well as flavonoids as protective agents in biotic interactions, i.e., symbiosis (mycorrhizae), allelopathy and competition with other plant species and herbivory. Zare-maian et al. (2014) reported on the ability of *A. auicheri* to regulate its enzyme activity to produce protective secondary metabolites and flovonoids in its roots and leaves in semi-arid to arid habitats.

Greater content of certain soil elements, such as silica, aluminum, magnesium, potassium, sodium and phosphorus along with increasing altitude in PPA implied that because of lower precipitation and less soil washing, *A. aucheri* was able to maintain itself under alkaline soil pH and slightly moderate salinity (Zare-maivan et al. 2014). Avoiding harmful effects of UV radiation in higher altitudes via production of strong antioxidants (Rice-Evans, 2004; Soon et al., 1997), plenty of seeds and developing special root morphology (Mesdaghi, 2005) have been indicated as other survival strategies of *A. aucheri* in high altitudes. On the other hand, research has shown that altitude, direction of sunlight and steepness of slope affects environmental factors, such as temperature fluctuations, humidity levels and nutrient availability (Cawker, 1980). Findings of this research, while corroborated findings of Shumar and Anderson (1986) and Zare-Chahouki (2001), in regards to the effects of topography on the distribution of sagebrush (*A. aucheri*) species, also reports on the adaptive ability of *Eremopyrum elengutum, Onobrychis cornuta, Astragalus ochrochlorous, Ac. glandulusum, C. pseudocntabria, Sisymbrium sp.* and *V. cheirantherifolium* to grow above 1700 m altitude. Besides, there were few species which were not recorded beyond 1700m ASL, For example, *Astragalus* sp., *G. verum, Helichrysum* sp., *Myosotis olymica*, Tanacetum sp., and *Z. clinopedis*.

Access to ecological knowledge, such as flora and vegetation of an area, climate soil and topography is necessary for proper and sustainable management and conserving of protected and fragile habitats (Shumar & Anderson, 1986; Guisan & Zimmerman, 2000). Although, PPA was designated as an area to be monitored and assessed for ecosystem stability, changes in population characteristics have not been monitored regularly nor there are defined ecophysiological traits that can be used in assessment programs. This investigation, though limited in scale, examined the trends in species population distribution and analyzed the effects of altitude and soil on plant assemblies. Although, occurrence of *Peganum harmala*, an indicator species of disturbance, was observed in plant communities inhabiting still lower altitudes than the study area, and we did not observe nor record *P.harmala* in our samplings, yet, closeness of plant communities and intensifying of grazing activities increase vulnerability of plant communities and threaten already stressed PPA ecosystem. In addition, changing climate towards a more arid condition may cause displacement of current plant communities to upper elevations in future.

Finding the sole determining factor (s) in successful establishing and sustainable flourishing of plant species is a task in need of much research and few researchers have pursued so (Austin, 1990; Pourbabaei et al., 2006; 2011). In doing so, selecting proper ecophysiological traits (physical and functional), in habitat and microhabitat scale, that can represent community health identity is a key component to be incorporated into proper ecological assessment programs. Then, data can be effectively analyzed and solutions devised through applying modeling tools, such as TOPSIS method (Zare-maivan & Memariani, 2002) and TWINSPAN and other data management programs. In this way, considering the fact that plant species interaction with environmental parameters at local level determines their community structure (abundance, diversity), scale and pattern of distribution (Hix & Pearcy, 1997) it is useful to link local adaptation strategies to global changes towards developing the tool of predicting responses (Rosado et al., 2013) to broader and comprehensive environmental changes.

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