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Research Article

Mapping and analysing the diversity of the genus *Acantholimon* taxa in Turkey by geographic information systems (GIS)

Hakan Mete DOĞAN[1,*], Musa DOĞAN[2], Galip AKAYDIN[3], Ferhat CELEP[2]

[1]Geographic Information Systems and Remote Sensing Unit of Soil Science Department, Gaziosmanpaşa University, Taşlıçiftlik 60240, Tokat - TURKEY

[2]Department of Biological Sciences, Middle East Technical University 06531, Ankara - TURKEY

[3]Department of Biology Education, Hacettepe University, Beytepe 06800, Ankara- TURKEY

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Abstract: We describe the spatial distribution of the genus *Acantholimon* Boiss. (Plumbaginaceae) taxa in Turkey, and assess the role that environmental variables may be playing on this distribution. We collected a large number of specimens from 418 geo-referenced sampling sites between 2000 and 2004, and established a point database using geographic information systems (GIS) software. As a result, we identified and mapped 67 taxa; 43 of the determined taxa appear to be endemic. We re-evaluated the current conservation status of the taxa at a national level using recent IUCN Red List categories. In addition, we extracted the corresponding environmental variables of each determined point from the updated and available environmental raster map layers of Turkey and analysed the obtained taxa and environmental data by Hierarchical Clustering and Canonical Correspondence Analysis (CCA). Hierarchical Clustering delineated the subgroups, which have similarities at various levels in respect to environmental variables. The CCA results indicated that 8 environmental variables including longitude, distance to sea, maximum temperature, mean temperature, minimum temperature, potential evapotranspiration, elevation, and precipitation are the most effective in explaining the spatial distribution of the 18 *Acantholimon* taxa in Turkey.

Key words: *Acantholimon*, Anatolia, biodiversity, ecology, GIS, mapping, spatial analysis, IUCN

Türkiye *Acantholimon* cinsi taksonlarının coğrafi bilgi sistemleri (CBS) ile haritalanması ve analizi

Özet: Bu çalışmada Türkiye *Acantholimon* Boiss. cinsi (Plumbaginaceae) taksonlarının uzaysal dağılımı tanımlandı ve bu dağılımda rol oynayabilecek çevresel değişkenler değerlendirildi. 2000 ve 2004 arasında 418 coğrafik referanslı örnekleme yerinden çok sayıda örnek toplandı ve coğrafi bilgi sistemleri (CBS) yazılımı kullanarak, nokta veri tabanı oluşturuldu. Sonuçta 67 takson tanımlandı ve haritalandı. Belirlenen taksonların 43'ü endemiktir. Taksonların halihazırdaki koruma statüsü son IUCN Kırmızı Liste kategorileri kullanılarak yeniden değerlendirildi. Bundan başka, belirlenen her bir noktaya karşılık gelen çevresel değişkenler, Türkiye'nin mevcut ve güncel çevresel raster harita katmanlarından çekildi ve elde edilen veriler Hiyerarşik Kümelendirme ve Konikal Uyum Analizi ile analiz edildi. Hiyerarşik Kümelendirme ile çevresel değişkenler yönünden çeşitli seviyelerde benzerliklere sahip alt gruplar

* E-mail: hmdogan@hotmail.com

gösterildi. Konikal Uyum Analiz sonuçları boylam, denize uzaklık, maksimum sıcaklık, ortalama sıcaklık, minimum sıcaklık, potansiyel evapotranspirasyon, yükseklik ve yağışı içeren 8 çevresel değişkenin Türkiye'deki 18 *Acantholimon* taksonunun uzaysal dağılımının açıklanmasında çok etkili olduğunu gösterdi.

Anahtar sözcükler: *Acantholimon*, Anadolu, biyoçeşitlilik, ekoloji, coğrafi bilgi sistemleri, haritalama, uzaysal analiz, IUCN

Introduction

The genus *Acantholimon* Boiss., first described by Boissier (1846), are perennial and pulvinate sub-shrubs forming thorn cushions (Doğan & Akaydın, 2007). They have considerable ecological, ornamental, and economic importance with nicely coloured and long-lasting flowers (Muvaffak et al., 2001; Doğan & Akaydın, 2004). Current estimates suggest that the genus comprise about 200 species worldwide, and their main centre of diversity may be located in the Irano-Turanian phytogeographical region (Bokhari, 1970). Bokhari and Edmondson (1982) recognised 25 species of *Acantholimon* in the *Flora of Turkey and the East Aegean Islands* (Bokhari & Edmondson, 1982), and also indicated the possibility of finding more species either imperfectly known (2 species) or doubtfully recorded (9 species). Basically, the species of *Acantholimon* can withstand extreme conditions such as high winds, erosion, and aridity. In this respect, determining the spatial distribution of the species is of importance because their presence may indicate eroded and arid regions in Turkey. This characteristic of the taxa can be utilised to monitor global warming effects and consequently desertification, both of which are important problems.

Since 2000, extensive field surveys and laboratory studies have been conducted into the family Plumbaginaceae in Turkey. The studies have been funded by the Scientific and Technological Research Council of Turkey (TÜBİTAK), and have revealed 13 additional new species, 3 subspecies, 3 varieties, and some new combinations. Moreover, 3 synonyms described from Turkey in the past have been recognised once again as good species and the presence of 8 species has been also confirmed (Akaydın & Doğan, 2002; Doğan & Akaydın, 2001, 2002a, 2002b, 2003a, 2003b, 2004, 2005, 2007). The study has also clarified the taxonomy of *A. laxiflorum* Boiss. ex Bunge, which is an endemic species in Turkey (Doğan et al., 2003). In contrast to previous floristic studies, the authors have determined the precise geographic locations of the species by using Global Positioning System (GPS) means. This recent and extensive geo-referenced data allowed us to carry out the mapping and monitoring of the species' distribution. Moreover, the relationships between the present spatial distribution of the species and a variety of other geographic and environmental variables may be investigated to gain a deeper understanding of the range of habitats and climatic conditions in which the species is presently found. This baseline information will inform further studies into how the distribution of the species may change in future as a result of climate change. With this in mind, the present study has aimed to achieve 2 important objectives by using GIS. These aims can be summarised as: mapping the spatial distribution of *Acantholimon* taxa in Turkey, and researching the relationships between the taxa and the environmental variables that may be playing a role in this distribution. Furthermore, the present study aims to provide a comprehensive assessment of the conservation status of *Acantholimon* taxa in Turkey.

Materials and methods

In the *Flora of Turkey*, Davis (1965-1985) and Davis et al. (1988) used a grid system based on intervals of 2 degrees of latitude and longitude as the primary division for the citation of specimens. According to Davis's grid system, Turkey was divided into 3 latitudinal (A, B, C) and 10 longitudinal (from 1 to 10) zones. This produced 29 grid squares.

The work done in this study can be summarised as (1) field-work, (2) identification of plant specimens (herbarium studies), and (3) office work. Within the frame of our revision study, extensive fieldwork was conducted between 2000 and 2004, and a large number of *Acantholimon* specimens (ca. 1200 specimens) were collected from 418 sites. During the fieldwork, the authors aimed to visit as many as different habitats and populations to ensure a representative geographical coverage. In the field, the specimens' GPS coordinates, habitat and relevant field observations were also recorded. In the geo-referencing process, a GPS device (Magellan SporTrak Colour) with 1.6 m accuracy was utilised. When the species was detected, the authors observed the following criteria: the area of occupancy and distribution, populations and their size, and the number of mature individuals. In addition, the current distribution areas of the species and their estimated distributional range were determined using GPS data. According to the results, national threat categories were proposed for all the taxa according to IUCN Red List Categories Version 3.1 (2001) and the Application of IUCN Red List Criteria at Regional Levels (Gardenfors et al., 2001). The following categories established and defined by IUCN (2001) have been used in this study. Data deficient (DD): inadequate information available to make a direct assessment. Critically endangered (CR): the taxon has an extremely high risk of extinction in the wild. Endangered (EN): the taxon has a very high risk of extinction in the wild. Vulnerable (VU): the taxon has a high risk of extinction in the wild in the medium-term future. Near threatened (NT): the taxon is none of the above, but is close to qualifying for or is likely to qualify for a threatened category in the near future. Least concern (LC): the taxon is none of the above. Widespread and abundant taxa are included in this category. The distribution areas (open address) of the taxa in Turkey were given by Doğan and Akaydın (2007). Plant specimens were pressed and dried carefully following the rules and definitions given by Davis and Heywood (1965, 1973).

In our revision study, we mainly used our own collections of *Acantholimon* from Turkey in addition to the specimens stored in other Turkish and foreign herbaria such as ANK, GAZI, HUB, ISTF, FUH, EGE, E, K, and G. The specimens were all cross-checked by utilising the relevant floras and monographs, such as Die Gattung *Acantholimon* Boiss. (Bunge, 1872), *Flora Orientalis* (Boissier, 1879), *Flora of Syria, Palestine and Sinai* (Post, 1933), *Flora of USSR* (Komarov, 1967), *Flora Europaea* (Moore, 1972), *Flora Iranica* (Rechinger & Schiman-Czeika, 1974), and *Flora of Turkey and the East Aegean Islands* (Bokhari & Edmondson, 1982). The authorities were specified according to *Authors of Plant Names* (Brummitt & Powell, 1992), and the specimens were named using the keys given by Doğan and Akaydın (2007).

In the office work stage, all the processed field data were entered into a database (dbf) file containing the geographic reference coordinates along with the species and attributes found at these coordinates (X, Y, and Z). Using a created (XYZ) database file, all attribute data stored as tabular information were transformed to a point map layer and saved as a shape file (shp) in ArcGIS (version 9.1) software (ESRI, 2004, 2005). In this transformation, a WGS84 Geographic coordinate system was used as a reference datum. Consequently, the geographic distribution of the identified *Acantholimon* taxa were precisely mapped and visualised in GIS. After this, the point shape file was utilised to create a series of thematic maps to show the spatial distribution of the *Acantholimon* taxa within Davis's grid system (Davis, 1965-1985).

We also used this point shape file to extract the required environmental data for statistical analyses. This extraction was done in ArcGIS by overlaying the point shape file on complementary data sets including updated and available raster map layers of elevation, slope, aspect, wind speed, water vapour pressure, distance to sea, sunshine fraction, minimum-maximum-mean temperatures, precipitation, potential evapotranspiration, latitude, and longitude (Figure 1). After this process, an XYZ data file containing the coordinates of 418 taxa sampling sites with 14 environmental variables was produced. Utilising this XYZ data file, the mean values of each environmental variable were calculated at the taxa basis. Consequently, we obtained an average data file that contained each of the taxa numbers and their corresponding average environmental variable values. We then used this average data file for Hierarchical Clustering Analysis in the SPSS 16.0. In Hierarchical Clustering Analysis, we chose the Complete Linkage Method (farthest neighbour), and Euclidean distance as a distance metric. We finally constituted 2 separate files in Microsoft Excel. In the first file, the taxa were arranged in a binary (presence-absence) data format for each sampling site, and this was designated as the taxa data file. Sampling sites and their environmental characteristics were organised in a second file, and

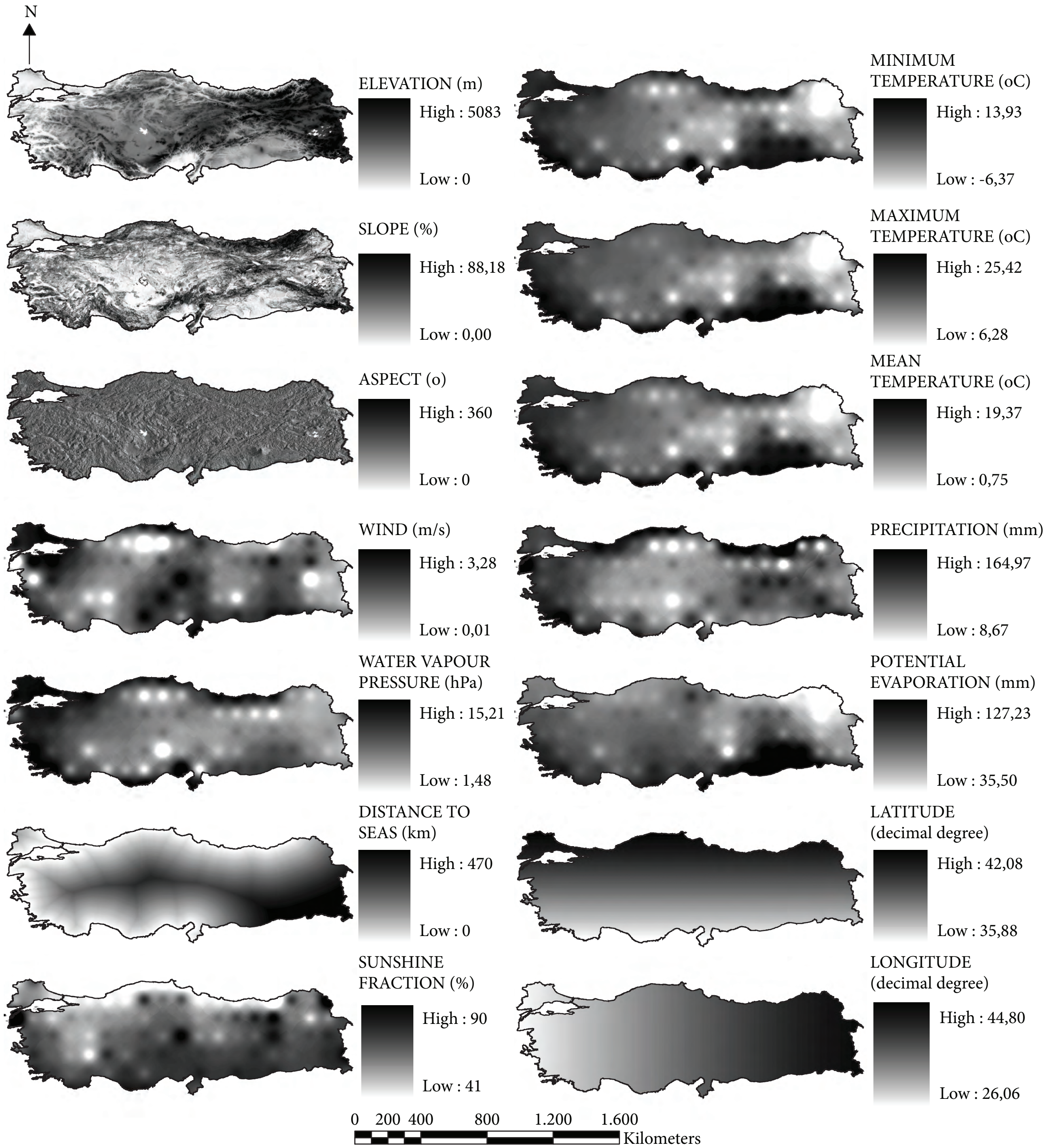

Figure 1. Complementary dataset (Note: All climatic variables were given on an annual mean basis generated from 50 years of climatic records).

called the environmental data file. The taxa and environmental data files were utilised to investigate relationships between the spatial distribution of the *Acantholimon* taxa and other pertinent ecosystem factors in CANOCO (version: 4.5.1) software (Ter Braak, 1986). For this aim, we firstly applied Detrended Canonical Correspondence Analysis (DCCA) to decide the appropriate gradient analysis (linear or unimodal) method. We then conducted Canonical Correspondence Analysis (CCA), which has proven to be an important weighted averaging ordination method in recent studies (Barinova & Tavassi, 2009; Temina et al., 2009), to arrange species along environmental variables.

Results

A total of 67 *Acantholimon* taxa were determined with their locations. Of the identified 67 taxa, 43 taxa were found to be endemic. According to IUCN (2001) criteria at a national level, 18 taxa are evaluated as Critically Endangered [CR B1ab (i, ii, iv); C2a (ii): extent of occurrence less than 100 km^2; area of occupancy less than 10 km^2; known to exist at only a single location; all mature individuals placed in 1 population and estimated mature individuals fewer than 100]. Another 15 taxa are evaluated as Endangered [EN B2ab (i, ii, iv): area of occupancy less than 500 km^2, known at no more than 5 locations], while 23 taxa are evaluated as Vulnerable [VU B2ab (i, ii, iv): area of occupancy less than 2000 km^2, known at no more than 10 locations; inferred decline in the area]. Three taxa are evaluated as Near Threatened (NT) since they are likely to qualify for a threatened category in the near future. The remaining 8 taxa are evaluated as Least Concern (LC) since they are widespread or abundant (Table 1, Figure 2).

The distribution of species according to phytogeographical regions is as follows: 59 taxa (88%) Irano-Turanian elements (17 taxa CR, 13 taxa EN, 20 taxa VU, 3 taxa NT, and 6 taxa LC) and 8 taxa (12%) Mediterranean elements (1 taxon CR, 2 taxa EN, 3 taxa VU, and 2 taxa LC) (Table 1, Figure 2). The full taxa names with their numerical symbols (taxon no.) and threat categories are given in Table 1, while shorter taxa names or numerical symbols (taxon no.) are used in the article and maps.

To understand the nature of the geographical distribution, we presented our results using several visualisation techniques. As a starting point, the taxa found in each grid square in Davis's Grid Square System (Davis, 1965-1985; Davis et al., 1988) were listed (Figure 3). Consequently, valuable spatial information including the geographic locations and numerical symbols (taxa numbers) of the *Acantholimon* taxa (Table 1) were efficiently summarised. At first glance (see Figure 3), the most remarkable locations were determined to be grid B6, which has the highest taxa number (23), and grid A1, which has no *Acantholimon* taxa. The remaining grid squares have between 1 and 17 taxa. Moreover, Figure 3 indicated that rougher terrain and higher elevation areas accommodate more *Acantholimon* taxa compared to flatter and lower elevation areas. The numbers symbolising *Acantholimon* taxa in Figure 3 and Table 1 are used throughout the article to describe the taxa.

Secondly, the determined 67 taxa were organised and summarised by considering both their frequencies and locations for a better interpretation (Figure 4). In this arrangement, we started from the most abundant and widespread taxa located in 3 latitudinal zones (ABC), and continued to the scarcest taxa located in only 1 latitudinal zone (C). Consequently, taxa frequencies within each determined latitudinal zones (ABC, AB, BC, AC, B, A, and C) were sorted from top to bottom, and summarised effectively. According to this order, *A. venustum* var. *venustum* was determined to be the most abundant and widespread taxon, while *A. petuniiflorum* was determined to be the scarcest and rarest distributed taxon (Figure 4).

The geographic distribution of the determined taxa was also visualised and summarised in 4 point maps (Figures 5, 6, 7 and 8). The taxa found in 3 latitudinal zones (ABC) were shown in the first point map (Figure 5). In total, 12 taxa, namely *Acantholimon venustum* var. *venustum*, *A. caryophyllaceum*, *A. puberulum* subsp. *puberulum*, *A. acerosum* subsp. *acerosum* var. *acerosum*, *A. calvertii* var. *calvertii*, *A. iconicum*, *A. armenum* var. *armenum*, *A. acerosum* subsp. *brachystachyum*, *A. ulicinum* var. *ulicinum*, *A. wiedemannii*, *A. capitatum* subsp. *capitatum,* and *A. huetii* var. *huetii* were found in this category.

The taxa encountered in 2 latitudinal zones (BC, AB or AC) were summarised in the following point maps (Figure 6). A total of 10 taxa in latitudinal zones BC were determined as *Acantholimon puberulum* subsp. *peroninii*, *A. kotschyi*, *A. armenum* var. *balansae*, *A. libanoticum*, *A. puberulum* subsp. *longiscapum*, *A. dianthifolium*, *A. bracteatum*, *A. venustum* var. *assyriacum*, *A. halophilum* var. *halophilum,* and *A. ulicinum* var. *creticum* (Figure 6). The 5 taxa located

Table 1. Full names of *Acantholimon* taxa found in Turkey and their threat categories (Note: endemics were marked with an asterisk (*) in the table). Abbreviations: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Irano-Turanian element (Ir.-Tur.), Mediterranean element (Med.), Euro-Siberian element (Eu.-Sib.), Unknown or multiregional (Un. or mu.).

TAXON NO.	TAXON NAME	PHYT. REGION ELEMENT	IUCN RED LIST CRITERIA (2001)	THREAT CATEGORY FOR NATIONAL LEVEL
1	*A. bracteatum* (Girard) Boiss.	Ir.-Tur.	B2ab(i,ii,iv)	VU
2	*A. capitatum* Sosn. subsp. *capitatum**	Ir.-Tur.	B2ab(i,ii,iv)	VU
3	*A. capitatum* subsp. *sivasicum* Dogan & Duman*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
4	*A. hoshapicum* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
5	*A. bashkaleicum* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
6	*A. artosense* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
7	*A. petuniiflorum* Mobayen	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
8	*A. evrenii* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
9	*A. latifolium* Boiss.	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
10	*A. tragacanthinum* (Jaub. & Spach.) Boiss.	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
11	*A. quinquelobum* Bunge var. *quinquelobum*	Ir.-Tur.	B2ab(i,ii,iv)	VU
12	*A. quinquelobum* var. *curviflorum* (Bunge) Dogan & Akaydın	Ir.-Tur.	B2ab(i,ii,iv)	EN
13	*A. laxiflorum* Boiss. ex Bunge*	Med.	B1ab(i,ii,iv); C2a(ii)	CR
14	*A. dianthifolium* Bokhari	Ir.-Tur.	B2ab(i,ii,iv)	VU
15	*A. hypochaerum* Bokhari *	Ir.-Tur.	B2ab(i,ii,iv)	VU
16	*A. köycegizicum* Dogan & Akaydın*	Med.	B2ab(i,ii,iv)	EN
17	*A. calvertii* Boiss. var. *calvertii**	Ir.-Tur.	-	NT
18	*A. calvertii* var. *glabrum* Akaydın & Dogan*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
19	*A. ekimii* Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	EN
20	*A. göksunicum* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
21	*A. huetii* Boiss. var. *huetii**	Ir.-Tur.	B2ab (i,ii,iv)	VU
22	*A. huetii* var. *breviscapum* Akaydın & Dogan*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
23	*A. turcicum* Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	EN
24	*A. wiedemannii* Bunge*	Ir.-Tur.	B2ab(i,ii,iv)	VU
25	*A. yildizelicum* Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
26	*A. anatolicum* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
27	*A. strigillosum Bokhari**	Ir.-Tur.	B2ab(i,ii,iv)	VU
28	*A. ulicinum* (Willd. ex Schultes) Boiss. var. *ulicinum*	Med.	Widely distributed	LC
29	*A. ulicinum* var. *purpurascens* (Bokhari) Bokhari & Edmondson*	Med.	B2ab(i,ii,iv)	EN
30	*A. ulicinum* var. *creticum* (Boiss.) Bokhari & Edmondson	Med.	B2ab(i,ii,iv)	VU
31	*A. puberulum* Boiss. & Bal. subsp. *puberulum*	Ir.-Tur.	Widely distributed	LC
32	*A. puberulum* subsp. *longiscapum* (Bokhari) Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	VU
33	*A. puberulum* subsp. *peroninii* (Boiss.) Akaydın & Dogan*	Med.	Widely distributed	LC
34	*A. karamanicum* Akaydın & Dogan*	Ir.-Tur.	B2ab(i,ii,iv)	EN

Table 1. (continued)

TAXON NO.	TAXON NAMES	PHYT. REGION ELEMENT	IUCN RED LIST CRITERIA (2001)	THREAT CATEGORY FOR NATIONAL LEVEL
35	*A. birandii* Doğan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	EN
36	*A. confertiflorum* Bokhari*	Ir.-Tur.	B2ab(i,ii,iv)	VU
37	*A. reflexifolium* Bokhari*	Ir.-Tur.	B2ab(i,ii,iv)	VU
38	*A. caesareum* Boiss. & Bal.*	Ir.-Tur.	B2ab(i,ii,iv)	VU
39	*A. caryophyllaceum* Boiss.	Ir.-Tur.	Widely distributed	LC
40	*A. acerosum* (Willd.) Boiss. subsp. *acerosum* var. *acerosum*	Ir.-Tur.	Widely distributed	LC
41	*A. acerosum* subsp. *acerosum* var. *parvifolium* Bokhari*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
42	*A. acerosum* subsp. *brachystachyum* (Boiss.) Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	VU
43	*A. acerosum* subsp. *longibracteolorum* Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	VU
44	*A. avanosicum* Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	EN
45	*A. armenum* Boiss. & Huet. var. *armenum*	Ir.-Tur.	Widely distributed	LC
46	*A. armenum* var. *balansae* Boiss. & Huet	Ir.-Tur.	Widely distributed	LC
47	*A. lepturoides* (Jaub. & Spach) Boiss.	Ir.-Tur.	B2ab(i,ii,iv)	EN
48	*A. kotschyi* (Jaub. & Spach) Boiss.*	Ir.-Tur.	-	NT
49	*A. iconicum* (Boiss.) Boiss. & Heldr.*	Ir.-Tur.	-	NT
50	*A. halophilum* Bokhari *var. halophilum**	Ir.-Tur.	B2ab(i,ii,iv)	EN
51	*A. halophilum* var. *coloratum* Dogan & Akaydın*	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
52	*A. lycaonicum* Boiss. & Heldr. subsp. *lycaonicum**	Med.	B2ab(i,ii,iv)	VU
53	*A. lycaonicum* subsp. *cappadocicum* Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	EN
54	*A. damassanum* Mobayen	Ir.-Tur.	B2ab(i,ii,iv)	VU
55	*A. hohenackerii* (Jaub. & Spach) Boiss.	Ir.-Tur.	B2ab(i,ii,iv)	EN
56	*A. saxifragiforme* (Hausskn. & Sint. ex) Bokhari*	Ir.-Tur.	B2ab(i,ii,iv)	EN
57	*A. glumaceum* (Jaub. & Spach) Boiss.	Ir.-Tur.	B2ab(i,ii,iv)	VU
58	*A. libanoticum* Boiss.	Med.	B2ab(i,ii,iv)	VU
59	*A. parviflorum* (Bokhari) Akaydın & Dogan*	Ir.-Tur.	B2ab(i,ii,iv)	VU
60	*A. senganense* Bunge	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
61	*A. spirizianum* Mobayen*	Ir.-Tur.	B2ab(i,ii,iv)	EN
62	*A. multiflorum* (Bokhari) Dogan & Akaydın*	Ir.-Tur.	B2ab(i,ii,iv)	VU
63	*A. araxanum* Bunge	Ir.-Tur.	B2ab(i,ii,iv)	EN
64	*A. fominii* Kusn.	Ir.-Tur.	B1ab(i,ii,iv); C2a(ii)	CR
65	*A. petraeum* Boiss. & Hausskn. ex Bunge	Ir.-Tur.	B2ab(i,ii,iv)	VU
66	*A. venustum* Boiss. var. *venustum*	Ir.-Tur.	Widely distributed	LC
67	*A. venustum* var. *assyriacum* (Boiss.) Boiss.*	Ir.-Tur.	B2ab(i,ii,iv)	VU

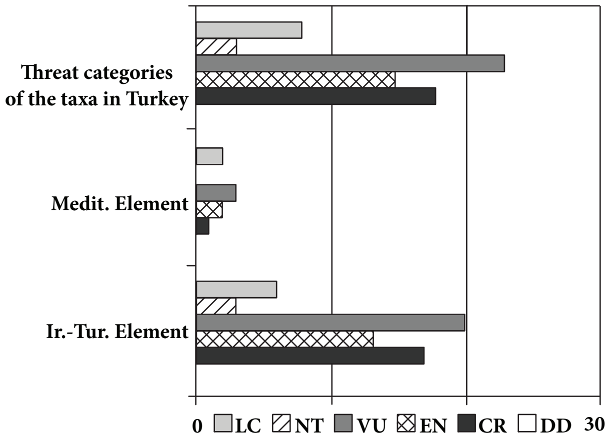

Figure 2. Distribution of the species according to IUCN Red List categories (national level) and phytogeographic elements.

in latitudinal zones AB were *A. hypochaerum*, *A. caesareum*, *A. glumaceum*, *A. acerosum* subsp. *longibracteolorum*, and *A. reflexifolium* (Figure 6), while only 1 taxon was determined in latitudinal zones AC, *A. lycaonicum* subsp. *lycaonicum* (Figure 6).

The taxa found in only one latitudinal zone (B, A, or C) are shown in the last 2 point maps (Figures 7-8). The 22 taxa detected in latitudinal zone B were *Acantholimon damassanum*, *A. strigillosum*, *A. petraeum*, *A. multiflorum*, *A. spirizianum*, *A. saxifragiforme*, *A. turcicum*, *A. ekimii*, *A. hohenackerii*, *A. avanosicum*, *A. huetii* var. *breviscapum*, *A. fominii*, *A. senganense*, *A. halophilum* var. *coloratum*, *A. acerosum* subsp. *acerosum* var. *parvifolium*, *A. yildizelicum*, *A. göksunicum*, *A. evrenii*, *A. artosense*, *A. bashkaleicum*, *A. hoshapicum* and *A. capitatum* subsp. *sivasicum* (Figure 7). The 9 *Acantholimon* taxa found in latitudinal zone A were *A. quinquelobum* var. *quinquelobum*, *A. parviflorum*, *A. lycaonicum* subsp. *cappadocicum*, *A. araxanum*, *A. lepturoides*, *A. quinquelobum* var. *curviflorum*, *A. anatolicum*, *A. calvertii* var. *glabrum*, and *A. tragacanthinum* (Figure 8). Finally, the 8 taxa determined in latitudinal zone C were *A. confertiflorum*, *A. karamanicum*, *A. ulicinum* var. *purpurascens*, *A. köycegizicum*, *A. birandii*, *A. laxiflorum*, *A. latifolium,* and *A. petuniiflorum* (Figure 8).

Hierarchical Clustering Analysis was used to create a hierarchical classification of the *Acantholimon* taxa in respect to their environmental (habitat) requirements, and the groups with their containing

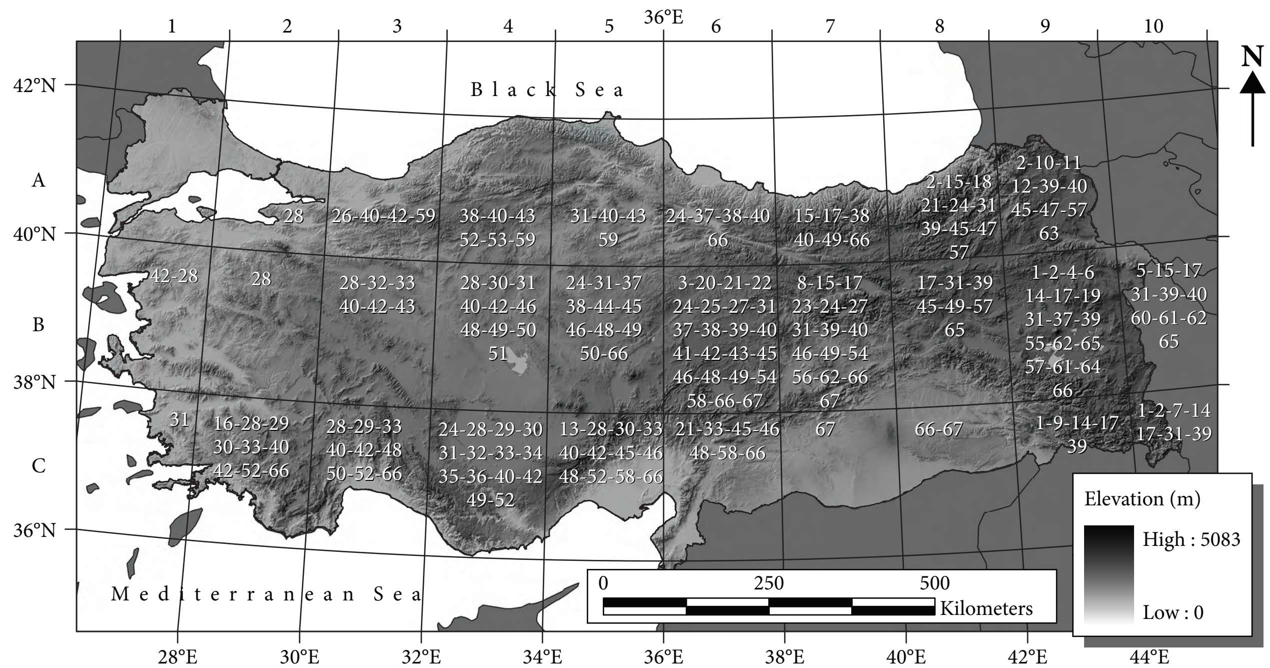

Figure 3. Spatial distribution of determined 67 *Acantholimon* taxa within Davis's Grid System (Davis, 1965-1985) and topographical aspects of Turkey (Note: The full taxon name of each numerical symbol [taxon no.] was given in Table 1).

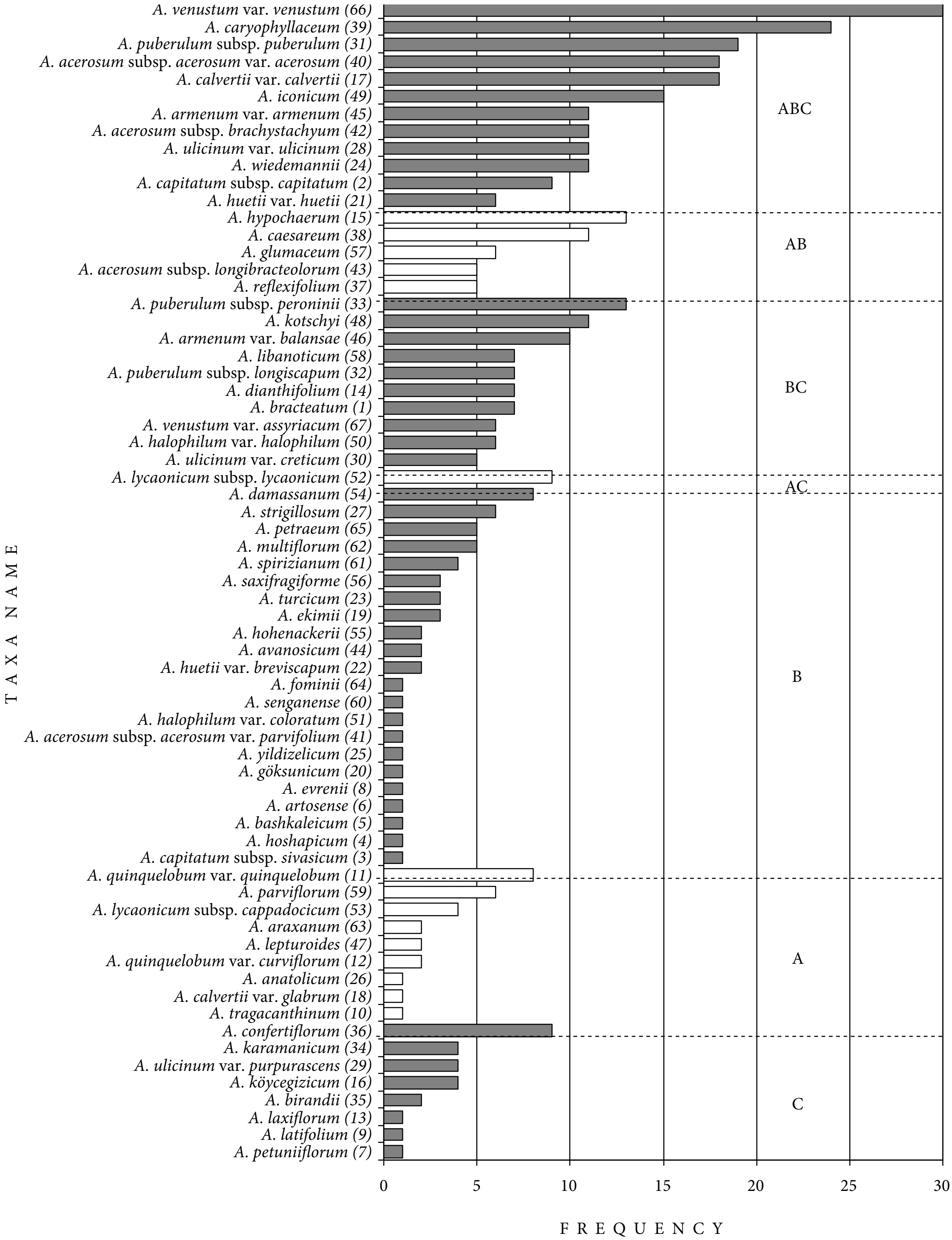

Figure 4. Taxa frequency distribution within latitudinal zones (taxa numbers symbolising full taxa names [Table 1] were given in parentheses).

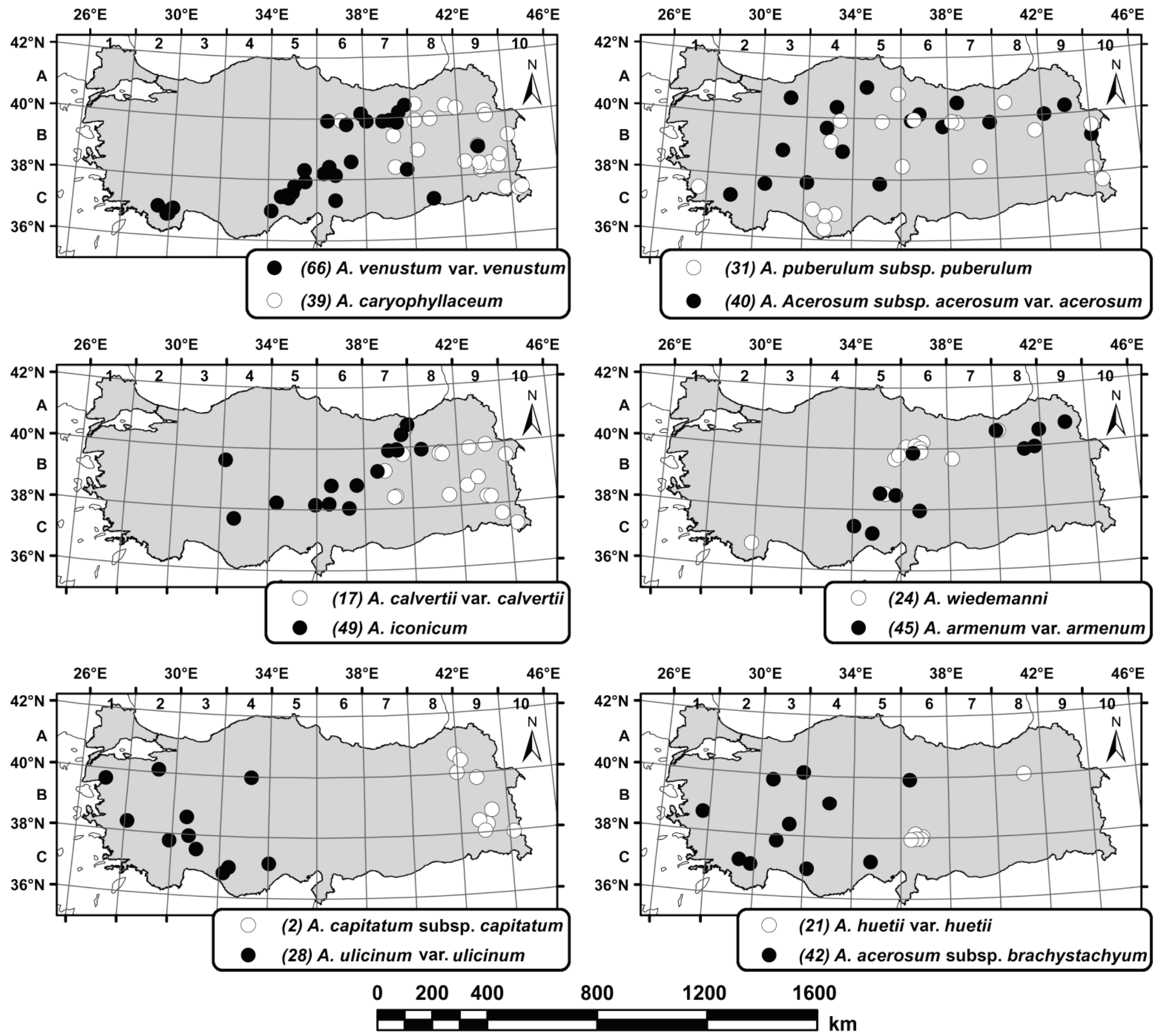

Figure 5. Spatial distribution of *Acantholimon* taxa located in ABC latitudinal zones (taxa numbers [taxon no.] symbolising full taxa names [Table 1] were given in parentheses).

subgroups were displayed as a dendrogram (Figure 9). Table 2 and Figure 9 show how the cases (taxa) were clustered together at each stage of the cluster analysis. The groups were formed from top to bottom in Table 2. The most similar objects (taxa 32 and 33) were first joined to form the first cluster, which was then considered as a new object (Table 2). All the subgroups were joined in the final cluster, containing all the taxa (Figure 9). The lowest distance value (4.453) indicated the closest habitat similarity, while the greatest distance value (726.097) suggested the least habitat resemblance of these taxa (Table 2, Figure 9).

Unimodal DCCA results are summarised in Table 3. Lepš and Šmilauer (2003) reported that the lengths of gradient determine the beta diversity in community composition (the extent of taxa turnover) along the individual independent gradients (ordination axes), and proposed that values larger than 4.0 indicate unimodal methods such as CCA. In this case, the largest length of gradient value in Table 3 (4.656) indicated that unimodal methods were appropriate. As a result, we decided to utilise CCA in our study.

The unimodal CCA results are shown in Table 4. CCA eigenvalues of the first 4 multivariate axes were

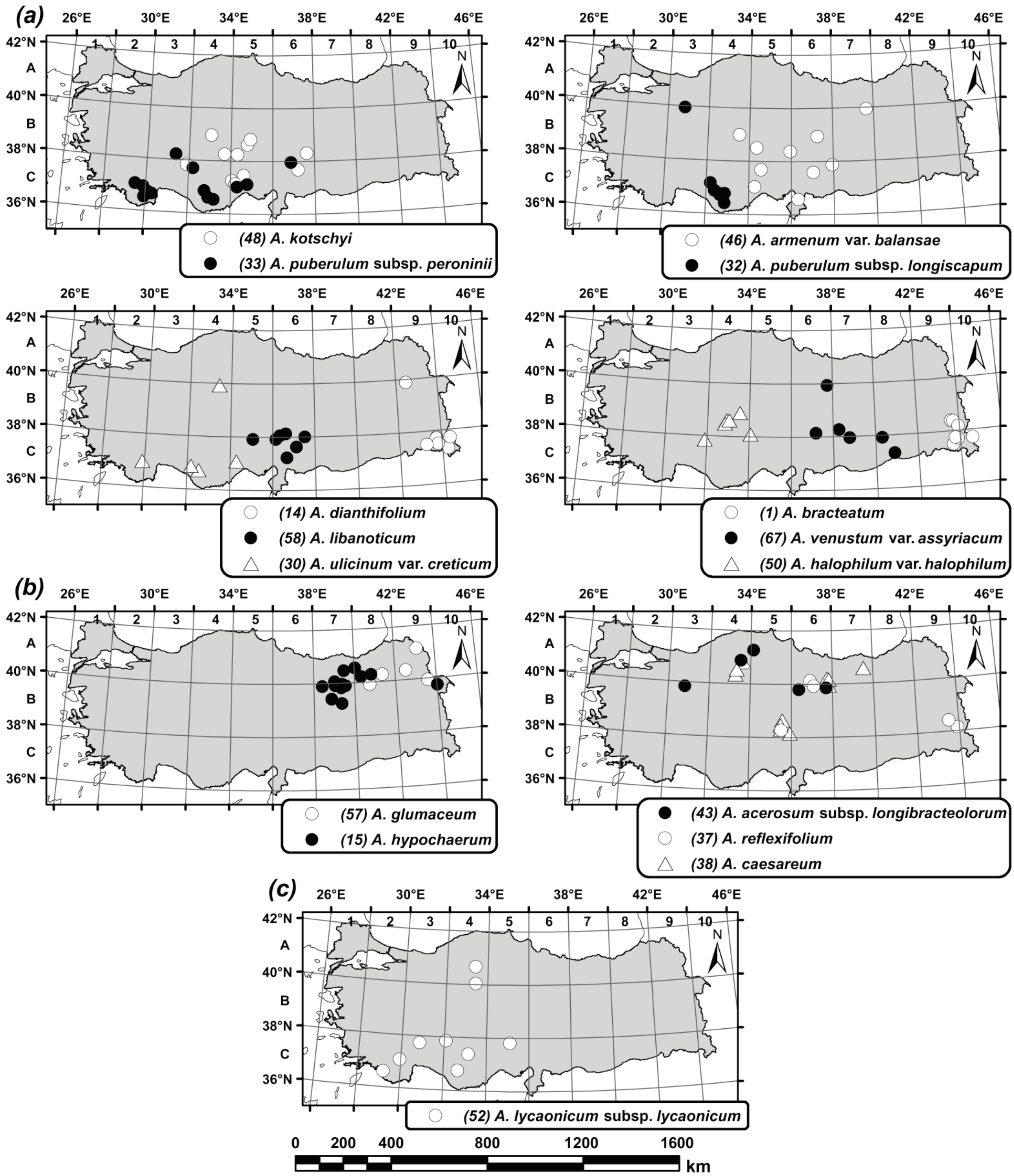

Figure 6. Spatial distribution of *Acantholimon* taxa located in BC (a), AB (b), and AC (c) latitudinal zones (taxa numbers [taxon no.] symbolising full taxa names [Table 1] were given in parentheses).

found to be 0.781, 0.585, 0.537, and 0.457 in the axes, respectively. Correlations between the presence of *Acantholimon* taxa and the values of environmental variables at those locations were calculated as values between 0.884 and 0.676. Total variance was found to be 66.00, and environmental components explained

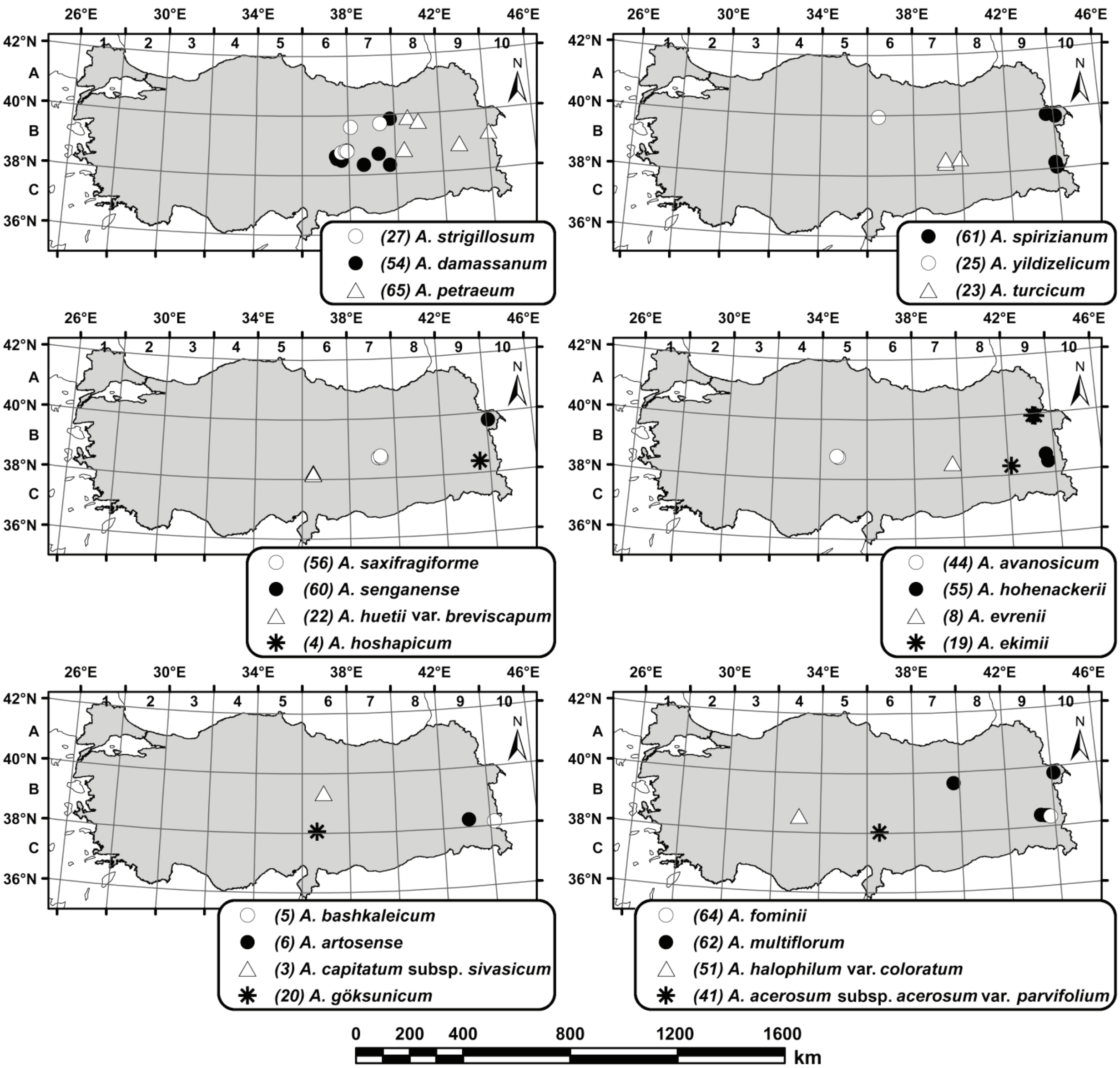

Figure 7. Spatial distribution of *Acantholimon* taxa located in B latitudinal zone (taxa numbers [taxon no.] symbolising full taxa names (Table 1) were given in parentheses).

4.563 of this variance. The first and second axes elucidated 2.1% of the total variance, and the sum of the other 2 axes explained 1.5% of the total variance. Moreover, all 4 axes explained 3.6% of the total variance (Table 4). Consequently, the results obtained from the first 2 axes were plotted (Figure 10).

According to the inter-set correlations of environmental variables with axes (Table 5), longitude, distance to sea, maximum temperature, mean temperature, minimum temperature, elevation, and potential evapotranspiration were found to be the main environmental components that determine the first axis. Precipitation was detected as the environmental variable that delimited the second axis. Vector lengths and their distances to the axes indicated the power of environmental variables. Longer vectors that close the axes indicated more strength. For example, longitude (-0.8685), had

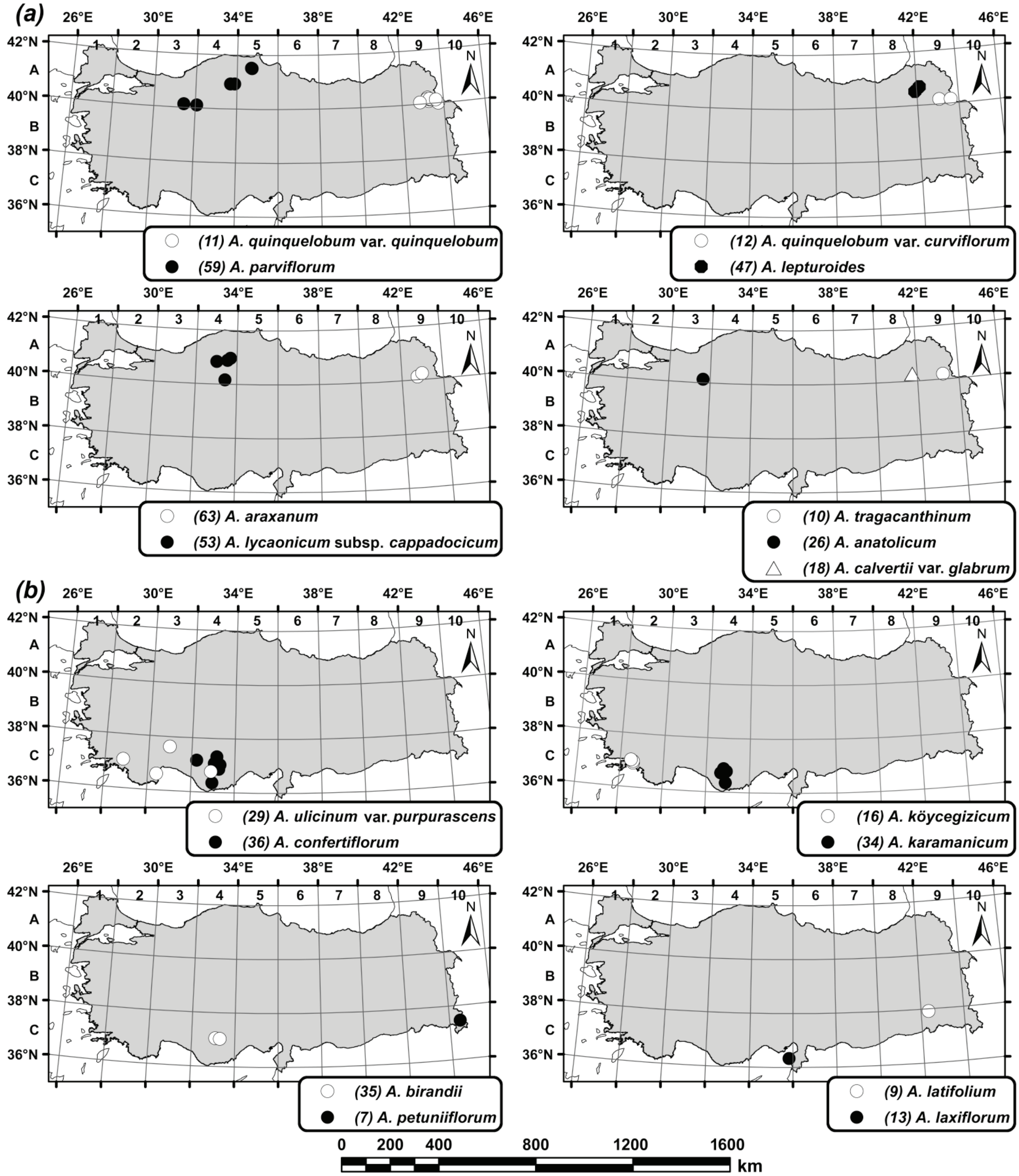

Figure 8. Spatial distribution of *Acantholimon* taxa located in A (a) and C (b) latitudinal zones (taxa numbers [taxon no.] symbolising full taxa names [Table 1] were given in parentheses).

the longest vector along the first axis, significantly correlated with the first axis and explained the most of the variation (1.2%) in the taxa data. The second axis, which explained a further 0.9% of the total variation, was only significantly (0.4563) associated with the precipitation variable (Figure 10, Table 5).

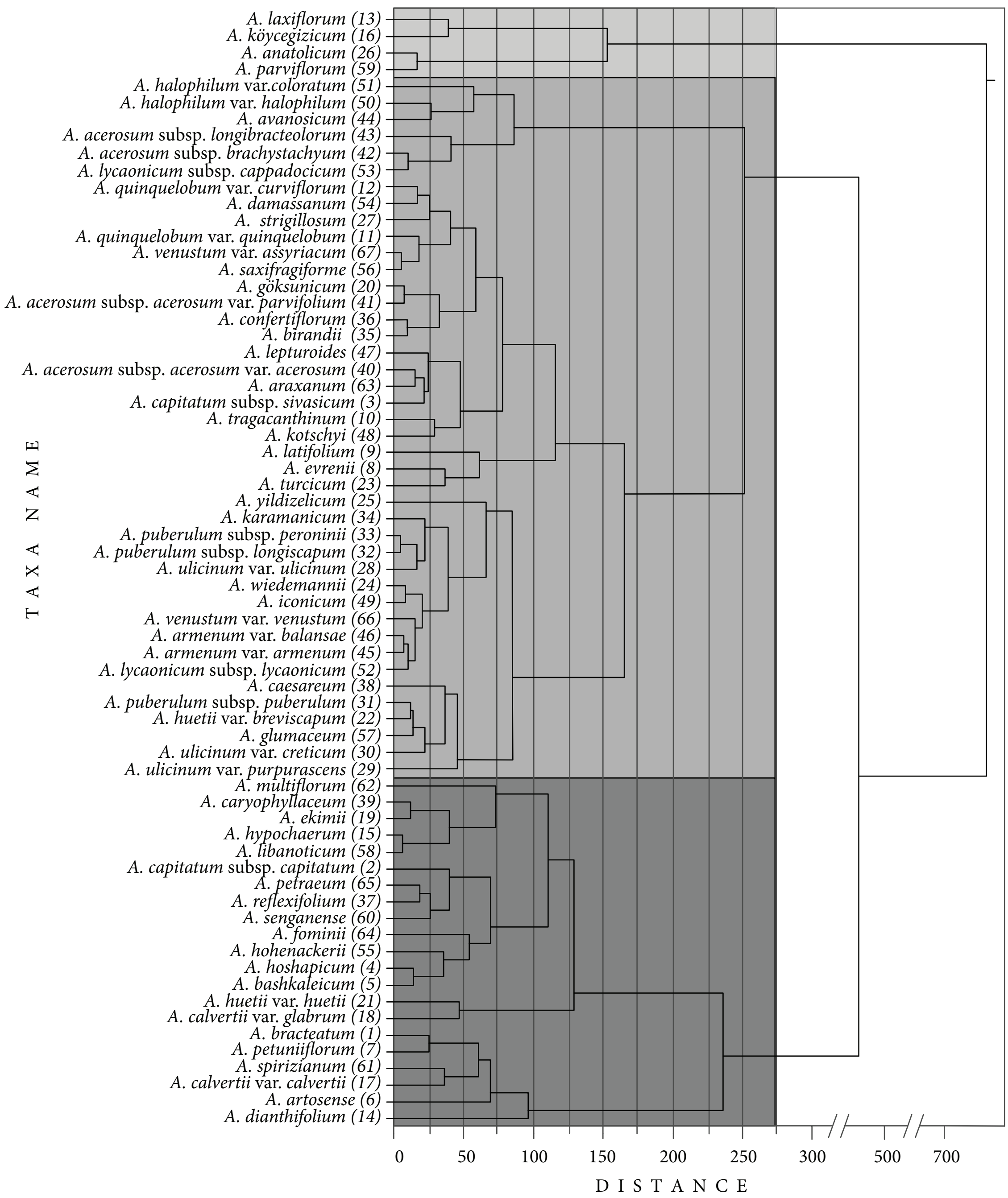

Figure 9. Dendrogram produced by Hierarchical Clustering Analysis (taxa numbers [taxon no.] symbolising full taxa names [Table 1] were given in parentheses).

A total of 6 different groups containing 18 of the *Acantholimon* taxa were determined according to the CCA plot (Figure 10). *A. capitatum* subsp. *capitatum* (taxon no. 2), *A. bashkaleicum* (taxon no. 5), *A. artosense* (taxon no. 6), *A. dianthifolium* (taxon no. 14), *A. hohenackerii* (taxon no. 55), and *A. petraeum* (taxon no. 65) established the first group that preferred both higher longitudes and greater distance from the sea. *A. ulicinum* var. *purpurascens* (taxon no. 29), *A. puberulum* subsp. *longiscapum*

Table 2. Hierarchical Clustering Analysis statistics.

Taxa No.	Taxa No.	Distance	No. of members in new cluster	Taxa No.	Taxa No.	Distance	No. of members in new cluster
33	32	4.453	2	30	38	36.632	5
67	56	5.144	2	23	8	36.711	2
58	15	6.028	2	49	33	38.617	10
46	45	6.823	2	16	13	39.2	2
41	20	7.307	2	2	65	39.656	4
49	24	7.811	2	58	39	39.789	4
36	35	9.133	2	27	11	40.645	6
53	42	9.714	2	53	43	41.035	3
52	46	9.77	3	30	29	45.245	6
39	19	11.536	2	21	18	46.653	2
31	22	11.893	2	48	3	47.148	6
57	31	13.075	3	55	64	54.005	4
5	4	14.13	2	50	51	57.116	3
66	52	14.934	4	36	27	58.233	10
63	40	14.988	2	7	61	60.697	4
33	28	16.222	3	23	9	60.84	3
59	26	16.23	2	49	25	66.197	11
54	12	17.106	2	6	7	69.083	5
11	67	18.188	3	2	55	69.566	8
65	37	18.349	2	62	58	73.032	5
49	66	20.196	6	48	36	77.825	16
3	63	22.421	3	30	49	84.374	17
33	34	22.597	4	53	50	85.822	6
30	57	22.618	4	14	6	95.936	6
3	47	24.095	4	62	2	110.569	13
7	1	25.207	2	48	23	115.849	19
27	54	25.361	3	21	62	128.687	15
65	60	26.06	3	16	59	152.655	4
50	44	26.654	2	30	48	165.324	36
48	10	29.221	2	21	14	235.903	21
36	41	32.729	4	30	53	252.773	42
55	5	35.23	3	21	30	471.64	63
61	17	35.957	2	16	21	726.097	67

Table 3. Unimodal Detrented Canonical Correspondence Analysis results.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.781	0.556	0.414	0.318	66.000
Lengths of gradient	2.930	4.656	2.337	2.314	
Taxa-environment correlations	0.884	0.754	0.681	0.622	
Cumulative percentage variance of taxa data	1.2	2.0	2.7	3.1	
Cumulative percentage variance of taxa-environment relation	17.1	29.6	0.0	0.0	
Sum of all eigenvalues					66.000
Sum of all canonical eigenvalues					4.563

Table 4. Unimodal Canonical Correspondence Analysis results.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.781	0.585	0.537	0.457	66.000
Taxa-environment correlations	0.884	0.765	0.733	0.676	
Cumulative percentage variance of taxa data	1.2	2.1	2.9	3.6	
Cumulative percentage variance of taxa-environment relation	17.1	30.0	41.7	51.7	
Sum of all eigenvalues					66.000
Sum of all canonical eigenvalues					4.563

(taxon no. 32), and *A. puberulum* subsp. *peroninii* (taxon no. 33) formed the second group, which is generally found in higher maximum temperature values. Only one species, *A. birandii* (taxon no. 35), set up the third group, preferring both higher mean temperature and potential evapotranspiration values. *A. karamanicum* (taxon no. 34) and *A. confertiflorum* (taxon no. 36) constituted the fourth group, which preferred higher minimum temperature values. *A. calvertii* var. *calvertii* (taxon no. 17), *A. calvertii* var. *glabrum* (taxon no. 18), and *A. senganense* (taxon no. 60) created the fifth group, which occurs at higher elevations. Finally, *A. göksunicum* (taxon no. 20), *A. huetii* var. *breviscapum* (taxon no. 22), and *A. acerosum* subsp. *acerosum* var. *parvifolium* (taxon no. 41) established the sixth group, which is found in areas of higher precipitation. The environmental variables clearly influencing the other 49 taxa could not be determined.

Discussion

The point maps developed and previous studies support our CCA results. The geographical position of the first CCA group, for example, showed that *A. capitatum* subsp. *capitatum* (taxon no. 2), *A. bashkaleicum* (taxon no. 5), *A. Artosense* (taxon no. 6), *A. dianthifolium* (taxon no. 14), *A. hohenackerii* (taxon no. 55), and *A. petraeum* (taxon no. 65) preferred higher longitudes and locations further from the sea (Figures 5-7). The taxa in this group were also found in the same cluster at a distance of 235.903 (Table 2, Figure 9). Sustaining our findings, all the taxa in this group have been described as Irano-Turanian elements found at high altitudes (1700-3600 m) in East and South-east Anatolia (Doğan & Akaydın, 2004, 2005, 2007).

Similarly, *A. ulicinum* var. *purpurascens* (taxon no. 29), *A. puberulum* subsp. *longiscapum* (taxon no.

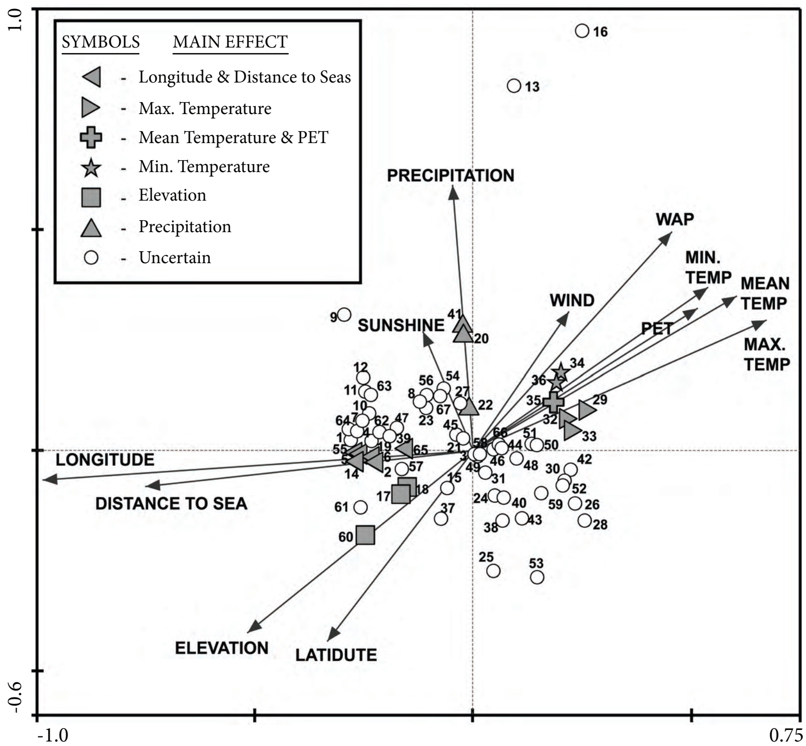

Figure 10. Canonical Correspondence Ordination Diagram with 67 *Acantholimon* taxa and 12 environmental variables (arrows). The first axis is horizontal and the second axis is vertical (Note: Taxa numbers [taxon no.] symbolise full taxa names [Table 1]. Slope and aspect variables are discarded to simplify the figure.)

32), and *A. puberulum* subsp. *peroninii* (taxon no. 33) in the second CCA group were geographically confined to the southern part of Turkey, where the Mediterranean climate prevails (Figures 6, 8). They were also found in the same cluster at a distance of 84.374 (Table 2, Figure 9). Parallel to our results, the taxa in this group have been described as Mediterranean elements found at high altitudes (830-2000 m) of the South-west, South, and Central Anatolia regions (Doğan & Akaydın, 2007).

The geographical situation of the third CCA group indicated that *A. birandii* (taxon no. 35) was present in Central Anatolia, where an arid climate prevails with high potential evapotranspiration values (Figure 8). Supporting our findings, the taxon in this group had been described previously as an Irano-Turanian element detected in mountainous areas around 1350 m (Doğan & Akaydın, 2007).

A. karamanicum (taxon no. 34) and *A. confertiflorum* (taxon no. 36) in the fourth CCA group were geographically distributed in the Mediterranean region, where higher minimum temperature values have been recorded (Figure 8). They were also recognised in the same cluster at a distance of 165.324 (Table 2, Figure 9). Likewise, the taxa in this group had been described as Irano-Turanian elements confined to mountainous areas between 1120 and 1600 m (Doğan & Akaydın, 2007).

The geographical position of the fifth CCA group showed that *A. calvertii* var. *calvertii* (taxon no. 17), *A. calvertii* var. *glabrum*, (taxon no. 18), and *A. senganense* (taxon no. 60) preferred very high elevations in Eastern Anatolia (Figures 5, 7, 8). The taxa in this group were also found in the same cluster at a distance of 235.903 (Table 2, Figure 9). Supporting these outcomes, the taxa in this group had been described as Irano-Turanian elements

Table 5. Inter-set correlations of environmental variables with axes.

N	NAME	AX1	AX2	AX3	AX4
	FR EXTRACTED	0.1978	0.0662	0.0717	0.0270
1	Longitude	-0.8685	-0.0505	-0.0136	-0.0201
2	Latitude	-0.2929	-0.3271	0.5405	0.0672
3	Elevation	-0.4548	-0.3138	-0.4489	-0.2128
4	Slope	-0.1302	-0.0665	-0.2497	-0.1129
5	Aspect	-0.0123	-0.0477	0.0124	0.0309
6	Mean Temperature	0.5304	0.2659	-0.2248	0.1966
7	Minimum Temperature	0.4731	0.2808	-0.2830	0.2536
8	Maximum Temperature	0.5914	0.2253	-0.1429	0.1687
9	Precipitation	-0.0420	0.4563	-0.1156	0.0223
10	Sunshine Fraction	-0.1000	0.2030	-0.3798	-0.0618
11	Potential Evapotranspiration	0.4523	0.2451	-0.2880	0.1262
12	Water vapour pressure	0.4002	0.3765	-0.0942	0.0380
13	Wind speed	0.1922	0.2377	-0.0571	-0.3060
14	Distance to seas	-0.6615	-0.0613	-0.2095	0.2596

confined to elevations between 2050 and 3535 m (Doğan & Akaydın, 2003a; Doğan et al., 2003; Doğan & Akaydın, 2007).

Finally, *A. göksunicum* (taxon no. 20), *A. huetii* var. *breviscapum* (taxon no. 22), and *A. acerosum* subsp. *acerosum* var. *parvifolium* (taxon no. 41) in the sixth CCA group geographically were found on the southern side of the Taurus Mountains (Figure 7), one of the areas with the most precipitation (>1000 mm) in South-east Anatolia (Dinc et al., 2001). These 3 taxa were found in the same cluster at a distance of 165.324 (Table 2, Figure 9). Correspondingly, the taxa forming this group are described as Irano-Turanian elements found in the mountainous areas (1070-2100 m) of South-east Anatolia (Doğan & Akaydın, 2003a, 2007).

The outcomes of this study were found to be suitable for future monitoring studies, especially those focusing on desertification and the effects of global warming on plants. For example, any observed expansion in the distribution of *A. ulicinum* var. *purpurascens*, *A. puberulum* subsp. *longiscapum*, and *A. puberulum* subsp. *peroninii* taxa or reduction in the distribution of *A. göksunicum*, *A. huetii* var. *breviscapum*, and *A. acerosum* subsp. *acerosum* var. *parvifolium* taxa could serve as indicators for increasing temperature and decreasing precipitation, respectively.

One shortcoming of this study was the sum of all canonical eigenvalues (Table 4), which explained the low proportion (4.563) of total variance (66.00). Although environmental variables were clearly in evidence for 18 different *Acantholimon* taxa, the environmental variables influencing the remaining 49 taxa could not be determined clearly. This problem was in part caused by the absence of a detailed soil database, which is one of the most important components of the ecosystem. The available soil database of Turkey (1/25,000 scale) produced by the General Directorate of Rural Affairs was too old (approximately 30 years), and did not contain enough detailed information such as important plant nutrition elements, pH, lime, salinity, alkalinity, and texture. It was clear that the validity and actuality of this established database could not answer the questions emerging from contemporary problems. Therefore, we could not utilise this soil database. The CCA results indicated that more environmental variables, including the soil details for Turkey, are needed to explain the environmental preferences of the remaining *Acantholimon* taxa.

Conclusion

In this study, we identified and mapped 67 *Acantholimon* taxa; 43 of the determined taxa appear to be endemic. The threat categories of the species were found to be as follows: 18 taxa Critically Endangered (CR), 15 taxa Endangered (EN), 23 taxa Vulnerable (VU), 3 taxa Near Threatened (NT), and 8 taxa Least Concern (LC). Most importantly, we have expanded our knowledge about the spatial distribution and habitat preferences of the *Acantholimon* taxa in a quantitative way for the first time in Turkey. Detailed geo-referenced field data and GIS referencing have enabled us not only to produce precise maps that visualise the geographic locations of *Acantholimon* taxa, but also to extract and analyse immense environmental data. In this way, we have acquired a deeper understanding of the ecology of the taxa. Consequently, we have been able to cluster the total 67 *Acantholimon* taxa according to their habitat preferences by utilising our countrywide raster database, which includes 14 environmental variables. Moreover, we have investigated the environmental variables effective on the taxa, and determined 8 environmental variables effective on 18 *Acantholimon* taxa. The relationships identified have opened up ways of consistent and reproducible information about the spatial distribution of the taxa, which is important for monitoring habitat fragmentation and desertification as well as global warming effects over time.

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