Turkish Journal of Botany

http://journals.tubitak.gov.tr/botany/

Research Article

Turk J Bot
(2017) 41: 37-46
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doi:10.3906/bot-1604-11

Mapping and analyzing the spatial distribution of the tribe Triticeae Dumort. (Poaceae) in Turkey

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Received: 06.04.2016 • **Accepted/Published Online:** 24.09.2016 • **Final Version:** 17.01.2017

Abstract: Triticeae Dumort. (Poaceae), or true grasses, the fifth-largest plant family in the world, are of great importance in terms of human life and civilization. Therefore, understanding the spatial distribution of the family members is important for botanists, plant producers, and breeders. Turkey is one of two gene centers of this family. In this study, the spatial distribution of Triticeae in Turkey was mapped in geographic information systems (GIS) by utilizing a large number of specimens collected from 1006 georeferenced sampling sites between 2004 and 2010. Canonical correspondence analysis (CCA) was carried out in order to understand the spatial distribution of determined taxa. Environmental data for CCA were extracted from the available environmental raster map layers of Turkey. We identified and mapped a total of 76 species including 42 annuals and 34 perennials. CCA indicated that 6 environmental variables, namely potential evapotranspiration, elevation, distance to seas, maximum temperature, slope, and longitude, are the most effective in explaining the spatial distribution of the 12 annual species. However, the 6 environmental variables potential evapotranspiration, water vapor pressure, latitude, longitude, distance to seas, and sunshine fraction were the most effective in explaining the spatial distribution of the 20 perennial species. *Aegilops triuncialis* L. subsp *triuncialis* (annual) and *Hordeum bulbosum* L. (perennial) were the most abundant and widespread taxa, while *Aegilops juvenalis* (Thell.) Eig (annual) and *Elymus libanoticus* (Hack.) Melderis (perennial) were the scarcest and most rarely distributed species.

Key words: Triticaeae, plant biodiversity, canonical correspondence analysis, geographic information systems, plant ecology, systematics

1. Introduction

The grasses (Poaceae Barnhart) are the fifth largest (monocotyledonous flowering) plant family in the world (Watson and Dallwitz, 1992). According to the latest update of the Kew World Grass Species database, 10,805 species are reported (Simon, 2007). The family Poaceae is of great importance in terms of human life and civilization. Cereal crops such as maize, wheat, rice, barley, and millet were domesticated from this family. Poaceae still constitute the most economically important plant family in modern times, providing forage, building materials (bamboo, thatch), and fuel (ethanol), as well as food (Wheeler et al., 1982). In the extensive domestication process, wild species regarded as weeds accompany the crop species in their global dissemination (Fahleson et al., 2008).

Members of the family are widely distributed, annual or perennial herbaceous or woody plants. Approximately, 1000 and 602 taxa have been estimated in Europe and Turkey, respectively (Tutin et al., 1980). Southwest Asia and Turkey were reported as the gene centers (Davis, 1985). The earliest firm records about grass pollen from the Paleocene (55–60 million years ago) indicated that South America and Africa are the centers of origin (Jacobs et al., 1999). The family was divided into two physiological groups as C3 and C4 plants according to photosynthetic pathways for carbon fixation (Kellogg, 2001). The C3 grasses are referred to as cool-season grasses, while the C4 plants are considered warm-season grasses; they may be either annual or perennial.

Turkey, especially its southeastern parts, belongs to the Fertile Crescent and could be among the areas first cultivating important crops such as wheat and barley. The flowering time of the members of this tribe in Turkey was reported as from April–May to August–September, depending on the species and their ecogeographical location (Harlan and Zohary, 1966). They show considerable variations regarding the flowering times.

The present study aimed to map and to analyze the spatial distribution of the tribe Triticeae taxa based on 14 environmental variables by utilizing geographic information systems (GIS) from its Turkish populations.

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2. Materials and methods

This study was conducted at the stages of field work, identification of plant specimens, and office work. At the field work stage, a total 1006 sites in Turkey (814,578 km^2) were sampled between 2004 and 2010. All sampling sites were georeferenced by global positioning system (GPS). Plant specimens were pressed and dried following the rules and definitions given by Davis and Heywood (1963). Species were mostly identified in Turkish herbaria including Ankara (ANK), Ege (EGE), Gazi (GAZI), Hacettepe (HUB), İstanbul (ISTF), and Fırat (FUH) universities. The collections housed at the herbarium of the Royal Botanic Garden Edinburgh (E) were also utilized. The specimens were all cross-checked using *Flora Orientalis* (Boissier, 1879), *Flora of Syria, Palestine and Sinai* (Post, 1933), *Flora of USSR* (Komarov, 1967), *Flora Iranica* (Rechinger and Schiman-Czeika, 1974), and *Flora of Turkey and the East Aegean Islands* (Davis, 1965-1985).

We followed the methodology explained by Doğan et al. (2011) at the office work stage. Georeferenced field data were firstly transformed to a point map layer in GIS. Then a series of species distribution maps, presented within Davis' 2° × 2° grid system (Davis 1965-1985), were generated by utilizing the produced point map layer. We also utilized this point map layer to extract the necessary environmental (spatial analysis) data from the complementary (grid) data set of Turkey. These complementary data consist of 14 environmental variables, namely latitude (°), longitude (°), elevation (m), slope (%), aspect (°), wind speed (m/s), water vapor pressure (hPa), distance to seas (m), minimum/maximum/mean temperatures (°C), sunshine fraction (%), precipitation (mm), and potential evapotranspiration (mm). In all GIS applications, ArcGIS (version 9.1) software (ESRI, 2004) was employed.

Finally, two separate files including species and environmental data were established in Microsoft Excel to conduct canonical correspondence analysis (CCA) in CANOCO (version 5) software (Ter Braak, 1986; Ter Braak and Smilauer, 2012). In the species data file, determined species were arranged as binary (presence/absence) data format for each sampling site. In the environmental data file, sampling sites and their environmental characteristics were organized.

3. Results

A total of 76 species including 42 annuals and 34 perennials were determined along with their locations. Determined species were sorted by name and frequency, and numbered from 1 to 76 in Microsoft Excel. Within each latitudinal zone (ABC, AB, BC, AC, A, B, and C), annual and perennial species frequencies were sorted from top to bottom, and summarized with their full scientific names (Figure 1). In annuals, *Aegilops triuncialis* L. subsp. *triuncialis* (1) was the most abundant and widespread taxon, while *Aegilops juvenalis* (Thell.) Eig was the scarcest and most rarely distributed species (Figure 1). In perennials, *Hordeum bulbosum* L. was the most abundant and widespread species, while *Elymus libanoticus* (Hack.) Melderis was the scarcest and most rarely distributed species (Figure 1). Full scientific names are given only in Figure 1, with abbreviated names used in the rest of the article.

The geographic distributions of the 42 annual taxa are shown in Figure 2. We detected 19 annual taxa spread over all three (ABC) latitudinal zones (Figures 2A–2E). Totally, 8 annual taxa were dispersed in two (AB, BC, or AC) latitudinal zones (Figures 2F and 2G). The remaining 15 annual taxa were found in only one (A, B, or C) latitudinal zone (Figure 2H and 2J). The locations of the 34 perennial taxa are presented in Figure 3. In total 6 perennial taxa were found in all three (ABC) latitudinal zones (Figures 3A and 3B), while 10 perennial taxa were dispersed in two (AB or BC) latitudinal zones (Figures 3C and 3D). The remaining 18 annual taxa were discovered in only one (A, B, or C) latitudinal zone (Figures 3E–3H).

According to the CCA results of annuals, total variance was 41.00, and environmental components explained 3.454 of this variance. In total 5 different groups containing 12 annual species were determined according to the CCA plot (Figure 4). PET, distance to sea, longitude, slope, and maximum temperature variables affected the CCA results of annuals.

According to the CCA results of perennials, total variance was 33.00, and environmental components interpreted 3.000 of this variance. In 20 perennial species 6 different groups were detected (Figure 5). PET, distances to sea, longitude, WAP, latitude, and sunshine fraction affected the CCA results of perennials.

4. Discussion

Aegilops cylindrica Host (4), *Aegilops biuncialis* Vis. (5), and *Dasypyrum villosum* (L.) P. Candargy (9) (Figures 1, 2A, and 2C) preferred high potential evapotranspiration values (Figure 4). Basically, potential evapotranspiration is the amount of water that could evaporate and transpire from a vegetated landscape without restrictions other than the atmospheric demand (Jensen et al., 1990). Consequently, our results indicated that this group could be drought tolerant. Supporting our findings, it was reported that all these species are salt or drought tolerant (Farooq and Azam, 2001; Yang et al., 2005).

Aegilops neglecta Req. ex Bertol. (8), *Hordeum geniculatum* All. (10), and *Secale cereale* L. var. *ancestrale* Zhuk. Kit Tan (12), and *Crithopsis delileana* (Schult.) Roshev. (14) (Figures 1, 2B, and 2I) chose high distance

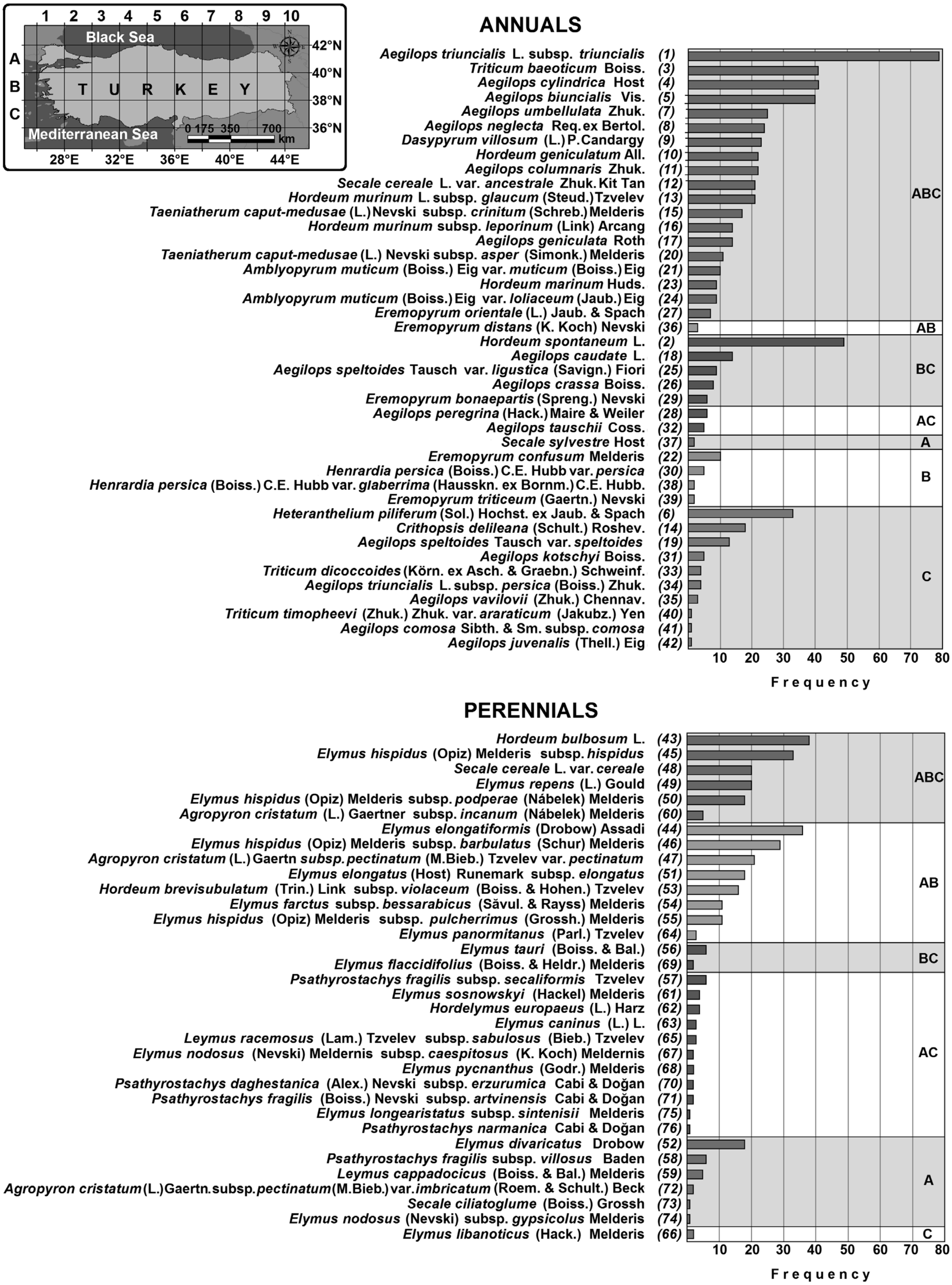

Figure 1. Frequency distribution of 42 annual and 34 perennial Triticeae Dumort. (Poaceae) taxa in the latitudinal zones of Turkey (Note: According to 2° × 2° grid system (Davis, 1965–1985); A, B, and C latitudinal zones are shown as a map reference in the upper left corner of the figure).

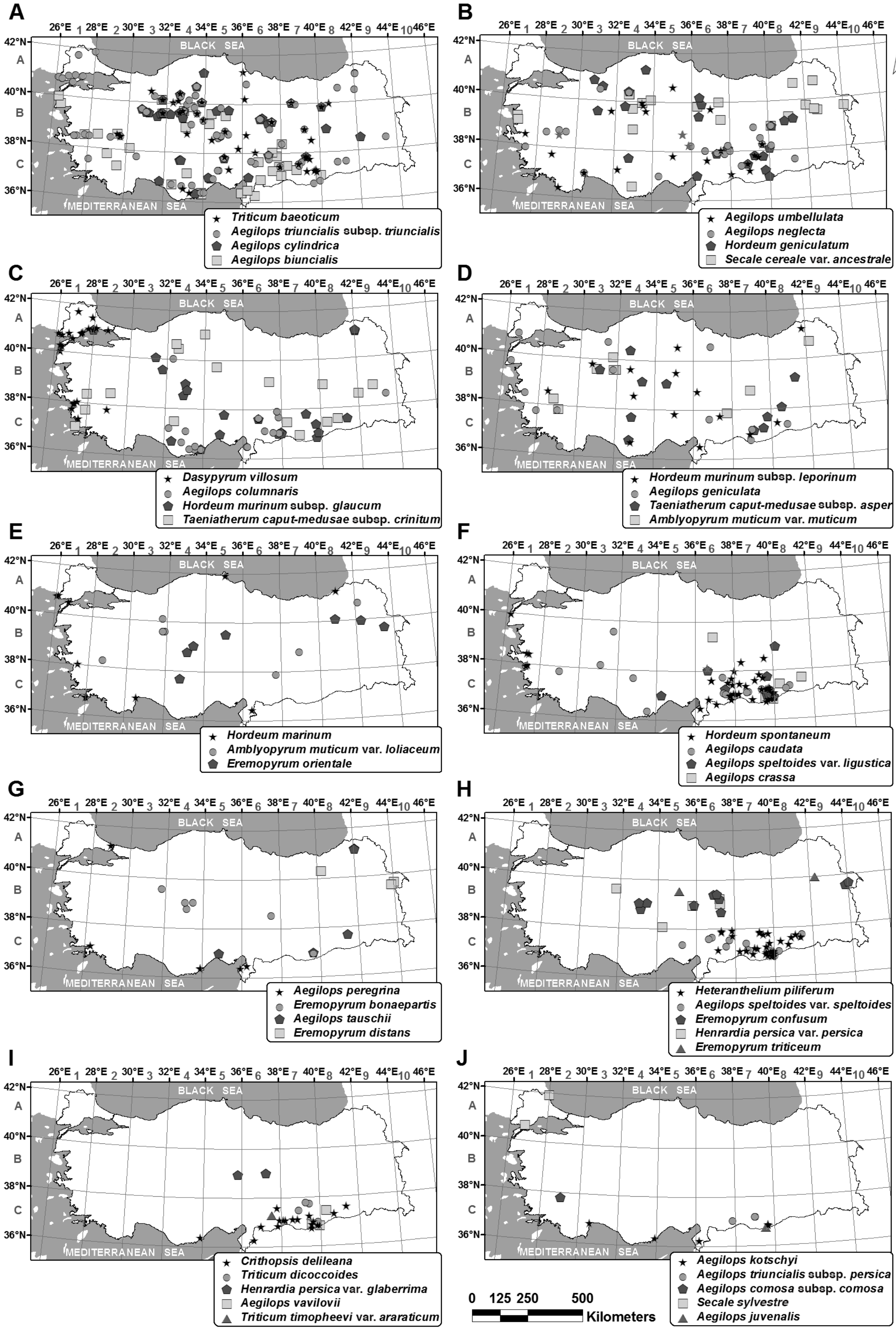

Figure 2. Spatial distribution of annual Triticeae taxa in Turkey (Note: Full scientific names of the taxa are given in Figure 1).

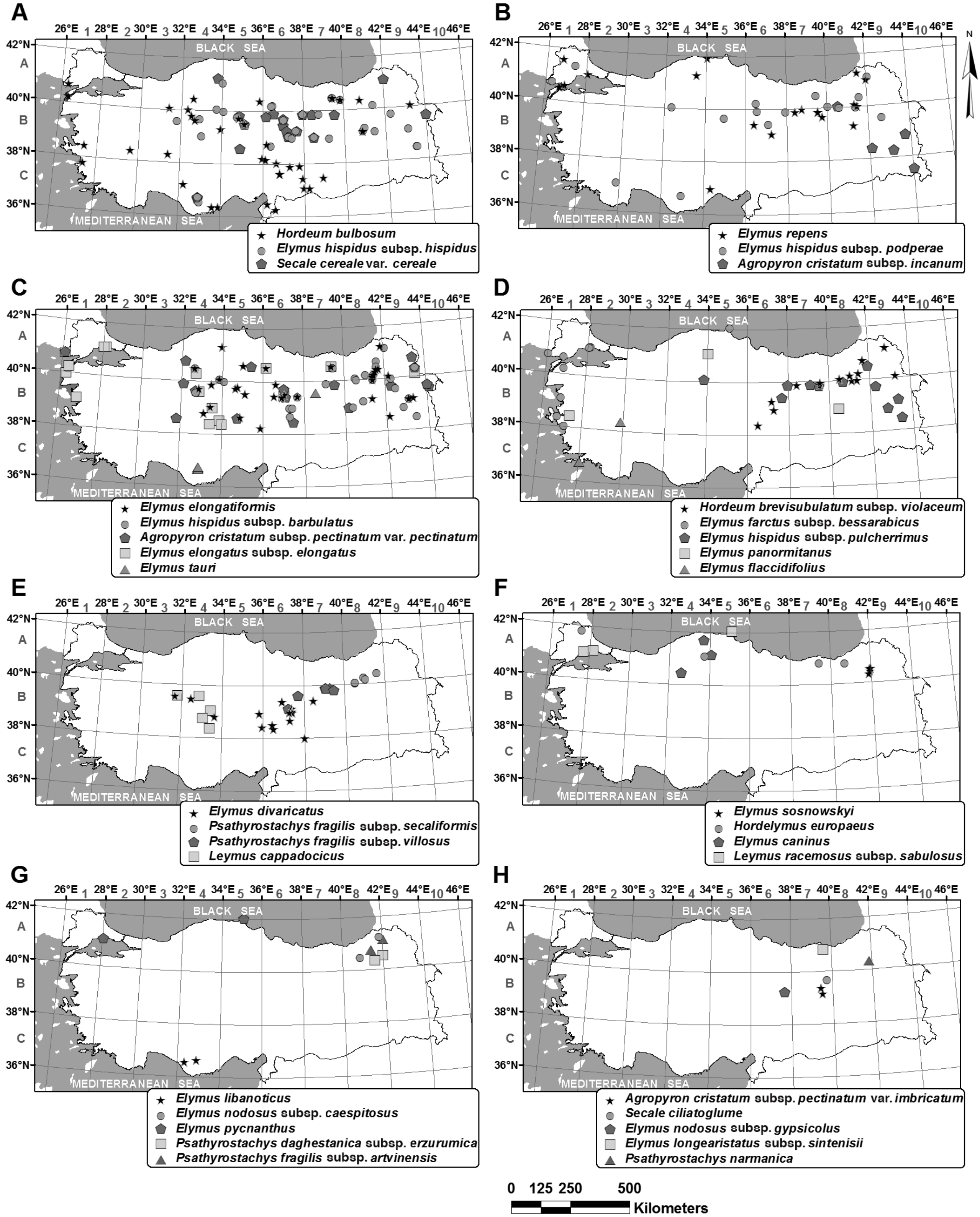

Figure 3. Spatial distribution of perennial Triticeae taxa in Turkey (Note: Full scientific names of the taxa are given in Figure 1).

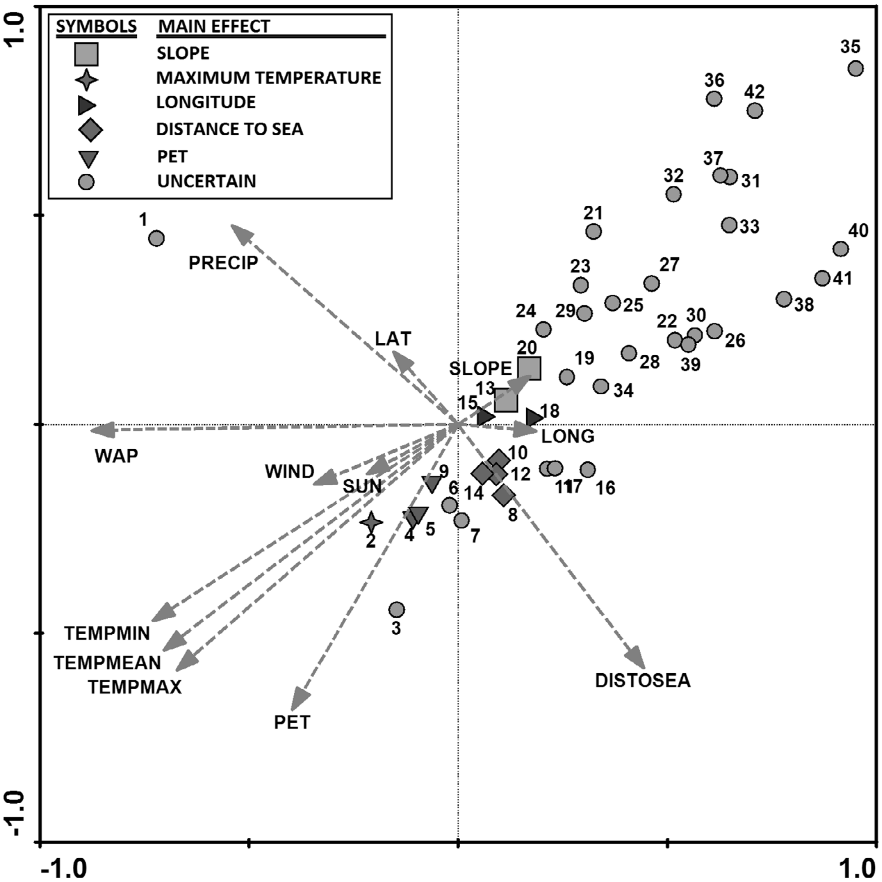

Figure 4. Canonical correspondence ordination diagram with 42 annual species and 12 environmental variables (arrows), namely latitude (LAT), longitude (LONG), elevation (ELEV), slope (SLOPE), aspect (ASPECT), wind speed (WIND), water vapor pressure (WAP), distance to seas (DISTOSEA), minimum temperature (TEMPMIN), maximum temperature (TEMPMAX), mean temperature (TEMPMEAN), sunshine fraction (SUN), precipitation (PRECIP), and potential evapotranspiration (PET) (Note: Species numbers symbolize the full scientific names of the taxa in Figure 1).

to seas (Figure 4), which means continental conditions. Previous studies verified these findings, and indicated that the habitats of these taxa have continental characteristics (Davis, 1965–1985; Holzapfel et al., 2006; Eliaš et al., 2013; TÜBİVES, 2014).

Taeniatherum caput-medusae (L.) Nevski subsp. *crinitum* (Schreb.) Melderis (15) and *Aegilops caudata* L. (18) (Figures 1, 2C, and 2F) preferred higher longitudes (Figure 4), which means eastern parts of the country. According to our results, the frequencies of these species increased from west to east following the locations having rugged (stony slopes), hot, dry, temperate grassland characteristics in Turkey. Supporting our findings, the habitat of *T. caput-medusae* subsp. *crinitum* was reported as temperate desert rangelands (Young, 1992), steppes, grassy mountain slopes, stony slopes, mountain thickets, and sandy plains (TÜBİVES, 2014). However, evidence about *A. caudata* habitat was not clearly reported in the literature. In this regard, our findings may add some new information about this species.

Hordeum murinum L. subsp. *glaucum* (Steud.) Tzvelev (13) and *Taeniatherum caput-medusae* (L.) Nevski subsp. *asper* (Simonk.) Melderis (20) (Figures 1, 2C, and 2D) chose higher slopes in mountainous areas (Figure 4). Verifying these results, the habitat of *H. murinum* subsp. *glaucum* was reported as the center of the Iberian Peninsula and in mountainous regions of the southeast where climate is continental but moderated by Mediterranean influence (Soler et al., 1997). Moreover, *H. murinum* was introduced nearly worldwide in temperate and dry regions, and occurred as weeds in disturbed and agricultural habitats (Blattner, 2009). Similarly, it was reported that *T. caput-medusae* can spread rapidly through degraded shrub steppe communities (Stewart and Hull, 1949).

On the spatial distribution of *Hordeum spontaneum* L. (2) (Figures 1 and 2F), maximum temperature was found to have an effect (Figure 4). Although the habitat of *H. spontaneum* ranges from warm and arid lowlands up to colder and more humid uplands (Nevo et al., 1979), our results showed that this species prefers warm places in Turkey.

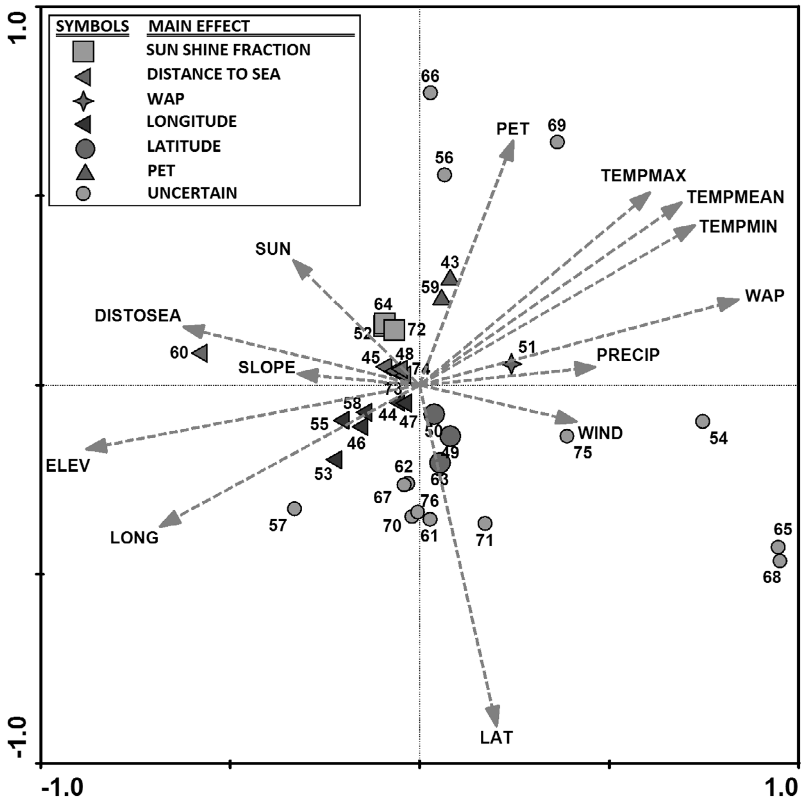

Figure 5. Canonical correspondence ordination diagram with 34 perennial species and 12 environmental variables (arrows), namely latitude (LAT), longitude (LONG), elevation (ELEV), slope (SLOPE), aspect (ASPECT), wind speed (WIND), water vapor pressure (WAP), distance to seas (DISTOSEA), minimum temperature (TEMPMIN), maximum temperature (TEMPMAX), mean temperature (TEMPMEAN), sunshine fraction (SUN), precipitation (PRECIP) and potential evapotranspiration (PET) (Note: Species numbers symbolize the full scientific names of the taxa in Figure 1).

Elymus elongatus (Host) Runemark subsp. *elongatus* (51) (Figures 1 and 3C) chose higher water vapor pressure values (Figure 5). This taxon was spread over the mild and humid Mediterranean (Marmara and Aegean) and Black Sea regions of Turkey. Basically, water vapor pressure is defined as a measurement of the amount of moisture in the air (Buck, 1981). Higher water vapor pressure values indicate hot and humid locations where relatively large numbers of water vapor molecules exists in the air (Buck, 1981). Supporting our results, it was reported that *E. elongatus* subsp. *elongatus* is found mainly around the Mediterranean Sea (Assadi, 1996) where higher water vapor pressure values are observed.

Elymus repens (L.) Gould (49), *Elymus hispidus* (Opiz) Melderis subsp. *podperae* (Nábelek) Melderis (50), and *Elymus caninus* (L.) L. (63) (Figures 1, 3B, and 3F) preferred higher latitudes (Figure 5). In Turkey, precipitation increases from south to north. This caused an increase in forest areas in northern parts of the country. Consequently, organic matter and nitrogen amounts of soil are higher in the northern sites of Turkey. The increase in the above-mentioned taxa from south to north could be related to this characteristic of the country. Supporting our findings, *E. repens* was reported as the worst worldwide weed (Melderis, 1980; Tsvelev, 1984) because of its wide phenotypic plasticity (Taylor and Aarssen, 1988). It was also reported that *Elymus* species are characterized as nitrophilous (Bockelmann and Neuhaus, 1999) with an increase in artificial atmospheric nitrogen depositions (Bakker et al., 1998).

Elymus elongatiformis (Drobow) Assadi (44), *Elymus hispidus* (Opiz) Melderis subsp. *barbulatus* (Schur) Melderis (46), *Agropyron cristatum* (L.) Gaertn subsp. *pectinatum* (M. Bieb.) Tzvelev var. *pectinatum* (47), *Hordeum brevisubulatum* (Trin.) Link subsp. *violaceum* (Boiss. & Hohen.) Tzvelev (53), *Elymus hispidus* (Opiz) Melderis subsp. *pulcherrimus* (Grossh.) Melderis (55), and *Psathyrostachys fragilis* subsp. *villosus* Baden (58) (Figures 1, 3C, and 3D) mainly chose higher longitudes (Figure 5), which means increasing mountainous and temperate grassland characteristics from west to east in Turkey. Verifying these results, the invasive character of *A. cristatum* subsp. *pectinatum* in dry rangelands was reported (Myers et al., 2004). The habitat of *P. fragilis* subsp.

villosus was described as calcareous and gypsum slopes at altitudes between 1450 and 2100 m (Baden, 1991; Cabi et al., 2011). It was also reported that *E. hispidus* subsp. *barbulatus* has a great xeromorphic adaptation, and thus it has the widest Euro-Asiatic distribution (Szczepaniak, 2009). Emphasizing the mountainous environment, *H. brevisubulatum* subsp. *violaceum* was reported as a Caucasian-Transcaucasian (Tsvelev, 1984) and Turkey/western Iran (Bothmer, 1996) taxon.

Hordeum bulbosum L. (43) and *Leymus cappadocicus* (Boiss. & Bal.) Melderis (59) (Figures 1, 3A, and 3E) preferred higher potential evapotranspiration (Figure 5), which may indicate drought resistance. Supporting our findings, it was reported that *H. bulbosum* is found in South Europe and the Mediterranean, and its habitat is defined as dry grassland (Humphries, 1980). The habitat of *L. cappadocicus* was described as salty dry steppes, slopes, roadsides, field margins, and altitudes between 454 and 1200 (Cabi and Doğan, 2010).

Elymus hispidus (Opiz) Meldernis subsp. *hispidus* (45), *Secale cereale* L. var. *cereale* (48), *Agropyron cristatum* (L.) Gaertner subsp. *incanum* (Nábelek) Melderis (60), *Secale ciliatoglume* (Boiss.) Grossh (73), and *Elymus nodosus* (Nevski) Meldernis subsp. *gypsicolus* Melderis (74) (Figures 1, 3A, 3B, and 3H) preferred higher distances to seas (Figure 5). Verifying our findings, the common feature of the habitats of these species was reported as high altitude mountain slopes (Hammer et al., 1987; Assadi, 1996; TÜBİVES, 2014), which means higher distances to seas.

Finally, *Elymus divaricatus* Drobow (52), *Agropyron cristatum* (L.) Gaertn. subsp. *pectinatum* (M.Bieb.) var. *imbricatum* (Roem. & Schult.) Beck (72), and *Elymus panormitanus* (Parl.) Tzvelev (64) (Figures 1, 3D, 3E, and 3H) chose high sunshine fractions (Figure 5). The absence of literature about this subject means further research is needed.

Taxa found in all three zones (ABC) with high frequency have the most adaptable or invading characteristics. Annuals with these characteristics comprise *Aegilops triuncialis* subsp. *triuncialis*, *Triticum baeoticum*, *Aegilops cylindrica*, *Aegilops biuncialis*, *Aegilops umbellulata*, *Aegilops neglecta*, *Dasypyrum villosum*, *Hordeum geniculatum*, *Aegilops columnaris*, *Secale cereale* var. *ancestrale*, and *Hordeum murinum* subsp. *glaucum*. Perennials within this group are *Hordeum bulbosum*, *Elymus hispidus* subsp. *hispidus*, *Secale cereale* var. *cereale*, and *Elymus repens* (Figure 1). Generally, these taxa prefer areas close to seas with high PET values (Figures 4 and 5). Considering Turkey's geographic position, there are many places that meet these criteria. This explains why these taxa are so common in Turkey.

However, taxa found in only one zone with low frequency have the most susceptible or selective characteristics. Annuals within these characteristics comprise *Secale sylvestre* (zone A), *Henrardia persica* var. *glaberrima* (zone B), *Eremopyrum triticeum* (zone B), *Triticum timopheevi* var. *araraticum* (zone C), *Aegilops comosa* subsp. *comosa* (zone C), and *Aegilops juvenalis* (zone C) (Figure 1). Preferences of these annual taxa could not explained by 14 environmental variables (Figures 4 and 5). Perennials in this group are *Agropyron cristatum* subsp. *pectinatum* var. *imbricatum* (zone A), *Secale ciliatoglume* (zone A), *Elymus nodosus* subsp. *gypsicolus* (zone A), and *Elymus libanoticus* (zone C) (Figure 1). The environmental preference of *A. cristatum* subsp. *pectinatum* var. *imbricatum* is sunshine fraction. *S. ciliatoglume* and *E. nodosus* subsp. *gypsicolus* prefer higher longitudes. The preference of *E. libanoticus* could not explained by 14 environmental variables (Figures 4 and 5).

In conclusion, the ecology of the Triticeae taxa was investigated in detail by GIS and an environmental database of Turkey. Habitat requirements of the taxa were investigated in a detailed manner for the first time in Turkey. In total 76 tribe Triticeae taxa were identified. *Aegilops triuncialis* L. subsp *triuncialis* (annual) and *Hordeum bulbosum* L. (perennial) were the most abundant and widespread taxa, while *Aegilops juvenalis* (Thell.) Eig (annual) and *Elymus libanoticus* (Hack.) Melderis (perennial) were the scarcest and most rarely distributed species. From an ecological point of view, the spatial distribution of the 12 annual taxa was mostly determined by potential evapotranspiration, elevation, distance to seas, maximum temperature, slope, and longitude. However, potential evapotranspiration, water vapor pressure, latitude, longitude, distance to seas, and sunshine fraction had the greatest effect on the spatial distribution of the 20 perennial taxa. The 14 environmental variables examined had no effect on the geographic distribution of the remaining 44 taxa. Other environmental variables may affect these taxa. This subject needs to be researched further. Finally, the taxa (*Secale sylvestre*, *Henrardia persica* var. *glaberrima*, *Eremopyrum triticeum*, *Triticum timopheevi* var. *araraticum*, *Aegilops comosa* subsp. *comosa, Aegilops juvenalis, Agropyron cristatum* subsp. *pectinatum* var. *imbricatum*, *Secale ciliatoglume*, *Elymus nodosus* subsp. *gypsicolus*, and *Elymus libanoticus*) found in only one zone with low frequency have the most susceptible or selective characteristics. These taxa are subject to conservation, and should be further researched with other possible environmental variables.

Acknowledgments
The authors thank the Scientific and Technological Research Council of Turkey for their grant (TÜBİTAK, Project No: TBAG-105T171), and herbaria of Ankara (ANK), Ege (EGE), Gazi (GAZI), Hacettepe (HUB), İstanbul (ISTF), and Fırat (FUH) universities, and the Royal Botanic Garden Edinburgh for their support.

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