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Diversity and degradation of the vegetation of mountain belt forests of central Adjara (the Lesser Caucasus), Georgia

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Abstract: The Colchis forests contribute to the biodiversity hotspot in the Caucasus eco-region. We investigated the plant diversity of these forests in the central part of Adjara (W Georgia). The aims of our study were (*i*) to differentiate the forest vegetation diversity in the mountain belt forests by means of phytosociology, (*ii*) to associate endemic taxa with the revealed forest types, and (*iii*) to assess degradation of the forest vegetation diversity by means of environmental abiotic and biotic factors. We sampled the forest vegetation on 135 plots with the size of 10×10 m^2 and 237 plant taxa were recorded. Principal Component Analysis (PCA) was used to reduce environmental variables to a few orthogonal composed variables. The derived factors (PC1, PC2) were used in ordination analysis to group the plot measured forest vegetation diversity. One-way ANOVA was used for the comparison of means between the separated clusters in PCA. Two-Way Indicator Species Analysis (TWINSPAN) and Indicator Species Analysis (ISA) were applied for the association of the plant taxa with the vegetation cluster groups separated by PCA. Our analysis revealed two general ecologically distinct forest types which were characterized as dry and humid forests. Endemic species had the main occurrence in dry forests of the studied territory which are heavily impacted by the local land use. The results indicated that the vegetation diversity of dry forests is under higher threat of degradation than that of humid ones because these forests are not protected and are subjected to non-sustainable forest exploitation. Additionally, many rural and invasive plant species change the native plant assemblages. Based on our findings, we recommend to the organization which manages the local forests to find a balance between the use of forest resources and protection of the unique floristic diversity of local forests in order to avoid their degradation.

Keywords: bioclimatic factors; indicator species; forest vegetation; diversity degradation; endemic plants; nature conservation

Deforestation and forest degradation belong among the biggest global environmental problems. The continuous deforestation throughout the world leads to a loss of many ecosystem services related to forests, e.g. timber and non-timber product provision, climate regulation through carbon sequestration, soil-erosion protection, biodiversity, and the stabilization of local multifunctional land-

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use systems (FAO 2011, 2018; IUCN 2017). Additionally, to the tropical and subtropical climate zones, deforestation and loss of the forest diversity are of growing concern in the world's mountainous regions. In Central Asia and the Caucasus region where almost half of the population lives in rural areas under socially vulnerable conditions, deforestation and forest degradation have been significantly intensified in the last few centuries (Akhalkatsi 2015; Zerbe et al. 2020). Where the use of forest resources and livestock agriculture are the major sources of income for the communities, the growing population is favouring further forest degradation (UNECE, FAO 2019).

With around 40% (6 970 000 ha), forests cover a larger area in Georgia. State forests cover about 3 M ha, out of which 2.3 M ha (76.4%) are available for the extraction of timber and other forest resources. In the recent period, about 23.65% of the local forests are classified as protected forests in Georgia, which is an alarming fact due to poor development of the forestry sector and mechanisms of the restoration of forest habitats in the country (Akhalkatsi 2015). For sustainable forest management and protection of forest resources, comprehensive knowledge of forest biodiversity is crucial. This has been proved for many countries in Europe by the respective ecological forest surveys (e.g. Leuschner, Ellenberg 2017). In Georgia, however, there is still a lack of the latest ecological forest surveys which should be the basis for the future sustainable forest management and could also serve as methodological blueprints for other Central Asian mountain areas.

The Caucasus is one of the most important world's ecoregions with a unique biological diversity (Davis, Heywood 1994; Myers et al. 2000; Olson, Dinerstein 2002). The westernmost part of Georgia, also known as Colchis, is a biodiversity hotspot located in the western Caucasus which shelters the relict flora of the Tertiary geological period (Zazanashvili et al. 2000; Nakhutsrishvili 2012). The Adjara-Shavsheti region is considered to be the southern geographical bound of the range of the particular Colchis forests (Ketzkhoveli 1959; Dolukhanov 2010; Nakhutsrishvili 2012) which stretch along the Black Sea coastline. The forest habitats occur from the lowlands up to about 2 400 m a.s.l. and cover almost 70% of the land of the Adjara region.

With regard to their vegetation, the Colchis forests were well studied in the period of the former Soviet Union, applying the then common phytocoenological methodologies and nomenclature (Grossheim 1936; Ketzkhoveli 1959; Dolukhanov 2010). Supraregional modern phytocoenological and phytogeographical approaches, however, are widely missing particularly for forests. According to the current European vegetation typology, the mountain belt forests in the Colchis constitute a particular altitudinal forest zone (Leuschner, Ellenberg 2017) with differentiation of the lower, middle and upper ranges in the southern Caucasus (Nakhutsrishvili 2012; Nakhutsrishvili, Abdaladze 2017). Up to present, data on forest vegetation diversity of the Adjara region is very limited, in particular as an important basis for phytogeography, biodiversity, and nature conservation management. To our knowledge, no study of degradation of the forest vegetation diversity in the Adjara region with regard to a decline of its unique occurrence of threatened and endemic species has been carried out yet and there are habitats of several rare and narrow endemic plant species. Some particular endemic species which are associated with the Colchis forests were only poorly studied (Manvelidze et al. 2009).

Accordingly, we focus on the forests of the mountain belt in the central part of Adjara. The aims of our study are (*i*) to differentiate the forest vegetation diversity in the mountain belt forests of the central Adjara by means of phytosociology, (*ii*) to associate endemic taxa with the revealed forest types, and (*iii*) to find the link between environmental factors and species richness and abundance of the invasive alien plants (IAPs) which are the indicators of degradation of the floristic diversity of the forest vegetation. From our results, we assess the threat of vegetation diversity decline in the Colchis forests and derive recommendations for nature conservation management.

MATERIAL AND METHODS

Study area. The surveyed mountain belt forests cover the territories of the municipalities of Keda, Shuakhevi, and Khulo in the central part of Adjara in west Georgia (Figure 1). The coordinates and descriptive data of the surveyed territory are shown in Table 1. The landscape is mountainous. However, a significant part is covered by the V-shaped valley of the Adjaristskali River gorge which forms a depression in the surroundings of the municipalities

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(A)

(B)

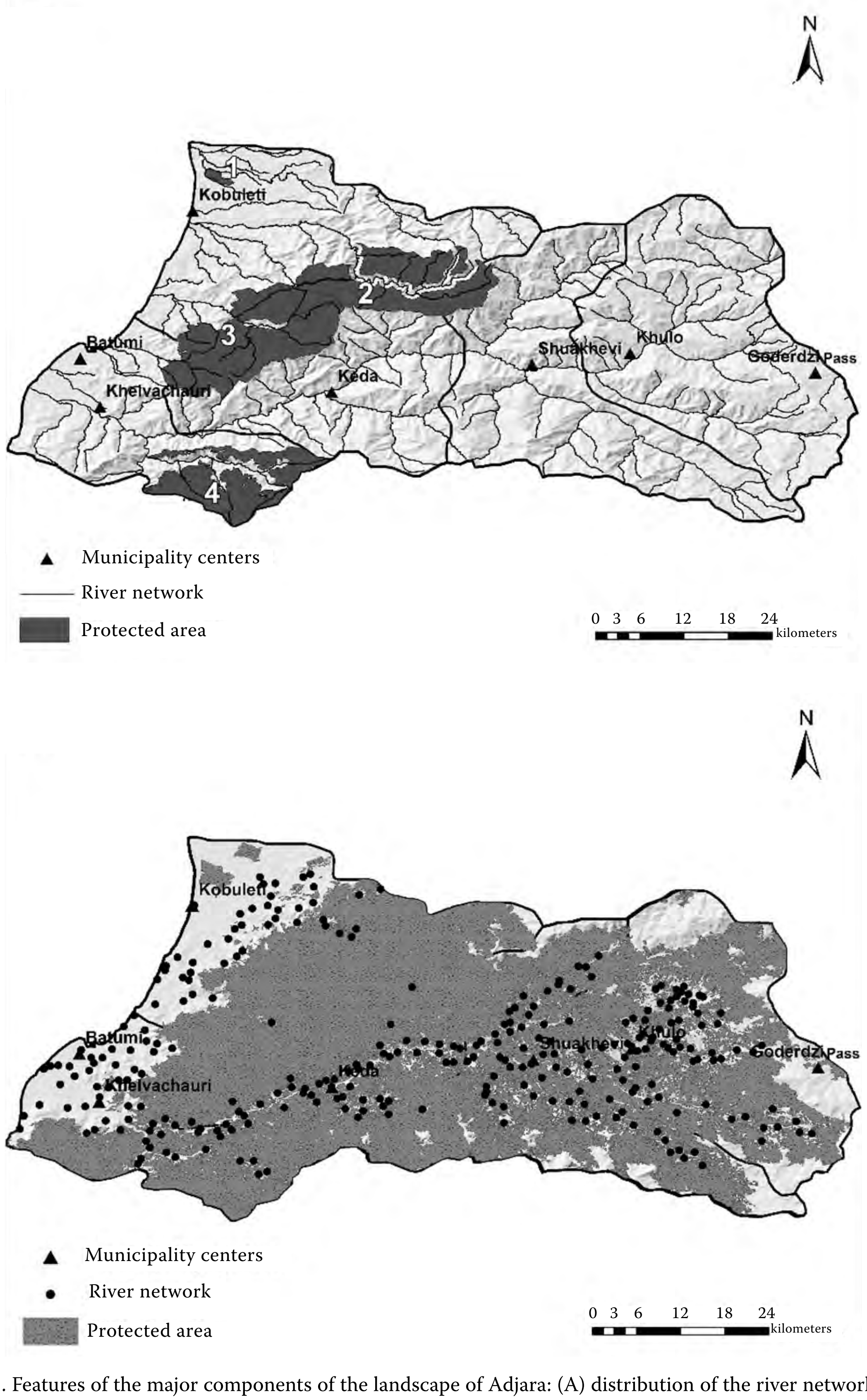

Figure 1. Features of the major components of the landscape of Adjara: (A) distribution of the river network and location of the protected areas: 1 – Kobuleti Managed Reserve; 2 – Kintrishi National Park; 3 – Mtirala National Park; 4 – Machakhele National Park; (B) distribution of the settlements and state forests

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Table 1. Description of the surveyed territory

Type of the surveyed forests	Municipality and site No.	Amount of the surveyed plots	Coordinates	Average distance	
				from the road verges	from the river beds
Mixed broadleaf forests with beech and chestnut and Pontic Rhododendron understory; Chestnut forest stands with shrub and herbaceous understory.	Keda No. 1	10	Lat.: 41.548004 Lon.: 41.74418 Alt.: 320	100 m vector/ 50 m altitudinal	100 m vector/ 50 m altitudinal
Mixed broadleaf and coniferous forest with beech, Oriental spruce and Pontic Rhododendron understory; Broadleaf forest with beech, common hornbeam and herbaceous understory; Mixed riparian forest with alder, hop-hornbeam, oriental spruce and herbaceous understory;	Keda No. 2	15	Lat.: 41.56978 Lon.: 41.97723 Alt.: 520	100 m vector/ 50 m altitudinal	50 m vector/ 20 m altitudinal
Mixed forests with pine, oriental hornbeam and herbaceous understory; Oak-pine forest stands with herbaceous understory; Riparian forest with alder, hazelnut, willow, hop-hornbeam and herbaceous understory.	Keda No. 3	15	Lat.: 41.54409 Lon.: 42.137613 Alt.: 1 295	150 m vector/ 70 m altitudinal	150 m vector/ 100 m altitudinal
Pine forests with *Cytisus ruthenicus* and herbaceous understory; Oak forest stands with salvia cistus and herbaceous understory; Broadleaf forest with beech, common hornbeam and herbaceous understory; Mixed riparian forest with alder, hop-hornbeam, oriental spruce and herbaceous understory.	Shuakhevi No. 4	20	Lat.: 41.64197 Lon.: 42.15655 Alt.: 650	100 m vector/ 50 m altitudinal	100 m vector/ 50 m altitudinal
Oak forest stands with shrub and herbaceous understory; Pine forest stands with herbaceous understory; Shrubbery with oriental hornbeam, Astragal species and herbaceous understory; Riparian forest with alder, hazelnut, willow, hop-hornbeam and herbaceous understory;	Shuakhevi No. 5	20	Lat.: 41.67274 Lon.: 42.01446 Alt.: 700	300 m vector/ 180 m altitudinal	100 m vector/ 50 m altitudinal
Mixed forests with beech and oriental spruce Mixed riparian forest with alder, hop-hornbeam, oriental spruce and herbaceous understory.	Shuakhevi-Khulo No. 6	20	Lat.: 41.5714 Lon.: 42.26381 Alt.: 810	200 m vector/ 120 m altitudinal	100 m vector/ 50 m altitudinal
Mixed forests with beech and oriental spruce Mixed riparian forest with alder, hop-hornbeam, oriental spruce and herbaceous understory; Fir and oriental spruce forest stands.	Khulo No. 7	20	Lat.: 41.67139 Lon.: 42.34855 Alt.: 1 100	200 m vector/ 120 m altitudinal	70 m vector/ 50 m altitudinal
Mixed forests with beech and oriental spruce Mixed riparian forest with alder, hop-hornbeam, oriental spruce and herbaceous understory.	Khulo No. 8	15	Lat.: 41.57312 Lon.: 42.36986 Alt.: 935	200 m vector/ 120 m altitudinal	120m vector/ 70 m altitudinal

Lat. – latitude; Lon. – longitude; Alt. – altitude

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of Keda and Shuakhevi. The territory of Adjara is considered as one of the wettest temperate regions in the northern hemisphere. The range of the mean annual precipitation from the lowlands to the high mountains is 1 800–2 800 mm, with a maximum over more than 4 000 mm on Mount Mtirala in the Black Sea coastal area and 4 500 mm at the highest altitudes of the Meskhetian mountain range (Kolakovsky 1961; Tabidze, Tskhovrebashvili 2000). In contrast, the central part of the region along the middle reaches of the Ajaristskali River is drier with a max. of 1 100 mm. The lowest precipitation is recorded in May with about 80 mm and the highest amount in December with about 190 mm. The mean annual temperature in the study area is 19.6 °C, with an average minimum of –1.7 °C (UNDP 2013).

River gorges in the central Adjara are composed of sandstones, Palaeocene-Low Eocene clay andesites and conglomerate sediments of the Quaternary geological period (Tabidze, Tskhovrebashvili 2000). On the foothills and mountain slopes, Eocene volcanic bedrocks (mainly andesites), marls, Palaeozoic granites and sandstone (flysch) are most frequent (Maruashvili 1964; Tskhovrebashvili 1978). Soils in the middle mountain belt of Adjara are represented by alluvial soils, yellow-brown forest soils, brown forest acid soils (umbric Cambisols) and brown forest podzolized soils (Maruashvili 1964; Urushadze 2013; Elizbarashvili et al. 2006).

The forests of our study site are characterized by various mixtures of oak, pine, beech, and chestnut. The riparian forests are considered azonal. The forests of the central part of Adjara which occur between the Adjara-Imereti and Adjara-Savsheti ranges, harbour unique habitats of mixed broadleaf-coniferous, broadleaf and mixed riparian forests. Evergreen and wintergreen shrub species are forming the forest understorey and floristic elements common to the semi-arid shrubbery and forests of the Middle East and eastern parts of Georgia. The state forests in the central part of Adjara are under equal anthropogenic impact. Low and moderately inclined slopes favour wood logging and livestock agriculture with vast pastures. Only a small part of forests is designated as protected area shown in Figure 1A (Davitadze 2013; UNDP 2013), which comprises the Kintrishi National Park (10 703 ha), Kintrishi Protected Landscape (3 190 ha), Mtirala National Park (15 806 ha), Machakhela National Park (8 733 ha), Kobuleti State Reserve (33 125 ha) and Kobuleti Managed Reserve (43 875 ha). For those forests not under a protection status, degradation has been reported due to the long-term anthropogenic impact (Ketzkhoveli 1959). The most densely populated area is situated within the range of the sub-mountain belt in Adjara (Figure 1B).

According to the latest forest survey, 92% of the forests are owned by the State of Georgia and up to 8% are in private ownership in Adjara (Todradze, Shavishvili 2018). More than two thirds of the landscape of this region are mountainous and 44% of the local landscapes is harsh due to a strong inclination of their slopes, which makes difficult to develop forest management strategies.

The vegetation of Adjara harbours 1 837 species of vascular plants which represent 742 genera and 160 families. There are 128 woody species with 57 tree and 71 shrub species. A total of 237 species are considered the exotic ones with 44 adventive, 11 invasive, 42 subspontaneous, 109 naturalized, and 31 feral species (Kolakovsky 1961; Dimitreewa 1990). The region is inhabited by 48 taxa of rare and endemic plants, out of which 26 occur in mountain forests (Manvelidze et al. 2009).

Mountain belt forests are distributed from 300 to 1 900 m a.s.l. in Adjara and they generally occupy its central part. These forests also occur in the other parts of the region, for example in the Chakvi mountain range located in the adjacent area of the Black Sea shore or in the valley of the Chirukhistskali River located in the southeastern part of the region. However, no oak-hornbeam, pure oak and especially pine stands occur there. The most probable reasons for this dissimilarity are: (*i*) the instant change in the hypsometric gradient within the short spatial ranges; (*ii*) strong influence of the seaside humidity on the microclimate of the Chakvi range. Mtirala Mountain (1 381 m a.s.l.) is a massif of the Chakvi mountain range, which is the most humid place in the Caucasus, where the maximum amount of annual precipitation reaches 4 000 mm; and (*iii*) the humidity produced by the river network in Adjara; this network is extremely rich and covers the entire region (Figure 1A). The humidity produced by the rivers must serve as an amplifying factor of the air and soil humidity limiting the distribution of several woody and herbaceous species in the microhabitats of the lowland and mountain belt forests.

Historical and ethnographic data (Braund, Nelson 1995; Asatiani, Janeliže 2009) explain that the central and lowland areas of Adjara have been the

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most populated in the region since the 7th century BC. These areas are the basic territories of the distribution of the mountain belt forests in Adjara which are densely populated also in the modern period (Figure 1B). Livestock farming is the major agricultural activity in the mountain areas of Adjara in the modern period. Wood is produced for the domestic use, however this resource is also the main source of the income for the local people who live in poverty.

Collection of field data. Vegetation sampling was conducted on 135 plots distributed on 8 sites of the sample collection. The size of the used experimental plots was 10 × 10 m^2, which fits the standard of the sampling of the diversity of degraded forests. The sampling was done in summer 2018, following the phytosociological methodology of Braun-Blanquet (1932). The spatial range of the sample distribution covered forests in the territories of the municipalities Keda, Shuakhevi and Khulo located in the valleys of the Shirukhistskali and Shuakhevistskali Rivers (Figure 2).Field sampling covered mountain belt forests within the altitudinal range from 170 to 1 170 m a.s.l. However, the basic number of the plots was concentrated in the range between 380 and 1 000 m a.s.l. (Figure 3).

For the statistical analysis, the abundance data according to Braun-Blanquet (1932) were converted into mean species cover (%) according to Peet and Roberts (2013). For each vegetation plot, species richness and evenness were calculated following Bonham (2013) and Magurran (2013). Site parameters recorded on the vegetation plots and methodology applied with references are provided in Table 2. The identification of the plant species followed the 'Flora of Adjara' Dimitreewa (1990) and checklists of the local flora Gagnidze et al. (2005) and Davlianidze et al. (2018). Information on habitat preferences of the plant species was derived from Dimitreewa (1990), Dolukhanov (2010), and Nakhutsrishvili (2012). Species nomenclature and validity of the taxonomic statuses of the plant taxa were verified using the online taxonomic database "The Plant List" (The Plant List, 2010).

Data analysis. Together with the topographic variables (Table 2), we also used 19 bioclimatic variables with 1 km^2 grid resolution to analyse the spatial variation of the vegetation distribution and diversity (Hijmans et al. 2005). The environmental variables were checked for multicollinearity by calculating pairwise correlations using PAST (Hammer et al. 2001). In each pair with a correlation higher than 0.8, one variable was excluded from follow-up analyses. As a result, 9 uncorrelated bioclimatic and plot-based environmental variables were included in our further analysis, i.e. altitude, aspect, slope inclination, soil type (qualitative variable), plot proximity to the road verges (m), riverbanks (m), and settlements; mean diurnal range of temperatures (BIO2), mean temperature of the driest quarter (BIO9), and annual precipitation (BIO12) were the remaining variables in the analysis.

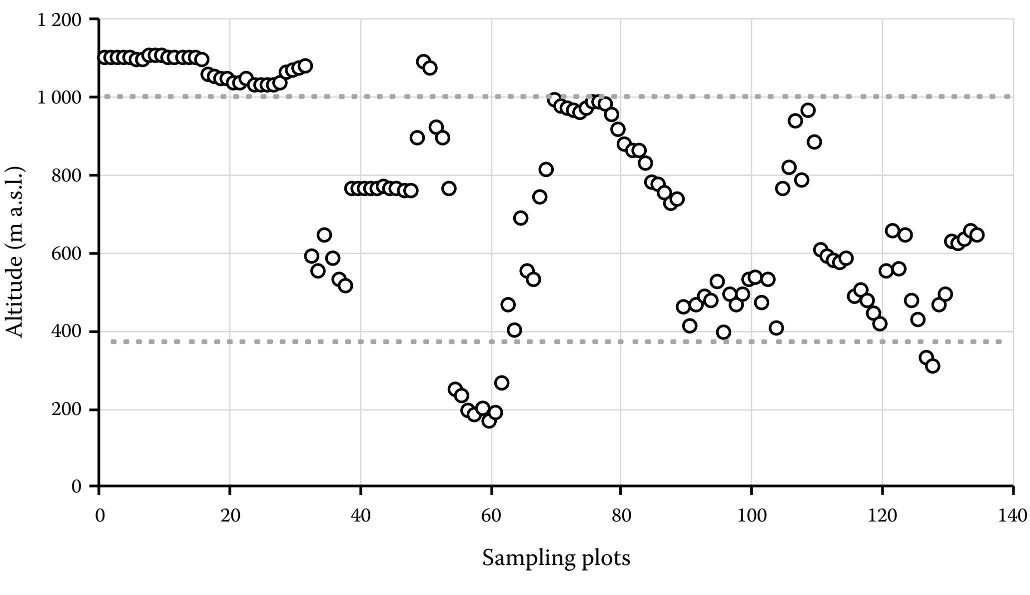

Figure 2. Distribution of sampling plots within the altitudinal range of the sampling area; the intermittent lines indicate the interval of the concentration of the main number of sampled plots

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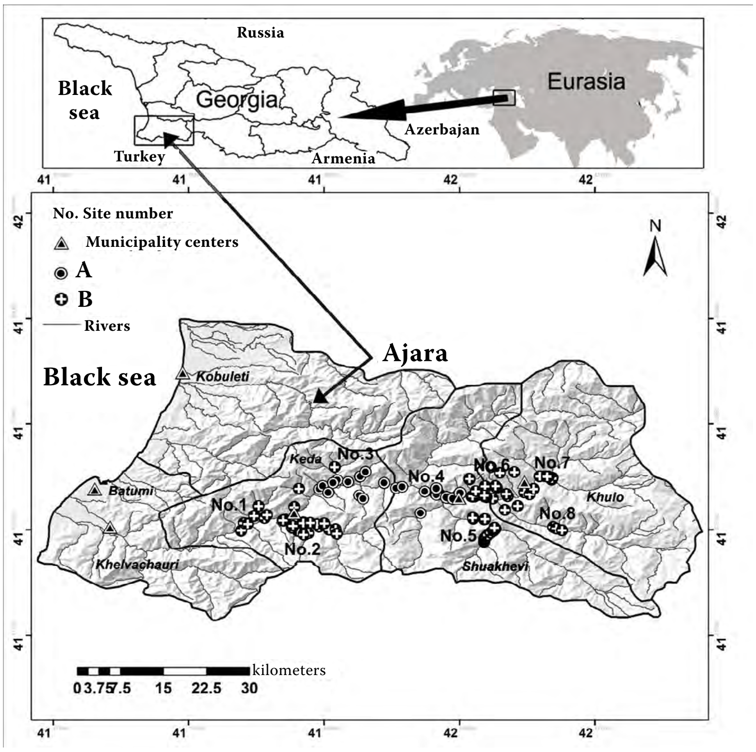

Figure 3. Distribution of vegetation sampling plots in the research area; the marks of the sampling plots provided on the map are related to the clusters separated by the Principal Component Analysis (PCA) (A – Cluster A, B – Cluster B; Figure 4)

We first performed the Principal Component Analysis (PCA) in order to reduce environmental variables to a few orthogonal composed variables. One-way analysis of variance (ANOVA) was applied to compare the mean values of environmental variables and features of the vegetation diversity between the cluster groups separated in PCA analysis. Similarity in plant diversity among cluster groups determined by PCA was estimated using the Jaccard similarity index and Sørensen-Dice coefficient of the diversity (Kent 2011; Magurran 2013). We performed Two-Way Indicator Species Analysis TWINSPAN (Hill 1979; McCune et al. 2002) to determine associations of the plant taxa with the clusters defined by PCA. The analysis followed the methodology of Lepš and Šmilauer (1999) and Dai et al. (2006).

Indicator Species Analysis (ISA) was used to define the relation of the rare and endemic taxa with the clusters determined by PCA. Species indicator values (IndVal) and significance of correlations of the species with cluster groups in ISA were calculated using a randomization test with bootstrap setting of 999 iterations. The analysis followed the methodology of Dufrêne and Legendre (1997) and De Cáceres and Legendre (2009). The analyses were conducted using the software PC-ORD v5 (McCune, Mefford 1999; Grandin 2006) and IBM SPSS Ver. 21 (SPSS 2012).

Extraction of the bioclimate variables for plot locations obtained from the WorldClim database (Fick, Hijmans 2017) and visualization of plot locations were done using the Quantum GIS software (QGIS Development Team 2018). Increased incidence and abundance of the rural and Invasive Alien Plant species (IAPs) were used as an indicator for the degradation of the forest plant diversity. The dependence of the plot measured vegetation characteristics on the proximity to the road verges, riverbanks and local settlements was determined based on the correlation coefficients and significance of these correlations evaluated by using the polynomial regression analysis.

The information about the distribution of rare and endemic plant taxa in the territories of the local forests was obtained from the literary sources. The assessment followed the floristic sources which provide general information on the distribution of the plant species in the territory of Adjara (Dimitreewa 1990) as well as the floristic and forestry sources providing the information specifically on

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Table 2. Site parameters recorded on the vegetation plots and methodology applied with references

Site parameter	Methodology	Reference
Elevation	data were recorded using a handheld GPS unit in metric system (m a.s.l.)	Bonham (2013)
Coordinates	data were recorded using a handheld GPS unit in format of decimal degrees	Bonham (2013)
Inclination	data were recorded using a handheld compass-clinometer in format of angle degrees	Bonham (2013)
Bioclimatic variables	BIO1 = annual mean temperature BIO2 = mean diurnal range [mean of monthly (max temp – min temp)] BIO3 = isothermality (BIO2/BIO7) (× 100) BIO4 = temperature seasonality (standard deviation × 100) BIO5 = max temperature of warmest month BIO6 = min temperature of coldest month BIO7 = temperature annual range (BIO5–BIO6) BIO8 = mean temperature of wettest quarter BIO9 = mean temperature of driest quarter BIO10 = mean temperature of warmest quarter BIO11 = mean temperature of coldest quarter BIO12 = annual precipitation BIO13 = precipitation of wettest month BIO14 = precipitation of driest month BIO15 = precipitation seasonality (coefficient of variation) BIO16 = precipitation of wettest quarter BIO17 = precipitation of driest quarter BIO18 = precipitation of warmest quarter BIO19 = precipitation of coldest quarter	Hijmans et al. (2005)
Distance variables	The proximity of sampling plots to road verges, settlements and river banks was measured cartographically as a real distance in meters. The distances were calculated using the algorithm of the proximity analysis in QGIS software.	Ahmed et al. (2018)
Soil and bedrock type	Data obtained from soil maps and literary sources were verified during field works	WRB (2006); Urushadze (2013); Urushadze and Kvrivishvili (2014)
Species occurrence	The pattern was defined on the basis of the registry of the taxa conducted in the field for each sampling plot	Elzinga and Salzer (1998); Bonham (2013)
Species abundance	Plot registered species were provided with descriptor values indicating the level of their abundance	Braun-Blanquet (1932); Peet and Roberts (2012)

the distribution of the endemic flora in Adjara (Memiadze 2005; Varshanidze et al. 2008; Manvelidze et al. 2009) or diversity which occurs in the territory of the protected areas located in Adjara (Davitadze 2013; Memiadze et al. 2013).

RESULTS

Vegetation diversity of the studied Colchis forest types. We identified a total of 267 species in the investigated forests. Mostly, the families Asteraceae, Fabaceae, Rosaceae, Lamiaceae, and Poaceae were represented, with more than 10 taxa in each family. The most frequent species that occur in more than 40 plots or 30% of all surveyed plots are the tree species *Picea orientalis*, *Carpinus betulus*, and *Fagus orientalis* in the various vegetation strata as well as the grass species *Brachypodium sylvaticum* and *Festuca drymeja*.

Four environment variables: altitude, annual precipitation (BIO12), plot proximity to the road verges and the river banks had the highest loadings on the PC1. The variables of the slope inclination and geographical aspect also had the highest loadings on the PC1. The eigenvalues of these factors were smaller than 0.7, which is the most acceptable level

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of power for factors to be included in the analysis. In spite of this, these factors were retained in the analysis due to their high (larger than 0.2) loadings on PC2, PC3 or PC4. Temperature factors: mean diurnal range of temperatures (BIO2) and mean temperature of the driest quarter (BIO9) were most important in case of PC2. The variable of the soil types had the highest loading on the PC2, however, coefficients of this variable were smaller than 0.7 on PC1, PC3, PC4 and greater principal components, which means that this factor had a much restricted influence on the ordination than the other factors (Table 3).

PCA ordination using PC1 and PC2 as environmental gradients separated the plot-based vegetation of the forest vegetation diversity into two groups (Figure 2). On the PCA plot, cluster A is significantly correlated with PC1 ($r = 0.99$; $P < 0.01$) and cluster B is correlated with PC2 ($r = 0.88$; $P < 0.01$). In PCA the first three PC with eigenvalues greater than 1 explained 85% of the spatial variation of sampled localities, with the first two accounting for 73.5%.

From the two cluster groups, differentiated by the PCA, cluster A comprises the riparian, beech-chestnut, and mixed broadleaf and coniferous forests. Cluster B is characterized by the oak, oak-hornbeam, and pine forests as well as shrub-dominated with the drought resistant plant species (Figure 4). The spatial distribution of the clusters in the study area is shown on the map of the distribution of the sampling plots in Figure 3. The results of ANOVA support the results of the PCA (Table 4) by indicating that the two forest types significantly differ in climate characteristics from each other. Also, species richness significantly differs in these two clusters. However, the herb cover and the Shannon index do not vary significantly between these cluster groups. The comparison of the floristic similarity of the two clusters of "dry" and "humid forest" types separated in the PCA showed that the value of the similarity between the compared clusters is 0.358 by the measure of the Jaccard similarity index and 0.524 by the Sørensen-Dice coefficient.

TWINSPAN categorized eight formations of forest vegetation and related them with two general

Table 3. The results of Principal Component Analysis (PCA) for the climate and topographic variables: variances and eigenvalues of the PC axes are provided in the section A and eigenvectors of the variables are provided in section B

A – variances				
Axis	eigenvalue	% of variance	cum. % of variance	broken-stick eigenvalue
PC1	3.453	54.842	54.842	2.463
PC2	1.402	18.681	73.523	1.463
PC3	1.035	11.783	85.306	0.963
PC4	0.52	10.01	95.316	0.63
PC5	0.297	3.504	98.82	0.38
PC6	0.107	1.055	99.875	0.18
PC7	0.011	0.125	100	0.013
B – eigenvector				
Variable	PC1	PC2	PC3	PC4
Altitude	0.837	–0.124	–0.089	0.017
Soil type	0.034	0.573	–0.167	0.045
BIO2	0.143	–0.749	0.445	–0.505
BIO9	0.133	–0.762	0.061	0.4
BIO12	0.989	0.05	0.025	0.072
Slope inclination	0.399	–0.21	–0.386	0.112
Geographical aspect	0.57	–0.35	0.106	–0.38
Plot proximity to the road verges	0.889	–0.121	0.443	0.22
Plot proximity to the river beds	0.682	0.032	0.008	0.07

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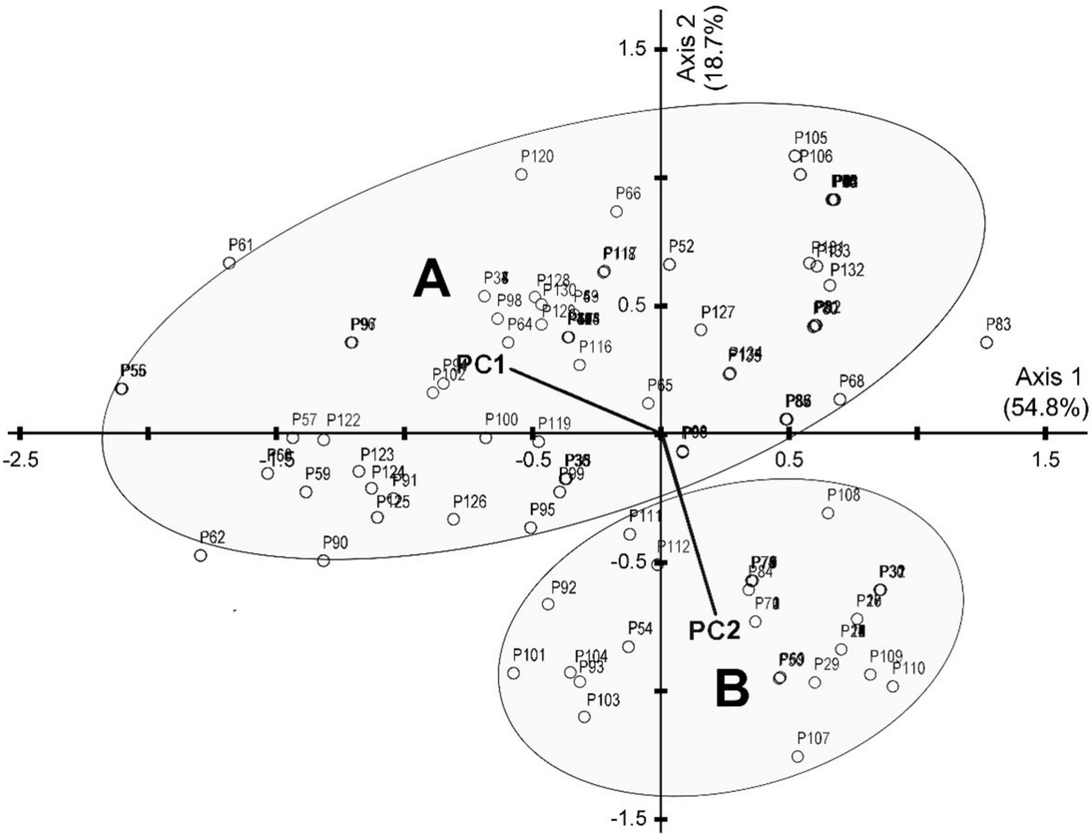

Figure 4. Results of Principal Component Analysis (PCA) ordination of sampled plots with environmental factors; Cluster A – forest vegetation diversity correlated with high atmospheric humidity and relatively low temperatures; Cluster B – forest vegetation diversity correlated with dry climate and high temperature regime

types of forests. The results of this analysis placed 88 experimental plots in cluster A and 47 in cluster B in the first division by giving the high eigenvalues (EVD) to the cluster groups (cluster A, EVD = 1.6; cluster B, EVD = 1.44). In the 2nd division, cluster A was divided into subclusters A1 containing 61 plots (EVD = 0.91) and A2 containing 23 plots (EVD = 0.78). In the 2nd division, cluster B was divided into subcluster B1 containing 30 plots (EVD = 0.85) and B2 containing 17 plots (EVD = 0.71). The 3rd division of TWINSPAN grouped a smaller amount of the forest vegetation diversity (27 plots in A1.1 and 18 plots in A2.2; 12 plots in B1.1 and 17 plots in B2.2) and removed the rest of possible associations of the plot measured vegetation diversity with lower power of EVD than 0.5 from the results. The clusters of each division are subgroups of the previous clusters. The cluster groups of the lower division grades share dominant species from the clusters of the previous divisions. Each of the next steps of the division relates new taxa to the most common species in the indicated major forest types. Based on the binary rule of the division, each major forest type is divided into 4 binary subclusters. The maximum number of the indicator species included in each cluster is five (Figure 5).

Table 5 provides the taxonomic identity of the plants included in the clusters of TWINSPAN as key species of the basic type of the forests (cluster A1, B1) and forest formations (conditional subclusters of the cluster A and B) associated with these clusters (Table 5).

Based on the association patterns to the cluster groups and ecological characteristics of the species included in the clusters, it is obvious that cluster A holds the vegetation diversity of the humid ecological type of forest formations and cluster B holds the meso-thermophilous forests and xerophilous shrub vegetation. For the visual simplification of the results, there are some common species shared by both clusters (*F. orientalis*, *C. betulus*, *Conyza canadensis* (L.) Cronquist and *Phytolacca americana* L.).

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Table 4. Results of ANOVA showing the variability of the environmental and vegetation diversity features between the cluster groups separated by the Principal Component Analysis (PCA) (Figure 4)

Features	Variance	Sum of squares	*df*	Mean square	*F*	Sig.
Altitude (m a.s.l.)	between groups (combined)	11 612.68	1	11 612.68	36.823	0.001
	within groups	81 312.22	95	873.68		
	total	92 924.9	96			
Soil type	between groups (combined)	37 241.35	1	37 241.35	23.978	0.028
	within groups	889 174.3	95	9 359.729		
	total	926 415.65	96			
Geographical aspect (°)	between groups (combined)	24 649.22	1	24 649.22	10.245	0.082
	within groups	23 411.36	95	668.283		
	total	48 060.58	96			
Slope inclination (°)	between groups (combined)	128.2	1	128.2	4.671	0.186
	within groups	126	95	22.732		
	total	254.2	96			
Species richness	between groups (combined)	1 872.86	1	1 872.86	29.512	0.001
	within groups	6 028.64	95	63.45		
	total	7 901.5052	96			
Shannon index	between groups (combined)	0.071	1	0.071	8.144	0.175
	within groups	0.835	95	0.008		
	total	0.907	96			
Plot cover (%)	between groups (combined)	163.93	1	163.93	0.722	0.397
	within groups	21 570.08	95	227.05		
	total	21 734.02	96			
Mean diurnal range of *t* °C (BIO2)	between groups (combined)	326.98	1	326.98	32.28	0.001
	within groups	962.3	95	10.12		
	total	1 289.27	96			
Mean *t* °C of driest quarter (BIO9)	between groups (combined)	28 885.64	1	28 885.64	37.061	0.001
	within groups	74 042.72	95	779.39		
	total	102 928.37	96			
Annual Precipitation (mm) [BIO12]	between groups (combined)	478 061.02	1	478 061.01	23.178	0.001
	within groups	1 959 356.2	95	20 624.8		
	total	2 437 417.3	96			
Plot proximity to the road verges (m)	between groups (combined)	0.8753	1	0.8753	10.344	0.001
	within groups	0.6402	95	0.6402		
	total	1.5155	96			
Plot proximity to the river banks (m)	between groups (combined)	1.3221	1	1.3221	8.645	0.033
	within groups	0.8756	95	0.8756		
	total	2.1977	96			

t – temperature; *df* – degree of freedom; *F* – Fisher's *F* ratio; Sig. – significance

Linkage of endemic plants with forest types and vegetation diversity. The results of the ISA related 12 taxa of the rare and endemic plants to the vegetation of the dry forest type and 9 taxa to the vegetation of the humid forests are shown in Table 6.

The results of the correlation analysis which determines the dependence of the distribution of vegetation diversity on the altitude and proximity of the plots to the road verges, river gorges and settlements are provided in Table 7.

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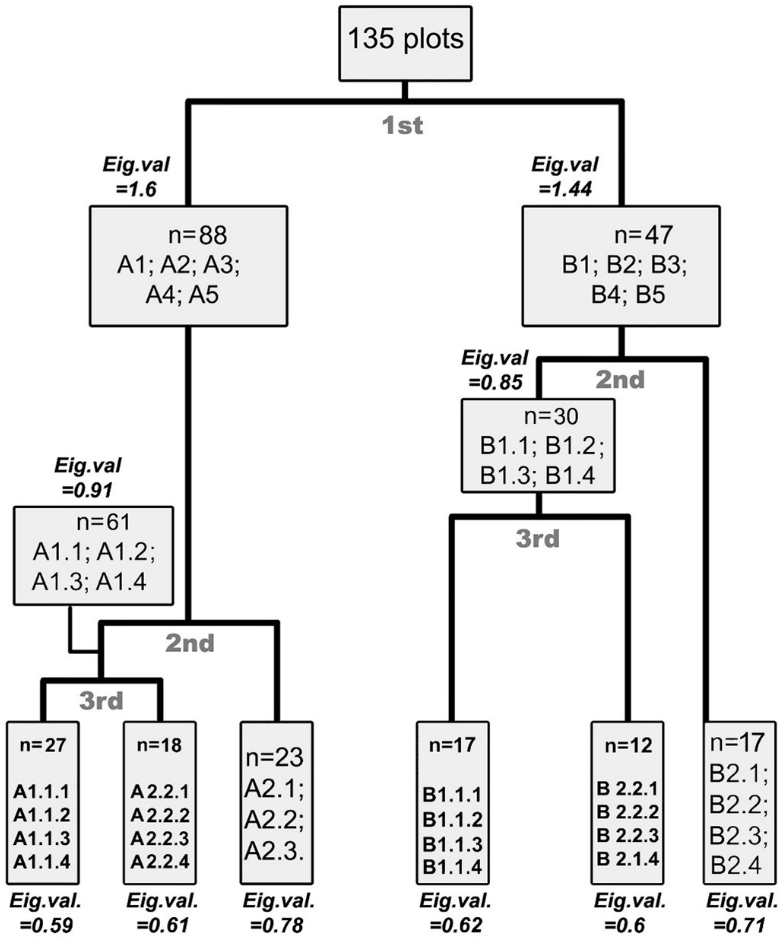

Figure 5. Results of TWINSPAN; the graph provides the order number of cluster divisions and eigenvalues of each cluster group; *n* – the number of plots out of the total of 135 plots included in the analysis in which the clustered taxa occur

The results of the correlation analysis show that the richness and Shannon index of vegetation diversity decrease with the increase of the altitudinal range in the sampled territory. A similar pattern is shown by the richness and abundance evaluated separately for the rural IAPs. Proximity of the sampling plots to the road verges decreases the richness and abundance of most taxa except the IAPs. Vegetation cover, species richness and Shannon index get lower in the sampling plots evaluated in the riparian habitats. In general, rural and IAP species have a significant share in the total plant diversity of the sampled plots as there is a significant positive correlation between the increase of the richness and Shannon index of the rural and IAP species and the same parameters for the entire diversity in the sampling plots. There is a weak negative relation to the proximity of the sampling plots to the road verges and the richness and Shannon index of the endemic plant species.

Abiotic site parameters and their relation to species and vegetation. The distribution of vegetation diversity is also dependent on the mean temperature of the driest quarter (BIO9) and annual precipitation (BIO12) which are in extremely high correlation with the altitude (BIO9 vs. altitude: $R^2 = -0.82$; $P < 0.001$; BIO12 vs. altitude: $R^2 = 0.56$; $P < 0.001$). Shannon index and the total species richness measured in the plot is in positive relation to the increase of the mean temperature of the driest quarter (Shannon index vs. BIO9: $R^2 = 0.58$; $P < 0.03$; species richness vs. BIO9: $R^2 = 0.63$; $P < 0.03$); The richness and Shannon index of the rural and IAP species are in positive relation to the increase of the mean temperature of the driest quarter (Shannon index vs. BIO9: $R^2 = 0.46$; $P < 0.03$; species richness vs. BIO9: $R^2 = 0.55$; $P < 0.03$) and negative relation to the increase of the annual precipitation (Shannon index vs. BIO9: $R^2 = -0.38$; $P < 0.03$; species richness vs. BIO9: $R^2 = -0.46$; $P < 0.03$). There is a weak, but significant positive relation between the increase of the annual precipitation and Shannon index of the endemic plant species ($R^2 = 0.54$; $P < 0.03$).

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DISCUSSION

Differentiation of forest vegetation types. The latest classification of the forests of Adjara (Manvelidze 2009) separates eight major habitat types within the forest belt of the region. In Adjara, the altitudinal range between zero and 25 (30) m a.s.l. is covered by the Black Sea coastal vegetation, including the habitats of sea cliffs and shingle or stony beaches; salt and gypsum inland steppes and coastal sand dunes (Manvelidze 2009; Akhalkatsi, Tarkhnishvili 2012). The forest belt starts at an altitude of 25 m a.s.l. and includes the following habitats:

Colchis type of the mixed lowland broadleaf forests [with *Fagus orientalis* Lipsky, *Alnus glutinosa* subsp. *barbata* (C.A.Mey.) Yalt., *Castanea sativa* Mill., *Carpinus betulus* L., *Ostrya carpinifolia* Scop., *Pterocarya pterocarpa* Kunth ex I. Iljinsk., *Tilia rubra* subsp. *caucasica* (Rupr.) V. Engl., *Corylus avellana* L.] (25–500 m a.s.l.);
Oak forests [*Quercus petraea* subsp. *iberica* (Steven ex M. Bieb.) Krassiln; syn. *Q. dshorochensis* K. Koch]; *Q. hartwissiana* Steven (300–800 m a.s.l.);
Pine (*Pinus sylvestris* var. *hamata* Steven [syn. *P. sosnowskyi* Nakai]) forest stands (280–600 m a.s.l.);
Chestnut (*C. sativa*) forest stands (450–1 100 m a.s.l.);

Table 5. Plant taxa and groups associated with the clusters separated by TWINSPAN (Figure 5)

Cluster A			
A1	*Quercus hartwissiana* Steven		
A2	*Festuca drymeja* Mert. & W.D.J. Koch.		
A3	*Carpinus orientalis* Mill.		
A4	*Fraxinus excelsior* L.		
A5	*Robinia pseudoacacia* L.		
A1.1	*Cornus sanguinea* subsp. *australis* (C.A.Mey.) Jáv. (syn *Swida australis* (C.A. Mey.) Pojark. ex Grossh.)	A2.1	*Pinus sylvestris* var. *hamata* Steven
A1.2	*Galium odoratum* (L.) Scop.	A2.2	*Chamaecytisus hirsutus* (L.) Link
A1.3	*Ambrosia artemisiifolia* L.	A2.3	*Cistus salviifolius* L.
A1.4	*Ulmus glabra* Huds.		
A1.1.1	*Quercus petraea* subsp. *iberica* (Steven ex M.Bieb.) Krassiln. (syn. *Q. dshorochensis* K.Koch)	A1.2.1	*Juniperus oxycedrus* L. (syn. J. *rufescens* Link)
A1.1.2	*Cirsium imereticum* Boiss.	A.1.2.2	*Astragalus sommieri* Freyn; L.
A1.1.3	*Rubus hirtus* Waldst. & Kit.	A1.2.3	*Rhus coriaria* L.
A1.1.4	*Osmanthus decorus* (Boiss. & Balansa) Kasapligil.	A1.2.4	*Ailanthus altissima* (Mill.) Swingle
Cluster B			
B1	*Picea orientalis* (L.) Link		
B2	*Fagus orientalis* Lipsky		
B3	*Rhododendron ponticum* L.		
B4	*Athyrium filix-femina* (L.) Roth.		
B5	*Circaea lutetiana* L.		
B1.1	*Vaccinium arctostaphylos* L.	B2.1	*Alnus glutinosa* subsp. *barbata* (C.A.Mey.) Yalt.
B1.2	*Clinopodium umbrosum* (M. Bieb.) K. Koch	B2.2	*Erigeron orientalis* Boiss.
B1.3	*Prunus laurocerasus* L.	B2.3	*Salix excelsa* S.G. Gmel.
B1.4	*Fragaria vesca* L.	B2.4	*Oplismenus undulatifolius* (Ard.) P. Beauv.
B1.1.1	*Sanicula europaea* L.	B2.2.1	*Ostrya carpinifolia* Scop.
B1.1.2	*Geranium robertianum* L.	B2.2.2	*Taxus baccata* L.
B1.1.3	*Abies nordmanniana* (Steven) Spach	B2.2.3	*Castanea sativa* Mill.
B1.1.4	*Primula vulgaris* subsp. *rubra* (Sm.) Arcang. (syn. *P. sibthropii* Hoff.)	B2.2.4	*Prunella vulgaris* L.

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Table 6. Results of Indicator Species Analysis (ISA); the table provides individual values relating the species to the specific habitats and the significance of this relation determined on the basis of the permutation test

Species	Beech and chestnut forests		Oak & oak-hornbeam forests		Pine forest		Xerophilous shrubbery		Mixed type of Colchis forests		Riparian habitats	
	IndVal (%)	$P \leq$	IndVal (%)	$P \leq$	IndVal (%)	$P \leq$	IndVal (%)	$P \leq$	IndVal (%)	$P \leq$	IndVal (%)	$P \leq$
Cluster A – humid forests												
Alnus glutinosa **subsp. *barbata*** (C.A.Mey.) Yalt.	–	–	–	–	–	–	–	–	–	–	73.5	0.001
Angelica adzharica Pimenov	76.8	0.042	–	–	–	–	–	–	–	–	–	–
Campanula pontica Albov	68.2	0.03	–	–	–	–	–	–	–	–	–	–
Convolvulus pseudoscammonia C. Koch	–	–	–	–	–	–	–	–	86.8	0.001	–	–
Gadellia lactiflora (M. Bieb.) Schulkina (= *Campanula lactiflora* M.Bieb.)	–	–	–	–	–	–	–	–	63.2	0.03	–	–
Galanthus krasnovii A.P. Khokhr.	–	–	–	–	–	–	–	–	–	–	87.2	0.001
G. woronowii Losinsk.	–	–	–	–	–	–	–	–	–	–	78.3	0.001
Linaria genistifolia (L.) Mill. subsp. *artvinensis* P.H. Davis	–	–	–	–	–	–	–	–	62	0.03	–	–
Verbascum adzharicum P.P.Gritz.	–	–	–	–	–	–	–	–	–	–	83.2	0.001
Cluster B – dry forests												
Arbutus andrachne L.	–	–	77.3	0.024	–	–	–	–	–	–	–	–
Astragalus imbricatus Boriss.	–	–	–	–	–	–	89.7	0.001	–	–	–	–
Astragalus adzharicus Popov	–	–	–	–	–	–	84.3	0.001	–	–	–	–
Astragalus sommieri Freyn	–	–	–	–	–	–	76.2	0.001	–	–	–	–
Centaurea dimitriewae Sosn. (= *Psephellus dimitriewae* (Sosn.) Greuter)	–	–	78.2	0.001	–	–	80.8	0.001	–	–	–	–
Chesneya ***elegans*** Fomine	–	–	–	–	74.7	0.001	–	–	–	–	–	–
Dianthus ketzkhovelii Makaschv.	–	–	–	–	–	–	68.5	0.002	–	–	–	–
Galium subuliferum Sommier & Levier	–	–	–	–	–	–	82.8	0.001	–	–	–	–
Genista adzharica Popov (= *G. suanica* Schischkin)	–	–	62.3	0.03	–	–	–	–	–	–	–	–
Origanum rotundifolium Boiss.	–	–	–	–	62.4	0.001	–	–	–	–	–	–
Osmanthus decorus (Boiss. & Balansa) Kasapligil	–	–	77.5	0.03	–	–	–	–	–	–	–	–
Quercus hartwissiana Steven	–	–	67.5	0.03	–	–	–	–	–	–	–	–
Arbutus andrachne L.	–	–	77.3	0.024	–	–	–	–	–	–	–	–

IndVal – Indicator Value; *P* – significance

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Table 7. Dependence of the features of vegetation diversity on the altitude and topographic factors

	Alt	Pr_Ro	Pr_Ri	Pr_Set	Cov	T_Sp.R	T_H'	RIAPs_R	RIAPs_H'	R_Sp.R	R_H'
Alt	1										
Pr_Ro	–0.48*	1									
Pr_Ri	0.05	0.36	1								
Pr_Set	–0.06	0.2	0.03	1							
Cov	0.12	–0.07	–0.36*	–0.14	1						
T_Sp.R	–0.68**	–0.49*	–0.45*	–0.01	0.51*	1					
T_H'	–0.71**	–0.57**	–0.52**	0.04	0.17	0.93**	1				
RIAPs_R	– 0.63**	0.37*	0.14	0.01	0.33*	0.56**	0.53**	1			
RIAPs_H'	– 0.54*	0.42*	0.16	–0.04	0.3*	0.58**	0.56**	0.94**	1		
R_Sp.R	–0.25	–0.36*	–0.07	–0.09	–0.09	0.3*	0.26	0.16	0.17	1	
R_H'	–0.21	–0.38*	–0.08	–0.09	–0.04	0.32*	0.17	0.13	0.14	0.94**	1

Alt – Altitude (m a.s.l.); Pr_Ro – proximity to road verges; Pr_Ri – proximity to river banks; Pr_Set – proximity to settlements; Cov – vegetation cover in the plot (%); T_Sp.R – total species (taxonomic) richness indicated in the sampling plots; T_H' – Shannon index of diversity measured by the number of all species registered in the plots; RIAPs_R – species richness calculated for the rural and IAP species; RIAPs_H' – Shannon index calculated for the rural and IAP species; R_Sp.R – species richness calculated for the short-ranged (endemic) species; R_H' – Shannon index calculated for short-ranged species; **significant at the 0.001 level; *significant at the 0.03 level

Beech (*F. orientalis*) forest stands (1 100–1 950 m a.s.l.);

The mixed broadleaf-coniferous forests (*Picea orientalis* (L.) Peterm., *F. orientalis*, *Carpinus orientalis* Mill., *Acer campestre* L. etc.) which are distributed from 300 to 1 600 m a.s.l. on northern slopes and from 500 to 1 500 m a.s.l. on southern slopes;

Spruce-fir (*P. orientalis*, *A. nordmanniana*) forests (1 550–2 100 m a.s.l.);

Krummholz or "crooked wood" forest (*F. orientalis*, *Quercus pontica* K. Koch, *Betula litwinowii* Doluch., *Rhododendron ponticum* L.), which is distributed from 2 200 m a.s.l. and forms a tree line at 2 350 (2 370) m a.s.l.;

Subalpine shrubbery (*Salix caprea* L., *Betula medwedewii* Regel, *Vaccinium myrtillus* L., *Rhododendron caucasicum* Sims, *Daphne mezereum* L., *D. pontica* subsp. *haematocarpa* Woronow [syn. *D. albowiana* Woronow ex Pobed]), which is frequently scattered in the Krummholz forest, which occurs at 2 200 m a.s.l. and reaches 2 400 m a.s.l. at the highest altitudes of its distribution.

The mountain belt forests are followed by subalpine (2 000–2 400 m a.s.l.) and alpine (2 400–2 700) belts. The highest peak in Adjara is Mt. Kanli (3 007 m a.s.l.) located on the Arsiani range. The vegetation is poorly developed on the top of this mountain (between 2 700 and 3 007 m a.s.l.) due to the domination of scree and bare rock substrates in its landscape.

Our study is in compliance with this classification and with a study authored by Khokhriakov (1991) which identifies several meso-xerophytic species in the sub-mountain forests of Adjara; however these studies provide only descriptive information supported by the phytocoenological data and they lack the explanation of the reasons for the occurrence of ecologically different forest types in Adjara. Our study explains this phenomenon by showing its dependence on the bioclimatic features of the studied locality. The level of uniqueness of the indigenous vegetation diversity of the studied dry and humid type of forests is significantly high as the similarity of floristic diversity of these forests equals only 35.8% by the measure of the Jaccard similarity index (0.358) and 52.4% by the Sørensen-Dice coefficient (0.524) as it is shown in the study results.

The dry microclimate is an environmental feature which occurs specifically in the lower altitudinal range of the mountain belt forests in the central part of Adjara. The second group of the forest vegetation interpreted as the cluster of the dry forests in the results of TWINSPAN (Table 5, Cluster B) includes the plant taxa registered in this area. Some of the key taxa such as *C. orientalis*, *C. sanguinea*

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subsp. *australis*, *F. excelsior*, *U. glabra*, *R. hirtus*, and *F. drymeja* are the components of the xerophilous oak-hornbeam forests; *J. oxycedrus* is one of the major components of the juniper communities and open woodlands and *P. sylvestris* var. *hamata*, *Ch. hirsutus* and *C. salviifolius* are the components of the pine forests which are commonly distributed in the semiarid zone of the eastern part of Georgia (Dolukhanov 2010; Nakhutsrishvili 2012). However, the short-ranged species such as *Q. hartwissiana*, *O. decorus*, *A. sommieri*, *C. imereticum* related to the cluster of the dry forest formations as the key species in the results of TWINSPAN and the other short-ranged endemic taxa associated with this cluster in the results of the ISA (Table 6), which are specific to Colchis type of forests, indicate that the composition of the formations of dry forests of the central part of Adjara and the semiarid zone of eastern Georgia significantly differs from each other.

The other group separated by TWINSPAN interpreted as the cluster of humid forests includes the floristic diversity which is specific mostly to the Colchis type of mixed broadleaf and coniferous forests (Kolakovsky 1961; Manvelidze 2009; Dolukhanov 2010). These forests are widely distributed in western Georgia and occur in the mountain areas between the altitudes of 300–1 200 m a.s.l. Altitudinal range and species composition of the vegetation of such forests is different in the Lesser and Greater Caucasus mountains due to the differences in climate and the shared species from the neighbouring regions. One of the determinants of uniqueness of this type of forests in Adjara is the distribution of the large populations of chestnut (*C. sativa*), hop-hornbeam (*O. carpinifolia*) and yew (*T. baccata*), which form the forest stands separately or mix with the beech (*F. orientalis*) stands within their range of distribution. These species are protected by the Red List of Georgia (Government of Georgia, 2018) because of the fragmented range in both western and eastern parts of the country.

The existence of the difference in the microclimate between the forest types separated in the PCA and TWINSPAN is supported by the climate characteristics displayed on the climate diagrams of the municipalities of Adjara (Figure 6). The locations of the municipalities form an altitudinal transect which crosses the entire range of forests in central Adjara. The last diagram in the Figure displays the averaged data of the mean annual precipitation and temperatures for the locations of the municipalities included in the transect which crosses the forested area of Adjara. This diagram explains the existence of the dry zone in central Adjara which is located within the altitudinal ranges of 200–500 m a.s.l. between the municipalities of Keda and Shuakhevi. We consider that the key species of the dry type of forests are associated with the landscapes situated within the mentioned altitudinal range as the amount of atmospheric precipitation significantly grows beyond this dry zone, along both higher and lower diapasons of the altitudinal gradients.

The soil type showed a strong power in the separation of forest vegetation diversity in the results of PCA (Table 3) and ANOVA (Table 4). The ecological type of dry forests included in cluster B of the PCA and TWINSPAN analyses (Tables 3 and 5) occurs principally on the yellow-brown forest soils which occupy the landscape of the valleys of the Chirukhistskali and Shuakhevistskaly Rivers at the lower altitudes of 150–800 m a.s.l. The humid forests included in cluster A occupy larger areas in the central part of Adjara and are distributed on diverse types of soils, including yellow-brown forest, brown forest acid and brown forest podzolized soils.

Geographical aspect and slope inclination were included as influential factors in the differentiation of the vegetation types in PCA (Table 3), however, the results of ANOVA (Table 4) indicated their insignificance. Some of the key taxa included in the clusters of TWINSPAN such as *Q. hartwissiana*, *Q. petraea* subsp. *iberica*, *P. sylvestris* var. *hamata*, *R. pseudoacacia* (Table 5) are related to the south exposed slopes with their distribution (Dimitreewa 1990; Manvelidze 2009). Most of the taxa included in the TWINSPAN clusters are not related to the specific geographical aspect with a pattern of their distribution, which explains the low power of this factor in the separation of the overall diversity of forests occurring on the study site. Similarly like the geographical aspect, the slope inclination also shows a low power in the differentiation of forest types or specific formations of the forest vegetation because of the relatively smaller variability of this factor in the study area than it is in the higher mountain areas of Adjara and absence of the abundant plant taxa associated with a specific inclination of the slopes.

Factors of degradation of vegetation diversity of local forests. The results of TWINSPAN identified IAP species as a key component of both separated forest types. *R. pseudoacacia*, *Ambrosia arte-*

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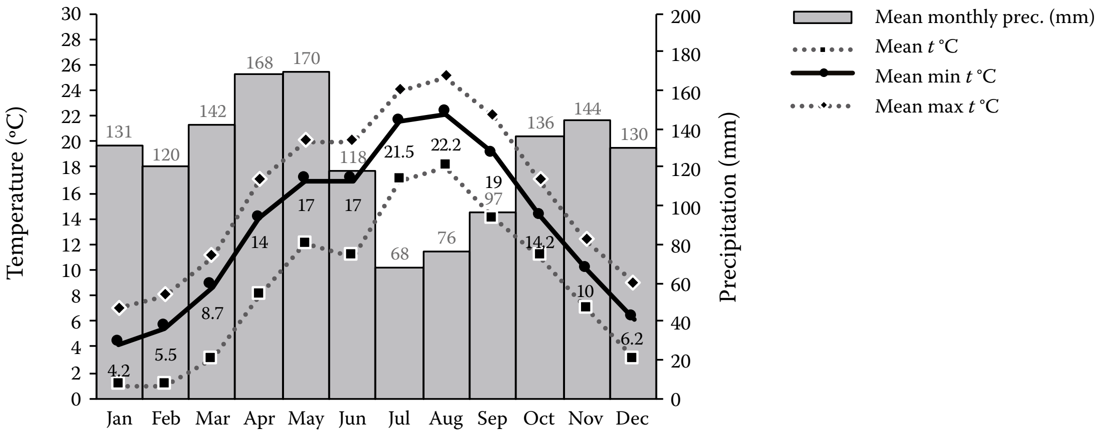
(A)



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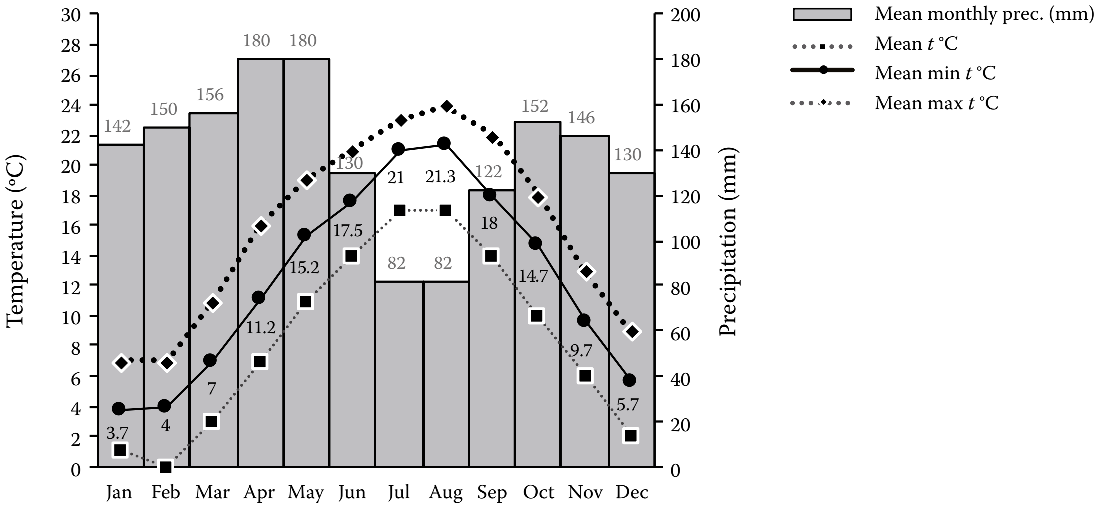

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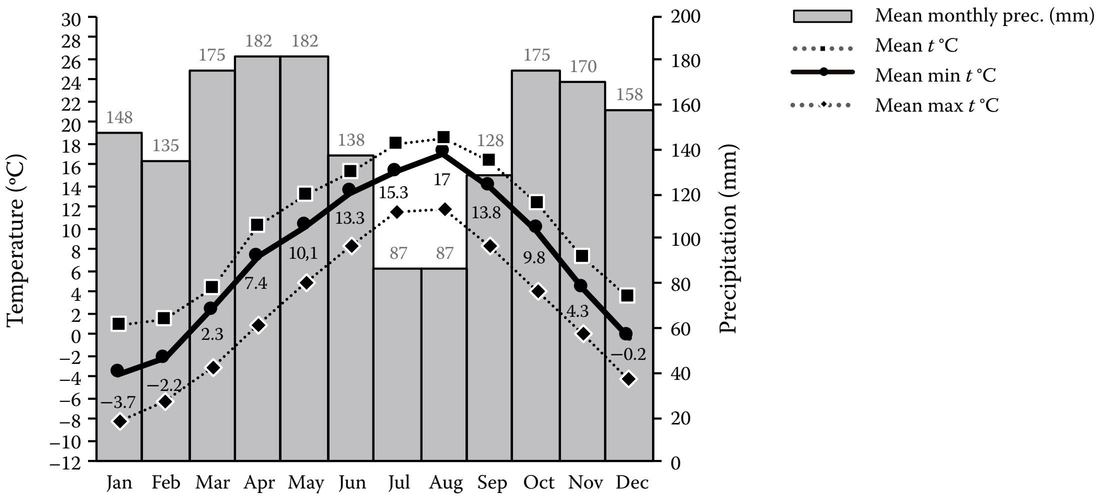

Figure 6. Climate diagrams: annual range of the mean monthly temperatures and precipitation for the localities arranged along the altitudinal transect of the forested area in Adjara; the last chart displays the distribution of the averaged mean annual temperatures and sum of the mean annual precipitation for the localities and the location of the dry zone within the altitudinal range of 200–500 m a.s.l. in the mountain belt

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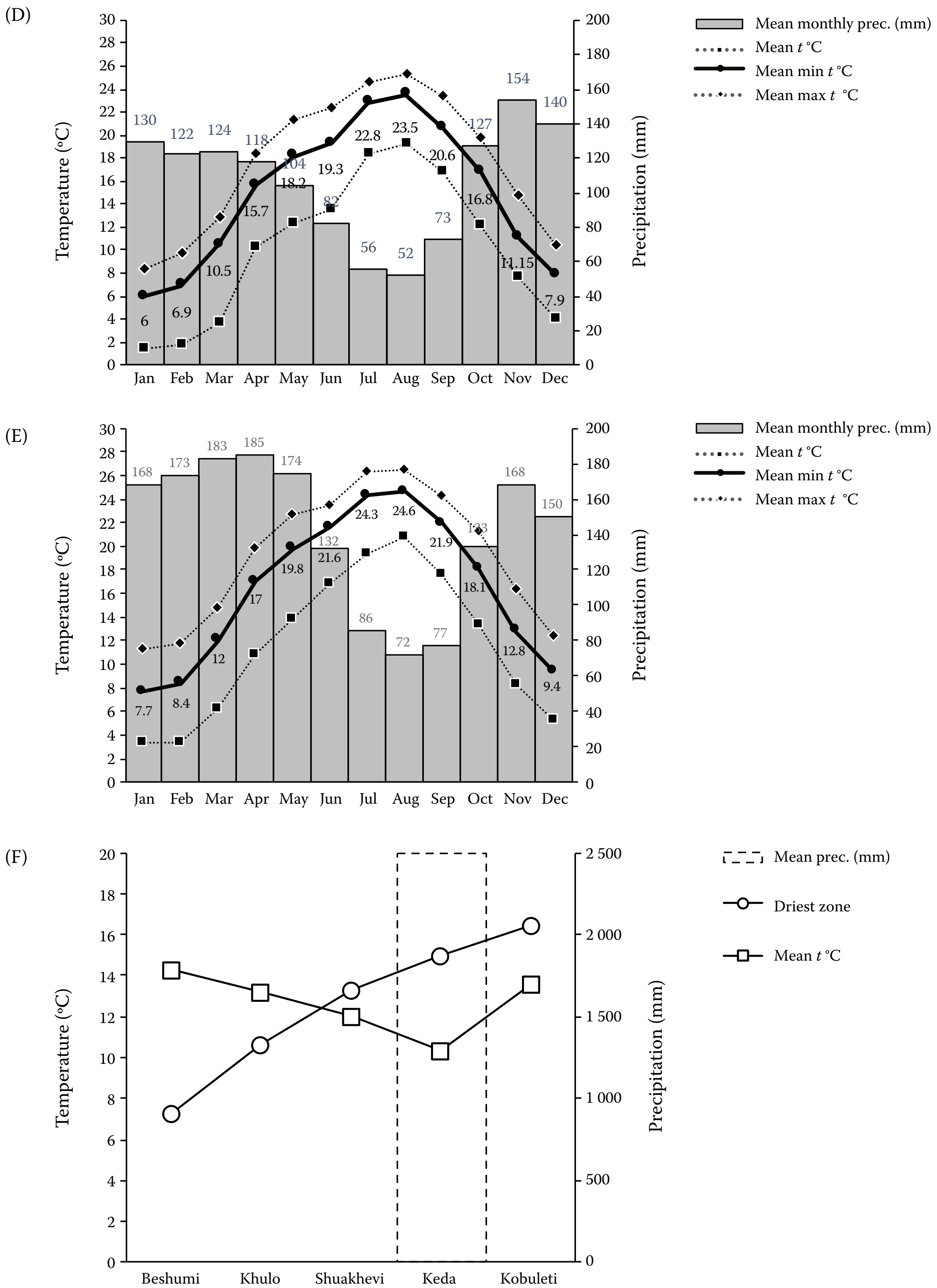

Figure 6. Climate diagrams: annual range of the mean monthly temperatures and precipitation for the localities arranged along the altitudinal transect of the forested area in Adjara; the last chart displays the distribution of the averaged mean annual temperatures and sum of the mean annual precipitation for the localities and the location of the dry zone within the altitudinal range of 200–500 m a.s.l. in the mountain belt

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misiifolia, *C. canadensis* and *P. americana* widely distributed in the mountain belt forests of central Adjara are recognized as the most common invasive plant species in Europe and Caucasus (Weber 2003; Pyšek et al. 2009; Slodowicz et al. 2018). The results of the analysis associated *C. canadensis* and *Ph. americana* with all forest vegetation types of the mountain belt forests in the study area, however, most of the invasive plants such as *R. pseudoacacia* and *Ambrosia artemisiifolia* were related to the cluster of dry forests, which indicates the higher level of degradation of forest vegetation diversity in the central part of Adjara.

Roads and settlements are considered as the most common infrastructural objects which are the carriers of anthropogenic stress acting as a permanent factor and causing the degradation of the vegetation structure (Trombulak, Frissell 2000; Newton, Echeverría 2014). The rivers in the anthropogenically active zones transport the seeds of the rural and invasive plant species and support their distribution (Newton, Echeverría 2014; Popradit et al. 2015). The analysis of the dependence of vegetation diversity features on the altitudinal range and proximity of the plots to the road verges, river banks and settlements in central Adjara reveals a specific pattern of forest vegetation degradation: the diversity and Shannon index, which can also be interpreted as the abundance or dominance of the rural and IAP species, increase at the lower altitudes of the studied territory. The network of the local roads becomes more intense at the lower altitudes in the central part of Adjara.

The existence of the positive relation with the richness and abundance of the rural and IAP species and the proximity of the sampling plots to the road verges link the cause of the degradation of forest vegetation diversity with the local road network. This result is logical as the roads provide the access to the forests, which supports wood logging and livestock grazing in the forests. Our study shows that the localization of the forests in the near distance from the local settlements and rivers has no significant effect on the structure of forest vegetation. However, the effect of these factors might be revealed in a more detailed study carried out on the larger sample size and involving the seasonal assessments of vegetation characteristics. The most common IAPs in the study territory such as *R. pseudoacacia*, *A. altissima*, *Ambrosia artemisiifolia*, *Artemisia vulgaris*, *C. canadensis* and the rural species such as *Datura stramonium* L., *Symphyotrichum graminifolium* (Spreng.) G.L. Nesom. and *Paspalum dilatatum* Poir. are not distributed in the high mountain forests (Dimitreewa 1990), which means that they are restricted by cold climate and high amount of annual precipitation. The abundance of these species, if they were found, was extremely low in the sampling plots evaluated at higher elevations than 750 m a.s.l.

Forest vegetation diversity and endemic plants. Based on the synthesis of the plot registered diversity of forest vegetation with the TWINSPAN results (Table 5) we conclude that the most common formations of dry and humid forests in the studied area according to their geobotanical classification (Dolukhanov 2010) are follows:

Humid forest formations:

Chestnut forest – Castanetum-rhododendrosum (composed of *C. sativa* and *R. ponticum*); Carpineto-Castanetum laurocerasosum (composed of *C. betulus*, *C. sativa*, *Prunus laurocerasus* L.);

Beech forest formation – Fageto-Castanetum trachystemonosum (*C. sativa*, *F. orientalis*, *Trachystemon orientalis* /L./ D. Don);

Mixed broadleaf and coniferous forest formation – Fageto-Piceetum mixtoherbosum (*P. orientalis*, *F. orientalis*, *R. luteum*, *F. drymeja*, *Bothriochloa ischaemum* (L.) Keng, *Galium odoratum* Scop.);

Riparian forests: Alder forest derivatives – Alnetum (composed of *A. glutinosa* subsp. *barbata*); Alnetum-mixtoherbosum (*A. glutinosa* subsp. *barbata*, *F. drymeja*, *Calamagrostis epigeios* Steud.).

Dry forest formations:

Oak forests – Quercetum mixtograminosum (*Q. petraea* subsp. *iberica*; *B. ischaemum* /L./ Keng, *B. sylvaticum* P. Beauv.); Quercetum-Pinetum carpinosum (composed of *Q. petraea* subsp. *iberica*, *C. orientalis*, *P. sylvestris* var. *hamata*); Quercetum cistosum (composed of *Q. petraea* subsp. *iberica* and *C. salvifolius*);

Pine forests – Pinus cytisosum (*P. sylvestris* var. *hamata*, *Cytisus ruthenicus*); Querceto-Pinetum mixtoherbosum (*P. sylvestris* var. *hamata*, *Q. petraea* subsp. *iberica*, *B. sylvaticum);*

Astragal shrubbery – Astragaletum imbricatii (*A imbricatus*); Astragaletum sommierii (*A. sommieri*); rocky and stony slopes.

The results of TWINSPAN and ISA associated threatened endemic plant taxa with these forest types, although significance of the linkage between the endemic taxa and specific formations of the

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forest vegetation diversity is low (Table 6). The results of TWINSPAN replaced the plot registered key species typical of the specific geobotanical formations of forest vegetation with the rural and widespread species of different vegetation types in the results because of the higher abundance and incidence of such species in the experimental plots. We consider that the degradation of the forests is the reason for receiving such result. The degradation fundamentally modifies the structure of forest vegetation diversity which is formed on the basis of the successional development of the forests. A scheme of the association of the threatened endemic species with the surveyed forest formations identified according the geobotanical classification of the forests of Georgia is provided in the supplementary materials of the article (Table S1 in Electronic Supplementary Material).

Endemic taxa related to the humid forests are relatively widespread and their populations occur in the territories of Kintrishi and Machakhela National Parks. The exception is *G. krasnovii* small populations which occur in the surroundings of the Khala and Chakvistavi villages of the Kobuleti municipality outside the protected areas. The species has been treated as narrow endemic to Adjara for a long time, but the modern data on the distribution of this species indicates that it also occurs in Turkey (Manvelidze et al. 2009; McGough et al. 2014). *G. woronowii* is protected by the Convention on International Trade in Endangered Species (CITES) as the bulbs of this species are collected in the wild for commercial purposes in Georgia. For the reason of economic importance of the *G. woronowii* bulbs, both *G. woronowii* and *G. krasnovii* are threatened as the collectors of the bulbs cannot distinguish these species from each other (McGough et al. 2014).

The results of the literature-based review of the distribution of endemic plant taxa in Adjara show that the endemic plants related to the cluster of dry forests by the results of the ISA are less protected than the taxa related to humid forests (Table 6). The ranges of the endemic species which relate to dry forests with their distribution are not covered by the protected areas located in Adjara and there is a higher concentration of the rural and invasive alien species of plants in the distribution area of the dry type of forests than in the area covered by humid forests. This finding of our study indicates the strong threat of the erosion of the unique diversity of vegetation of the dry type of forests distributed in central Adjara.

Recommendations for nature conservation. Based on our findings, we recommend an optimized comprehensive approach to the management and protection of the forests in Adjara. Botanical importance of the forest types is a key factor to become crucial in the management plan of the forests of Adjara. The strict recommendation that we address to the LEPL (Legal Entity Under Public Law) "Adjara Forest Agency" (AFA), which manages the local forests, is to involve botanists specialists in the development of the forest management plan who will determine the threat statuses of the plant species based on the global (IUCN 2020), regional (Nakhutsrishvili et al. 2014) and local (Government of Georgia 2014, 2018) Red Lists; map the distribution of the near threatened and threatened plant species in the local forests according to these lists and add these data to the forest taxation bulletins. These data are important for the protection of the populations of endemic plant species of conservation priority in local forests, especially in the dry type of local forests as our study shows. Therefore, our study shows that the studied territory is abundant in IAP species due to the diversity degradation of forest vegetation. In this category of plants, three species: *A. artemisifolia*, *R. pseudoacacia* and *A. altisima* are categorized as invasive species which pose a high threat to the forests of Caucasus region (Slodowicz et al. 2018) and Europe (Drake 2009). This result indicates the importance of the development of a management plan of the IAPs in the forests of Adjara to support the sustainability of local forests. Strategy for the management of the forests of Adjara declared for 2015–2019 by AFA (2015) does not include any management plans of the IAPs and endemic plant taxa. We believe that the results of this study are important to take into consideration to fill this gap in future.

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