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Investigation of the possibility to use *Quercus macranthera* Fisch. et C.A.Mey. woody plant in the management of the sustainability of the forest ecosystem

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Abstract: The main aim of this research was an integrated assessment of the ecological condition of natural forest complexes for the management of sustainable development in Khizi district, located on the territory of the Republic of Azerbaijan. Two test sites with different levels of anthropogenic impact were selected in Khizi. One of those sites is in the protected area of Altiaghac State Nature Reserve. The other test site is in the roadside area of Qizilqazma. The ecological condition of forest ecosystems on these test sites was investigated by a comparative analysis of the disruption degree of individual developmental stability at the ontogenesis of *Quercus macranthera* Fisch. et C.A.Mey. species' individuals. It is one of the dominant tree species in the forests of the study area. The degree of developmental stability of individuals was estimated by the level of fluctuating asymmetry of leaves morphological traits. The identification of the mineralogical composition of soil samples taken from test sites was carried out by XRD. The accumulative properties of oak were investigated by elemental analysis of leaf and soil samples. According to the results of research, fluctuating asymmetry of *Q. macranthera* leaves can be used as an effective indicator of the ecological condition of forest ecosystems in the Khizi district. But the results of the elemental analysis show that it is inexpedient to use the accumulation of elements in the *Q. macranthera* leaves as an indicator in environmental quality monitoring.

Key Words: *elemental analysis, fluctuating asymmetry, individual developmental stability, integrated assessment, Khizi*

INTRODUCTION

The sustainability of forest ecosystems depends on the resilience of living organisms, and it is considered as the ability of an ecosystem to maintain its internal homeostasis within a certain range under the impact of various external factors [Zakharov, 2001]. One of the promising and sensitive methods for assessment of ecosystem condition is bioindication analysis. This effective and the same time inexpensive method relies on the responsive reaction of living organisms to environmental influences, and it provides the opportunity for an adequate integral assessment of the environmental situation [Palmer, 1986]. Biomonitoring methods are considered as more appropriate and reliable for the assessment of the ecological condition of forest ecosystems [Gelashvili, 2004; Mammadova, 2019]. Thus, it is possible to determine the general ecosystem condition based on the internal state of the organism of the indicator species. Overall changes in the forest ecosystems effects at the micro- and macro- level of the species groups characteristic for the area. It is useful both methodically and informatively using these tree species as a model object and interpreting the obtained results for integrated assessment and early diagnostics of the ecological condition of the forest ecosystems. Phenotypic variability of morphological traits of trees characterizes their individual developmental stability and can be used in assessing the degree of developmental homeostasis [Van Valen, 1962; Palmer, 1986]. The disturbance of development is manifested in the deviations of various morphological traits from the normal structure.

One of the most widely used measures of developmental stability is fluctuating asymmetry, the variance in random deviations from perfect bilateral symmetry [Sakai, 1965; Graham, 1993]. Several researchers have investigated the methodological aspects to study the change of morphological traits' fluctuating asymmetry level that reflects the disruption of individual developmental stability of an organism [Melekhova, 2007; Mammadova, 2009]. A more accurate assessment of developmental stability can be obtained by pooling the fluctuating asymmetry measures of several traits per individual [Tomkins, 2002]. This simple and informative method enables researchers to

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assess the effects of genetic or environmental stress on individuals and ecosystems, in general. The main aim of the research work is to assess the ecological status of natural forest complexes in Khizi district, located in the Republic of Azerbaijan by using the bioindication methods for sustainable development. For this, two test sites with different levels of anthropogenic impact were selected in Khizi. *Quercus macranthera* Fisch. et C.A.Mey. is one of the dominant tree species in natural forests of the study area. So the ecological condition of forest ecosystems on these test sites was investigated by a comparative analysis of the disruption degree of individual developmental stability at the ontogenesis of this tree species' individuals. Individual developmental stability was determined by the fluctuating asymmetry level of leaves morphological traits. The elemental analysis of the same leaves was carried out for the determination of the oak leaves accumulative properties. The mineralogical composition and chemical elements concentrations of soil samples also were analyzed. The oak trees in compared areas were distinguishable due to its appearance, height, crown branching, dispersion density, thickness and color brightness of the leaves.

MATERIAL AND METHODS

Quercus macranthera Fisch. et C.A.Mey.- Caucasian oak is a long-lived tree that belongs to the genus *Quercus* (oak) of the Fagaceae (beech) family. The wood and bark contain the tanning agent. It is widely used in the planting of greenery [Flora of Azerbaijan, 1952]. Two test sites were selected in the Khizi district and their geographical coordinates were determined. One of those sites with a relatively low level of anthropogenic impact was in the protected area of Altiaghac State Nature Reserve (ASNR). The other test site with a relatively higher level of anthropogenic impact was in the roadside area of Qizilqazma (Qq). The forest ecosystems of these sites vary in the level of anthropogenic impact. The geographical coordinates of protected forest ecosystem on the first test site within the protected territory of ASNR are 40°55 '02.8"N, 49°01'13.4"E. The geographical coordinates of roadside forest ecosystem on second test site around the road Yarımca-Qizilqazma in the territory of Qq are 40°89'19.2"N, 49°07'48"E.

On each test site ten trees were selected. 20-30 undamaged leaves were collected from each plant along the lower crown at approximately the same distance from the soil surface - 1.5-2 m [Melekhova, 2007]. For each leaf, 5 morphological traits were measured and the investigated traits were noted in figure 1. The difference between the left and the right side was calculated for each bilateral trait. Observations and analyses were repeated several times in order to ensure the statistical reliability of the investigation results. The morphometric measurements of each leaf were inserted in MS Excel into the special program prepared in Java script (ECMA script 6) programming language [Salvatore, 2002]. The indicators of variation within the investigated bilateral traits were determined according to the results of morphometric measurements of each leaf collected from the studied areas. These indicators are the coefficient of variation (V), dispersion (D), fluctuating asymmetry coefficient (FAC), average module (Mod), the difference between the minimum and maximum values of the bilateral difference within

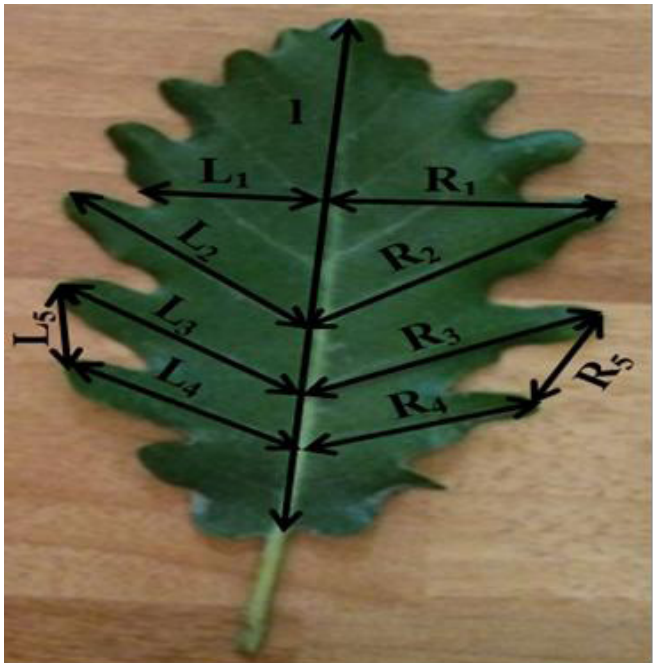

Figure 1. Morphometric signs investigated in the leaves: the width of the left (L1) and right (R1) of the maximum width of lamina (from the border of the primary vein to the leaf margin); the length of the longest second-order vein on the left (L2) and right (R2) halves of the leaf; the length of the III row vein of second-order to the right (R3) and left (L3) sides from the primary vein; the length of the II row vein of second-order to the right (R4) and left (L4) side from the primary vein; the distance between the ends of II and III row veins of second-order to the right (R5) and left (L5) side from the primary vein; the length of the primary vein of the leaf (L).

the trait (R) [Gelashvili, 2004; Mammadova, 2009].

All studied indicators were calculated with known mathematical formulas and the probability of reliability was checked [Lakin, 1990]. Analysis of the main chemical components in leaves and soil samples on the same test areas was carried out by using inductively coupled plasma mass spectrometer - 7700 e ICP-MS (Agilent Technologies, USA) and atomic absorption spectrometer – Agilent 200 Series AA (Agilent Technologies, USA) [Methods of determination of trace elements in soils, plants and waters, 1974; Havezov, 1983]. The micro-components in leaves and soil samples were analyzed on the x-ray fluorescence spectrometer S8 Tiger (Bruker AXS GmbH, Germany) (for plants – with preliminary dry ash at a temperature of 525° C) in accordance with GOST 33850-2016. The mineralogical composition of the soil was identified by the x-ray diffractometer Miniflex 600 (Rigaku, Japan). The determination of soil organic matter was carried out by the gravimetric method in accordance with GOST 26213-91. Each experiment was conducted three times with three replicates.

RESULTS AND DISCUSSION

The mineralogical composition of soil samples taken from the test sites of study area was presented in table 1. No very different results were obtained in the mineralogical composition of soil samples. The results amount of chemical compounds in soil samples taken from test sites were determined and presented in table 2.

Also, the chemical composition of leaf samples was analyzed for the determination of the accumulative properties of metal elements in the leaves of the oak. The obtained results are presented in table 3.

Concentrations of microelements in the soil samples from the test sites were analyzed comparatively with concentrations of microelements collected in the leaves samples of trees in the same test sites. The results of the analysis are presented in table 4.

The results of the analysis of the elemental composition of the leaves and soil samples collected from the test sites of the study area have showed that although the Qq test site had a relatively large amount of metal elements in the soil, the accumulation of elements in the leaves of the oak plants growing at this test site can not be used in ecological monitoring as an indicator of environmental quality. The results have shown higher accumulation of zinc (Zn) and copper (Cu) than other metals in the leaves of the eastern oak plant. On both test sites, oak leaves accumulated various degrees of different metal elements. Metal elements do not occur naturally in the soil in elemental form, but only in compounds with other elements and constantly have a synergetic or antagonistic interaction.

The levels of fluctuating asymmetry parameters of five morphometric traits were determined in the leaves of the oak plants growing in the forest ecosystems of both test sites. Table 5 shows the results of the calculations of leaves analyzed morphometric traits made by using known formulas and statistical software. The absolute average value of bilateral difference and fluctuating asymmetry indicators of all morphometric signs, except the fifth was higher in the leaves collected in the Qq roadside forest area. This increase is shown more clearly in a schematic diagram in figure 2.

Analysis of the results showed that the fluctuating asymmetry of the bilateral difference of the width of the left and right halves of the lamina maximum is a

Table 1. Mineralogical composition of soil samples, in %.

Study area	Quartz	Calcite	Feldspar	Illite	Montmo rillonite	Kaolinite	Aragonite	Soil organic matter
ASNR	27.3	12	12	10	24	7	5	2.7
Qq	30	7	11.5	12	22.5	8	7	2

Table 2. The results of the analysis of soil samples, in %.

Study area	Na_2O	MgO	Al_2O_3	$Si\ O_2$	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	FeO_3	LOI
ASNR	0.67	1.76	12.32	46.02	0.15	0.14	2.44	11.36	0.68	0.15	5.77	18.54
Qq	0.72	1.86	14.14	52.49	0.14	0.11	2.77	8.62	0.88	0.19	7.17	10.91

Note: LOI– Loss on ignition at 950° C temperature.

Table 3. The results of the analysis of *Q. macranthera* leaves samples, in %.

Territory	Na	Mg	AL	Si	P	S	K	Ca	Ti	Mn	Fe	Cl^-	LOI
ASNR	0.0100	0.06	0.02	0.28	0.08	0.12	0.58	0.96	0.0014	0.0024	0.0218	0.05	97.8
Qq	0.0096	0.09	0.02	0.29	0.09	0.08	0.69	0.94	0.0025	0.0030	0.0225	0.04	97.7

Note: LOI- Loss on ignition at 950° C temperature.

Table 4. Micro-elements in soil and eastern oak leaves samples in mg /kg.

Micro - elements mg /kg	Test site			
	ASNR		Qizilqazma	
	Soil (pH 7,2)	Leaf	Soil (pH 6,8)	Leaf
Cr	76.8	0.06	163.7	0.68
Zn	173.6	9.14	197.8	15.25
Ba	496.7	0.91	525.4	1.24
Zr	276.3	1.3	287.6	1.4
Cu	43.6	3.2	89.7	7.4
Pb	8.7	0.14	14.6	0.16
Ni	70.2	1.02	86.3	1.31
Mo	0.7	-	0.6	-
Nb	11.3	-	12.7	-
V	72.7	1.39	118.5	2.63
Ga	2.5	-	2.5	-
Cd	2.7	0.009	3.1	0.01
As	2.6	0.08	2.5	0.08
Co	7.5	0.55	9.1	0.62
Se	-	0.02	-	0.02
Br	-	0.94	-	1.14
Hg	-	0.009	-	0.011

Table 5. Fluctuating asymmetry parameters of *Q. macranthera* leaves.

Territory	Trait	Bilateral differences $x_1 \pm m_i$	D	FAC	V	Mod	R
ASNR	I	0.238±0.043	0.031	0.028	0.7397	0,1	1
	II	0.205±0.04	0.016	0.005	0.6170	0	0.7
	III	0.249±0.043	0.031	0.008	0.7071	0	1.1
	IV	0.224±0.042	0.021	0.028	0.6469	0,1	0.9
	V	0.212±0.041	0.022	0.020	0.6996	0,1	1
Qq roadside area	I	0.321±0.038	0.041	0.033	0.6307	0,1	1
	II	0.296±0.037	0.034	0.004	0.6229	0,2	1
	III	0.329±0.038	0.044	0.007	0.6375	0,2	1.1
	IV	0.331±0.038	0.046	0.03	0.6479	0,2	1
	V	0.197±0.032	0.021	0.021	0.7360	0,1	1

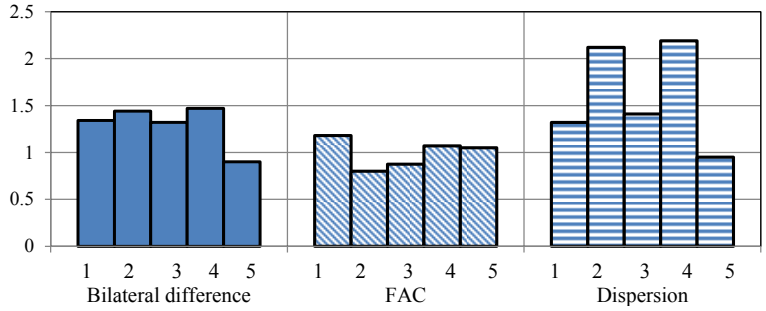

Figure 2. The levels of increasing of fluctuating asymmetry parameters of *Q. macranthera* leaves morphometric traits in Qq roadside forest ecosystem.

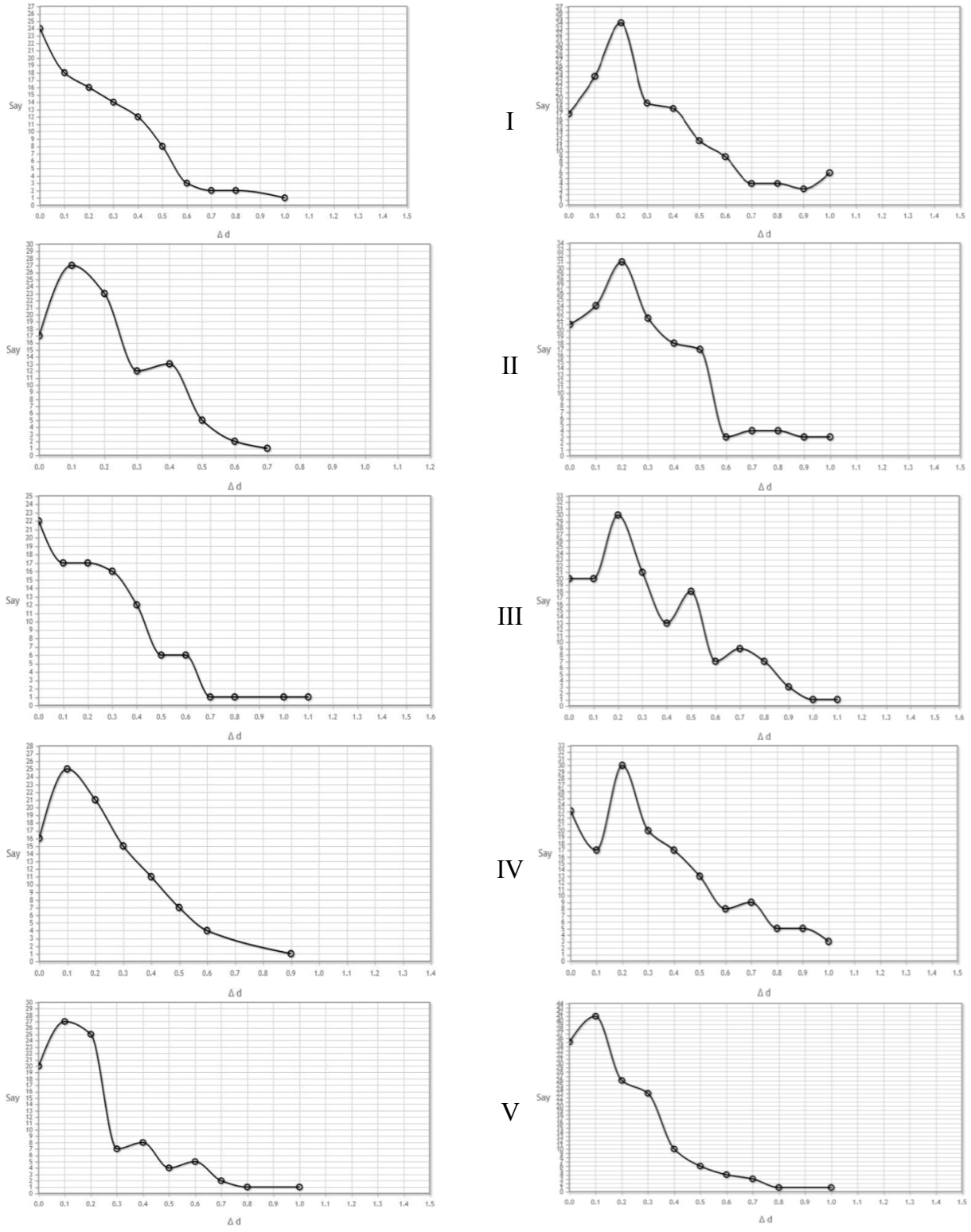

Figure 3. Graphical curves of the distribution of the bilateral difference of *Q. macranthera* leaves morphological signs in study areas: a) the natural protected forest area of ASNR; b) Qq natural roadside forest area. On the abscissa axis – bilateral difference in cm, on the ordinate axis – the number of leaves. The investigated traits were noted in figure 1.

Table 6. Interval assessment of the bilateral difference of *Q. macranthera* leaves.

Study areas	Bilateral difference	
	Lower border	Upper border
Altiaghac State Nature Reserve	0.1820	0.2940
Qizilqazma roadside forest area	0.2556	0.4058

more sensitive sign. Accordingly, the research of *Q. macranthera* leaves morphometric traits found that the use of the first trait as a test indicator of the disruption of individual developmental stability is more informative. Figure 3 shows the graphical curves displaying the frequency distribution of each investigated trait in order to visually see the internal variation of the morphometric traits within studied leaf samples. The graphs were presented by the software on the basis of each trait measured. The graphical illustrations of the frequency distribution of the bilateral differences of leaves investigated traits (except the 5th) in Qq natural roadside forest area are more variable than in ASNR.

The statistical analysis has enabled us to determine the changing borders of the integral value of the bilateral difference of the most variable trait in the leaves of oak tree (Tab. 6). It was defined that the absolute value of the bilateral difference in the leaves of a modified area can vary from 0.26 to 0.41. This indicates the pollution. In particular conditions in the area regarded as a relative control, this limit can range from 0.18 to 0.29. The obtained values provide an opportunity to get preliminary information about the general ecological status of the forest ecosystems. The mathematical analysis determined that 87 is a minimum leaf sample size that must be analyzed during the study for providing the average representation of fluctuating asymmetry indicators. Maximum Likelihood (ML) Binary Logit (Quadratic hill climbing) method was used to undertake the statistical analysis. Consequently, it was found out that, indicators of oak leaves fluctuating asymmetry increased to 0.1 unit of measure in Qizilqazma natural roadside forest area in comparison to the protected area of ANSR. The pollution hypothesis was checked by the ANOVA test, and it was established that pollution was confirmed by $F_{coefficient}248.3 > 3$. It is defined according to variations of fluctuating asymmetry indicators per study areas, and H_0 hypothesis is rejected.

Thus, the research has shown that oak is a dominant tree plant of Khizi district and can be used in the assessment of the ecological state of natural forest ecosystems for the initial forecast. Even during a small variation in the balance of studied areas ecosystems, it is possible to assess the ecological situation of the environment through the integral absolute value of the morphometric traits of oak plant. Because it responds sensitively even to the slightest changes in the balance of the forest ecosystem. It also creates a basis for new researches in this direction by making it possible to predict the environmental pollution risk. The leaves of *Q. macranthera* accumulated metal elements from the soil in a various degree. Zn and Cu were accumulated in the leaves more than other analyzed elements. However, it is unsuitable for using in ecological monitoring as an indicative parameter. In general, the leaves of oak plant can be used in the remediation of soils.

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Meşə ekositeminin davamlığının idarə edilməsində *Quercus macranthera* Fisch. et C.A.Mey. ağac bitkisinin istifadə edilmə imkanlarının tədqiqi

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Tədqiqatın əsas məqsədi Azərbaycan Respublikasının ərazisində yerləşən Xızıda əraf mühitin idarə edilməsi üçün təbii meşə komplekslərinin ekoloji vəziyyətinin kompleks qiymətləndirilməsi olmuşdur. Xızı rayonunda antropogen təsirin müxtəlif səviyyələrinə malik iki sınaq sahəsi seçilmişdir. Sahələrdən biri Altıağac Dövlət Təbiət Qoruğunun mühafizə olunan ərazisində, digəri isə Qızılqazmada yolkənarı zolaqda yerləşirdi. Bu sınaq sahələrində meşə ekosistemlərinin ekoloji vəziyyəti dominant olan ağac *Quercus macranthera* Fisch. et C.A.Mey. növünün ontogenezində fərdi inkişaf sabitliyinin pozulma dərəcəsinin müqayisəli təhlili yolu ilə araşdırılmışdır. Bu tədqiqat ərazisində fərdlərin inkişafının davamlılığının dərəcəsi morfoloji xüsusiyyətlərin fluktuasiya asimmetriya göstəricilərinin səviyyəsinə görə qiymətləndirilmişdir. Sınaq meydançalarından götürülmüş torpaq nümunələrinin mineral tərkibinin identifikasiyası rentgenoqrafiya üsulu ilə aparılmışdır. Palıdın akkumulyativ xüsusiyyətləri yarpaq və torpaq nümunələrinin element təhlili metodu ilə tədqiq edilmişdir. Tədqiqatın nəticələrinə görə *Q. macranthera* bitkisinin yarpaqlarının fluktuasiya asimmetriyası Xızı rayonunun meşə ekosistemlərinin ekoloji vəziyyətinin effektiv göstəricisi kimi istifadə edilə bilər. Ancaq element analizinin nəticələri göstərir ki, ətraf mühitin keyfiyyətinin monitorinqi zamanı *Q. macranthera* yarpaqlarının elementlərin akkumulyasiya etmək xüsusiyyətini bir göstərici kimi istifadə etmək məqsədəuyğun deyil.

Açar sözlər: *element analizi, fluktuasiya asimmetriyası, fərdi stabil inkişaf, inteqral qiymətləndirmə, Xızı*

Исследование возможности использования *Quercus macranthera* Fisch.et C.A.Mey. древесное растение в управлении устойчивостью лесной экосистемы

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Основной целью данного исследования явилась комплексная оценка экологического состояния природных лесных комплексов для управления устойчивым развитием Хызинского района, расположенного на территории Азербайджанской Республики. В Хызы были выбраны две испытательные территории с разным уровнем антропогенного воздействия. Один из таких объектов находился на охраняемой территории Алтыагачского государственного природного заповедника. Другой испытательный полигон находился в придорожной зоне Гызылгазмы. Экологическое состояние лесных экосистем на этих пробных площадках было исследовано путем сравнительного анализа степени нарушения индивидуальной устойчивости развития в онтогенезе *Quercus macranthera* Fisch.et C.A.Mey. особи вида. Это одно из доминирующих древесных растений в лесах исследуемого района. Степень устойчивости развития особей оценивали по уровню флуктуирующей асимметрии морфологических признаков листьев. Идентификация минералогического состава образцов почвы, взятых с испытательных площадок, проводилась методом рентгенографии. Аккумулятивные свойства Восточного дуба исследовались методом элементного анализа образцов листьев и почвы. По результатам исследований флуктуирующая асимметрия листьев *Q. macranthera* может быть использована в качестве эффективного индикатора экологического состояния лесных экосистем Хызинского района. Но результаты элементного анализа показывают, что нецелесообразно использовать накопление элементов в листьях *Q. macranthera* в качестве индикатора при мониторинге качества окружающей среды.

Ключевые слова: *элементный анализ, флуктуирующая асимметрия, индивидуальная устойчивость развития, интегральная оценка, Хызы*