# CONTENTS

**Acknowledgement to reviewers of the manuscripts submitted to Forestry Ideas in 2018:**

Mohammad Naghi **Adel** – University of Guilan, Rasht, Iran

Hossein **Akhani** – University of Tehran, Iran

Marta **Alonso** – University of Geneva, Switzerland

Andaea **Amici** – University of Tuscia, Viterbo, Italy

Sezgin **Ayan** – Kastamonu University, Turkey

Zlatozar **Boev** – National Museum of Natural History, Sofia, Bulgaria

Girish **Chandra** – Delhi University, India

Andrea **Cutini** – Research Centre for Forestry and Wood, Arezzo, Italy

Dimitar **Dimitrov** – National Natural History Museum, Sofia, Bulgaria

Denis **Dirin** – Altai State University, Barnau, Russia

Amram **Eshel** – Tel Aviv University, Israel and University of Western Australia, Perth, Australia

Emil **Galev** – University of Forestry, Sofia, Bulgaria

Sergey **Gavrilyuk** – Ukrainian National Forestry University, Lviv, Ukraine

Brij **Gopal** – Centre for Inland Waters in South Asia, Jaipur, India

Aureliu-Florin **Halalisan** – Transilvania University of Brasov, Romania

Mathias **Hofmann** – Technical University, Dresden, Germany

Kemal **Kirikci** – Selcuk University, Konya, Turkey

Mzia **Kokhia** – Ilia State University, Institute of Zoology, Tbilisi, Georgia

Ralitsa **Kuzmanova** – University of Forestry, Sofia, Bulgaria

Sergey **Kuzmin** – Sukachev Institute of Forest of the Siberian Branch of the Russian Academy of Sciences, Krasnoyarsk, Russia

Paweł **Lech** – Forest Research Institute, Raszyn, Poland

Ali **Mahdavi** – Ilam University, Ilam, Iran

Plamen **Maldzhanski** – University of Architecture, Construction and Geodesy, Sofia, Bulgaria

Daniel **McKenney** – Natural Resources Canada, Great Lakes Forestry Centre, Ottawa, Canada

Boris **Nikolov** – Institute of Biodiversity and Ecosystem Research at the Bulgarian Academy of Sciences, Sofia, Bulgaria

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 105–120

# GROWTH RESPONSE OF DOUGLAS-FIR PROVENANCES TO CLIMATE CHANGE

Krasimira Petkova

Department of Silviculture, Faculty of Forestry, University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria. E-mail: kpet@abv.bg

Received: 11 May 2018 Accepted: 16 October 2018

## Abstract

The aim of the study is to establish the height growth response of Douglas-fir provenances in different climatic conditions in provenance test in Bulgaria. The provenance test is located on the lower part of the northern slopes of the Western Balkan Range (North-Western Bulgaria) and includes 54 provenances originating from North America. The provenances were separated into three groups – coastal, continental and Western Cascade Mountains. Regression models between the average height at the age of 24 and some climatic indicators were developed to reveal the correlation between climatic variables and height growth. The transfer distance was calculated as a difference between the respective climatic indicator of planting site (provenance test) and seed sources (provenances). For continental provenances, the transfer is to more humid and warmer climate, but its height growth is poorer. The coastal and West Cascade Mountains provenances were moved to more continental and drier climate but have a good height growth.

**Key words:** average height, climatic indicators, transfer.

## Introduction

Climate change is expected to have an impact on the growth of tree species. There are opinions about reduced growth due to increased air temperature and rainfall reduction, but also for increased growth due to prolongation of the growing period and the higher rate of photosynthesis. According to O'Neill and Nigh (2011), climate change will lead to reduction in growth or slight increase for several decades, followed by decline in growth. The authors predict decline in the productivity of *Pinus contorta* in British Columbia, Canada, by at least 7–13 % by the end of this century. Reich and Oleksyn (2008) analyse the growth of 283 Scots pine (*Pinus sylvestris* L.) populations, originating from a broad geographic range in provenance tests in Europe.

They found that climate change, equivalent to warming by 1–4 °C, would lead to an increase in the growth of the most northern populations and to a reduction for the more southerly Scots pine population. Pedlar and McKenney (2017) reach to a similar conclusion for the growth of the northern and southern provenances of *Picea mariana* and *Pinus banksiana*. Messaoud and Chen (2011) study the impact of climate change on growth in height of natural stands of *Populus tremuloides* Michx and *Picea mariana* Mill. B.S. in British Columbia and found that the height growth of both species was positively related to temperature variables at the regional scale and with soil moisture and nutrient availability at the local scale.

Restaino et al. (2016) predicted a decrease in Douglas-fir growth across all latitudes in the western United States due to increased water vapour pressure deficit (VPD) as a result of increased air temperature. According to Spittlehouse (2003), the productivity of Douglas-fir will be reduced by about 30 % when the average daily temperature increases by 1–4 °C, due to the reduction of the moisture available during the summer period. He found a growth reduction of the habitats with shallower soils due to moisture stress at the beginning of the summer. Isaak-Renton et al. (2014) predict health worsening and reduced productivity of the Douglas-fir, not only for the more southern provenances and those ones of lower altitudes. This is because all locally adapted populations experience a discrepancy between the new climatic conditions and their individual climatic niches, to which they have been adapted. Nordic populations of Douglas-fir can be more vulnerable to climate change than those in the south. Chakraborty et al. (2015), based on studies in 50 Douglas-fir provenances test in Europe, predict decreasing growth performance at low and middle elevations of the case study area, but increasing growth performance on high elevation sites.

In a number of studies, models have been developed to assess the impact of climate change on the growth of the tree species. Andalo et al. (2005) develop models for the transfer of *Picea glauca* (Moench) Voss provenances, based on differences in temperatures and precipitation between seed sources and the location of the trial sites. The authors found that the provenances were optimally adapted to the thermal conditions of the experimental trials but not for moisture conditions, populations that originated from sites receiving more precipitation generally showed higher tree growth than the local sources.

Leites et al. (2012) establish that the most sensitive indicator of climate was the mean temperature of the coldest month for continental provenances of Douglas-fir. The maximum population height and height growth response to changes in climate were dependent on seed source climate. All populations had optimal height growth when transferred to climate with warmer winters. Those originating from sites with warmest winters were taller across sites and with highest growth at a transfer distance closest to zero; those from colder climates were shortest and had an optimal height when transferred utmost far away. Although this different response makes height growth differences among populations smaller, cold-climate populations still achieve their maximum growth at lower temperatures than warm-climate populations. The results highlight the relevance of understanding climate change impact on population level, particularly for species with big genetic variation among populations.

Schmidtling (1994) has suggested the use of a regression method to analyse the response of provenances to temperature differences between the provenance source and the provenance test planting sites. He found significant correlation between temperature and growth variables for loblolly pine (*Pinus taeda* L.) and Norway spruce (*Picea abies* (L.) Karst.), and predicted that an increase in average annual temperature of 4 °C would result in a relative height growth loss of about 5–10 % for these species. Carter (1996) applies Schmidtling's regression method for published provenance test data about the following 10 forest tree species native to eastern North America: *Acer rubrum* L., *Abies balsamea* (L.), *Betula alleghaniensis* Britton, *Picea glauca* (Moench) Voss, *Pinus strobus* L., *Pinus banksiana* Lamb., *Prunus serotina* Ehrh., *Fraxinus americana* L., *Fraxinus pennsylvanica* Marshall and *Larix laricina* (Du Roi) K. Koch. For all species except *Acer rubrum* and *Fraxinus pennsylvanica*, the northern provenances did not respond to warmer growing conditions with increased growth. Growth even decreased for some species on warmer sites.

The aim of the study is to establish the height growth response of North American Douglas-fir provenances in different climatic conditions in a provenance test in North-Western Bulgaria.

## Material and Methods

The Douglas-fir provenance test is located on the lower northern slopes of the Western Balkan Range (North-Western Bulgaria) in the Training-and-Experimental Forest Enterprise in Petrohan. The trial was established in a flat terrain facing the east, at an altitude of 600 m a.s.l., latitude 43°11'23.48" N and longitude 23°08'47.24" E. The soil is Orthic Luvisol (FAO), mixed sandy and clayey, slightly stony and very deep. The site is medium rich to rich. The climate in the region is temperate with an average annual temperature of 10.2 °C and annual precipitation of 1004 mm. The duration of the growing season is about 6 to 6.5 months. The 54 studied provenances originate from natural stands of Douglas-fir in North America and were classified into three groups: continental (CON), Western Cascade Mountain (CASC) and coastal (COAS) provenances. Along with the American provenances, the provenance Dimovets is included in the provenance test. This is the oldest Douglas-fir plantation in Bulgaria, established about 110 years ago and accepted for 'local' provenance in this study. In this plantation, the species is fully naturalized to local conditions. It is characterized by rapid growth, high productivity and successful regeneration (Popov 1991). Data about the provenances and weather stations, from which the climate data were included, are presented in Table 1. All climate data about the American provenances was normalized climate data (1982–2012) collected from weather stations closest to the population's origins (Anonymous 2018). The climate data about the 'local' provenance and about the trial site were as follows – for the temperatures for the period 1931–1970 (Kyuchukova et al. 1983) and for precipitations for the period 1931–1985 (Koleva and Peneva 1990).

The following climatic indicators were included in the analyses: mean annual temperature (MAT), average annual minimum temperature (AAMT), mean coldest month temperatures (MCMT), mean warmest month temperatures (MWMT) – Wang et al. (2006), continentality index (Ic, which is the difference between MWMT and MCMT, Chakraborty et al. 2015, Wang et al. 2016, Rivas-Martinez et al. 2017), mean annual precipitation (MAP: sum of monthly precipitation). These climatic indicators and average height of each provenance at the age of 24 (according to Petkova et al. 2014) are listed in Table 2.

Analysis of variance (ANOVA) was used to determine if there were significant effects of populations on the height growth. The influence of the provenance groups on height growth was investigated by one way ANOVA and the differences between the means values in groups

**Table 1. Data for Douglas-fir provenances and used climate stations.**

| Provenance group | Provenance number | Seedzone | Provenance name | Geographical latitude | Geographical longitude | Altitude, | Climate station | Geographical latitude | Geographical longitude | Altitude, |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ° N | ° W | m | | ° N | ° W | m |
| CONTINENTAL | | | | | | | | | | |
| Montana | 3 | Montana | Whitefish | 48.5 | 114.5 | 1050 | Whitefish | 48.4 | 114.3 | 927 |
| New Mexico | 55 | 840 | Alamogordo | 33.0 | 105.8 | 750 | Alamogordo | 32.9 | 106.0 | 1317 |
| Washington | 1 | 612 | Greenwood | 49.0 | 119.0 | 1350 | Omak | 48.4 | 119.5 | 255 |
| | 2 | 600 | Keremeos | 49.0 | 120.0 | 750 | Keremeos | 49.2 | 119.8 | 414 |
| | 13 | 641 | Naches | 46.5 | 121.3 | 1050 | Naches | 46.7 | 120.7 | 443 |
| East Cascade Mountains | 14 | 661 | Parkdale | 45.5 | 121.5 | 1650 | Dufur | 45.5 | 121.1 | 410 |
| Oregon | 15 | 661 | Parkdale | 45.5 | 121.7 | 1500 | Dufur | 45.5 | 121.1 | 410 |
| | 16 | 661 | Parkdale | 45.5 | 121.5 | 1350 | Dufur | 45.5 | 121.1 | 410 |
| | 17 | 661 | Parkdale | 45.5 | 121.5 | 1200 | Dufur | 45.5 | 121.1 | 410 |
| | 18 | 661 | Parkdale | 45.5 | 121.5 | 1050 | Dufur | 45.5 | 121.1 | 410 |
| | 19 | 661 | Parkdale | 45.5 | 121.5 | 900 | Dufur | 45.5 | 121.1 | 410 |
| | 20 | 661 | Parkdale | 45.5 | 121.5 | 750 | Dufur | 45.5 | 121.1 | 410 |
| | 33 | 662 | Warm Springs | 45.0 | 121.5 | 667 | Long Creek | 44.7 | 119.1 | 1145 |
| | 32 | 662 | Warm Springs | 45.0 | 122.0 | 900 | Long Creek | 44.7 | 119.1 | 1145 |
| | 38 | 675 | Santiam Pass | 44.3 | 121.6 | 1125 | Sisters | 44.3 | 121.6 | 971 |
| | 47 | 681 | Crescent | 43.3 | 121.8 | 1650 | Crescent | 43.5 | 121.7 | 1358 |
| | 48 | 681 | Crescent | 43.3 | 122.0 | 1500 | Crescent | 43.5 | 121.7 | 1358 |
| East Oregon | 21 | 863 | Bates | 45.0 | 118.5 | 1667 | Ukiah | 45.1 | 118.9 | 1039 |
| | 22 | 863 | Bates | 45.0 | 118.5 | 1500 | Ukiah | 45.1 | 118.9 | 1039 |
| | 23 | 863 | Bates | 45.0 | 118.5 | 1333 | Ukiah | 45.1 | 118.9 | 1039 |
| | 35 | 892 | Canyon City | 44.5 | 119.0 | 1500 | Prairie City | 44.5 | 118.7 | 1079 |
| | 36 | 892 | Canyon City | 44.5 | 119.0 | 1350 | Prairie City | 44.5 | 118.7 | 1079 |
| | 37 | 892 | Canyon City | 44.5 | 119.0 | 1650 | Prairie City | 44.5 | 118.7 | 1079 |
| Coastal Mountains | 49 | 501 | Crater Lake | 42.7 | 122.5 | 1200 | Chiloquin | 42.6 | 121.9 | 1273 |

| Provenance group | Provenance number | Seedzone | Provenance name | Geographical latitude | Geographical longitude | Altitude, | Climate station | Geographical latitude | Geographical longitude | Altitude, |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ° N | ° W | m | | ° N | ° W | m |
| South Oregon | 50 | 501 | Medford | 42.5 | 122.5 | 1050 | Medford | 42.4 | 122.9 | 415 |
| | 51 | 502 | Medford | 42.6 | 122.8 | 900 | Medford | 42.4 | 122.9 | 415 |
| WESTERN CASCADE MOUNTAINS | | | | | | | | | | |
| Washington | 4 | 402 | Newhalem | 48.5 | 121,5 | 667 | Concrete | 48.5 | 121.7 | 79 |
| | 5 | 402 | Newhalem | 48.5 | 121.5 | 500 | Concrete | 48.5 | 121.7 | 79 |
| | 6 | 403 | Darrington | 48.0 | 121.5 | 1167 | Darrington | 48.3 | 121.6 | 169 |
| | 7 | 403 | Darrington | 48.0 | 121.5 | 1000 | Darrington | 48.3 | 121.6 | 169 |
| | 8 | 403 | Darrington | 48.0 | 121.5 | 833 | Darrington | 48.3 | 121.6 | 169 |
| | 9 | 411 | Monroe | 47.8 | 121.3 | 525 | Monroe | 47.9 | 122.0 | 21 |
| Oregon | 24 | 452 | Idanha | 45.0 | 122.0 | 1050 | Government Camp | 45.3 | 121.8 | 1195 |
| | 25 | 452 | Idanha | 45.0 | 122.0 | 1200 | Government Camp | 45.3 | 121.8 | 1195 |
| | 26 | 452 | Idanha | 45.0 | 122.0 | 1050 | Government Camp | 45.3 | 121.8 | 1195 |
| | 27 | 452 | Idanha | 45.0 | 122.0 | 900 | Government Camp | 45.3 | 121.8 | 1195 |
| | 28 | 452 | Idanha | 45.0 | 122.0 | 1333 | Government Camp | 45.3 | 121.8 | 1195 |
| | 29 | 452 | Idanha | 45.0 | 122.0 | 750 | Government Camp | 45.3 | 121.8 | 1195 |
| | 30 | 452 | Idanha | 45.0 | 122.0 | 750 | Government Camp | 45.3 | 121.8 | 1195 |
| | 31 | 452 | Idanha | 45.0 | 122.0 | 750 | Government Camp | 45.3 | 121.8 | 1195 |
| | 39 | 473 | Santiam Pass | 44.3 | 121.8 | 1500 | Sisters | 44.3 | 121.6 | 971 |
| | 40 | 472 | Oakridge | 44.0 | 122.0 | 1667 | Oakridge | 43.7 | 122.5 | 369 |
| | 41 | 472 | Oakridge | 44.0 | 122.0 | 1500 | Oakridge | 43.7 | 122.5 | 369 |
| | 42 | 473 | Oakridge | 44.0 | 122.0 | 1333 | Oakridge | 43.7 | 122.5 | 369 |
| | 43 | 482 | Oakridge | 44.0 | 122.0 | 900 | Oakridge | 43.7 | 122.5 | 369 |

| Provenance group | Provenance number | Seedzone | Provenance name | Geographical latitude | Geographical longitude | Altitude, | Climate station | Geographical latitude | Geographical longitude | Altitude, |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | ° N | ° W | m | | ° N | ° W | m |
| | 44 | 482 | Oakridge | 43.8 | 122.5 | 1350 | Oakridge | 43.7 | 122.5 | 369 |
| | 45 | 482 | Oakridge | 43.8 | 122.5 | 1200 | Oakridge | 43.7 | 122.5 | 369 |
| | 46 | 472 | Oakridge | 43.8 | 122.5 | 1500 | Oakridge | 43.7 | 122.5 | 369 |
| COASTAL | | | | | | | | | | |
| Washington | 12 | 12 | Moclips | 47.5 | 124.0 | 600 | Moclips | 47.2 | 124.2 | 40 |
| | 10 | 222 | Bremerton | 47.7 | 123.0 | 600 | Brinnon | 47.7 | 122.9 | 68 |
| | 11 | 222 | Bremerton | 47.7 | 123.5 | 450 | Brinnon | 47.7 | 122.9 | 68 |
| Oregon | 34 | 53 | Toledo | 44.6 | 123.8 | 150 | Toledo | 44.6 | 123.9 | 3 |
| | 52 | 82 | Brookings | 42.0 | 124.5 | 833 | Gold Beach | 42.4 | 124.4 | 17 |
| | 53 | 82 | Brookings | 42.0 | 124.5 | 667 | Gold Beach | 42.4 | 124.4 | 17 |
| Local provenance | | | Dimovetz | 42.6 | 25.4 E | 750 | Kazanlak | | | 380 |

Note: Source for the climate data – https://en.climate-data.org/continent/north-america/; Sources – for the provenance data (Popov 1990, Popov 1991, Petkova et al. 2014), the climate data CLIMATE-DATA.ORG (Anonymous 2018).

by Tukey multiple comparisons of mean method.

For the development of a regression model, established by Schmidtling (1994) and confirmed by Carter (1996), the difference between the mean height of each provenance with the mean height of the 'local' provenance (height deviation, relative height, HD) was determined and accepted as a dependent variable and the difference between the average annual minimum temperature of each provenance and provenance test (TD) as an independent variable.

**Table 2. Climatic indicators and average height at age 24 of the Douglas-fir provenances.**

| Group | Provenance name/number | MAT | AAMT | MTCM | MTWM | Ic | MAP | $H_{24}$ |
|---|---|---|---|---|---|---|---|---|
| | | ºC | ºC | ºC | ºC | ºC | mm | m |
| CON | Whitefish 3 | 5.6 | -1.2 | -6.5 | 17.4 | 23.9 | 532 | 10.6 |
| CON | Alamogordo 55 | 15.8 | 7.4 | 5.5 | 26.2 | 20.7 | 282 | 6.2 |
| CON | Greenwood 1 | 10.0 | 3.5 | -3.2 | 22.3 | 25.5 | 296 | 9.9 |
| CON | Keremeos 2 | 9.2 | 3.7 | -3.7 | 21.3 | 25 | 278 | 9.7 |
| CON | Naches 13 | 8.8 | 1.9 | -2.2 | 19.9 | 22.1 | 280 | 15.3 |
| CON | Parkdale 14 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 15.8 |
| CON | Parkdale 15 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 16.6 |
| CON | Parkdale 16 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 15.3 |
| CON | Parkdale 17 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 16.1 |
| CON | Parkdale 18 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 16.2 |
| CON | Parkdale 19 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 13.6 |
| CON | Parkdale 20 | 9.8 | 2.4 | -0.2 | 19.8 | 20 | 345 | 13.2 |
| CON | Warm Springs 33 | 7.4 | -0.5 | -1.7 | 17.4 | 19.1 | 394 | 12.9 |
| CON | Warm Springs 32 | 7.4 | -0.5 | -1.7 | 17.4 | 19.1 | 394 | 14.9 |
| CON | Santiam Pass 38 | 7.4 | -0.7 | -1.2 | 16.8 | 18 | 425 | 12.9 |
| CON | Crescent 47 | 6.3 | -1.8 | -2.6 | 16.3 | 18.9 | 574 | 15.7 |
| CON | Crescent 48 | 6.3 | -1.8 | -2.6 | 16.3 | 18.9 | 574 | 14.7 |
| CON | Bates 21 | 6.7 | 0.5 | -3.3 | 16.7 | 20 | 447 | 7.1 |
| CON | Bates 22 | 6.7 | 0.5 | -3.3 | 16.7 | 20 | 447 | 6.4 |
| CON | Bates 23 | 6.7 | 0.5 | -3.3 | 16.7 | 20 | 447 | 10.4 |
| CON | Canyon City 35 | 7.8 | -0.5 | -2.6 | 18.9 | 21.5 | 360 | 10 |
| CON | Canyon City 36 | 7.8 | -0.5 | -2.6 | 18.9 | 21.5 | 360 | 10.4 |
| CON | Canyon City 37 | 7.8 | -0.5 | -2.6 | 18.9 | 21.5 | 360 | 6.4 |
| CON | Crater Lake 49 | 7.4 | -0.6 | -1.7 | 17.8 | 19.5 | 511 | 15.3 |
| CON | Medford 50 | 11.8 | 4.4 | 3.3 | 21.5 | 18.2 | 516 | 14.9 |
| CON | Medford 51 | 11.8 | 4.4 | 3.3 | 21.5 | 18.2 | 516 | 15.2 |
| CASC | Newhalem 4 | 9.9 | 5.1 | 2.3 | 17.8 | 15.5 | 1834 | 16.7 |
| CASC | Newhalem 5 | 9.9 | 5.1 | 2.3 | 17.8 | 15.5 | 1834 | 18 |
| CASC | Darrington 6 | 9.4 | 4.2 | 1.4 | 17.6 | 16.2 | 2064 | 20 |
| CASC | Darrington 7 | 9.4 | 4.2 | 1.4 | 17.6 | 16.2 | 2064 | 17.9 |
| CASC | Darrington 8 | 9.4 | 4.2 | 1.4 | 17.6 | 16.2 | 2064 | 16.1 |
| CASC | Monroe 9 | 10.4 | 5.4 | 3.7 | 17.8 | 14.1 | 1244 | 17.9 |

| Group | Provenance name/number | MAT | AAMT | MTCM | MTWM | Ic | MAP | $H_{24}$ |
|---|---|---|---|---|---|---|---|---|
| | | $^oC$ | $^oC$ | $^oC$ | $^oC$ | $^oC$ | mm | m |
| CASC | Idanha 24 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 12.3 |
| CASC | Idanha 25 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 11.7 |
| CASC | Idanha 26 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 14.2 |
| CASC | Idanha 27 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 17.5 |
| CASC | Idanha 28 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 16.9 |
| CASC | Idanha 29 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 16.7 |
| CASC | Idanha 30 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 16 |
| CASC | Idanha 31 | 5.5 | 0.8 | -1.4 | 13.8 | 15.2 | 2137 | 16.4 |
| CASC | Santiam Pass 39 | 7.4 | -0.7 | -1.2 | 16.8 | 18 | 425 | 11.4 |
| CASC | Oakridge 40 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 13.9 |
| CASC | Oakridge 41 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 14.6 |
| CASC | Oakridge 42 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 14.8 |
| CASC | Oakridge 43 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 14.5 |
| CASC | Oakridge 44 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 14.7 |
| CASC | Oakridge 45 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 14.8 |
| CASC | Oakridge 46 | 10.9 | 4.1 | 3.4 | 19.1 | 15.7 | 1184 | 12.7 |
| COAS | Bremerton 10 | 10.2 | 5.1 | 3.3 | 17.7 | 14.4 | 1329 | 16.2 |
| COAS | Bremerton 11 | 10.2 | 5.1 | 3.3 | 17.7 | 14.4 | 1329 | 17.9 |
| COAS | Moclips 12 | 9.7 | 5.4 | 4.5 | 15.2 | 10.7 | 2699 | 16.5 |
| COAS | Toledo 34 | 11.0 | 6.6 | 6.4 | 16 | 9.6 | 1958 | 11.5 |
| COAS | Brookings 52 | 11.8 | 7.3 | 8.5 | 15.6 | 7.1 | 2012 | 14.6 |
| COAS | Brookings 53 | 11.8 | 7.3 | 8.5 | 15.6 | 7.1 | 2012 | 15.9 |
| LOCAL | Dimovetz | 10.7 | 4.9 | -0.7 | 21.4 | 22.1 | 588 | 14.2 |
| Test site | Berkovitza | 10.4 | 5.8 | -2.2 | 21.2 | 23.4 | 825 | |

Note: MAT – mean annual temperature, AAMT – average annual minimum temperature, MCMT – mean coldest month temperature, MWMT – mean warmest month temperature, Ic – continentality index, MAP – mean annual precipitation, $H_{24}$ – average height at age 24.

Simple linear and parabolic regression models between the dependent variable HD and some climatic indicators were developed. The transfer distance was calculated as the difference of the respective climatic indicator of planting site (the provenance test) and seed sources (the provenance) – Leites et al. (2012), Lamy et al. (2013). For temperature related climatic indicators (MAT, MCMT, MWMT, Ic), the transfer distance is respectively denoted as MTD (the difference between the average annual temperature), CTD (the difference between the mean coldest month temperatures), WTD (difference between mean warmest month temperatures), DIc (the difference between the continentality index). The positive values denote transfers from climate cooler than the climate of the test site, while negative values represent transfers from climates warmer than that of the test site. Zero denotes the climate of the test site and the best match (Oke and Wang 2013). The transfer distance for mean annual precipitation (MAP) is denoted as DMAP (the difference between mean annual precipitations). Positive values mean that provenances were transferred to a place with more precipitation (more moist climate) and negative values indicate transfer to a drier climate.

Analysis of the data was carried out with the R package stats (R Core Team 2014) and the models were visualized with the graphical functions in the R package ggplot2 (Wickham 2009).

## Results and Discussion

With a one-factor dispersion analysis, the statistical effect ($p < 0.01$) of the group of provenances (Coastal, Continental and Western Cascade) was found at the age of 24 (Table 3).

**Table 3. ANOVA for the height of provenance groups.**

| Indicator | Df | Sum. Sq | Mean Sq | F value | Pr (>F) |
|---|---|---|---|---|---|
| Group | 2 | 114.3 | 57.17 | 6.947 | 0.00215** |
| Residuals | 51 | 419.7 | 8.23 | | |

Note: Signif. codes: *** – 0; ** – 0.001; * – 0.01.

The mean values for the provenance groups in parentheses were compared by Tukey multiple comparisons of mean method and the differences were plotted (Fig. 1). No differences were found between coastal (COAS) and Western Cascades (CASC) provenances – the graph was symmetrically located on both sides of the zero. The provenances of these two groups were comparatively fast-growing and therefore there were no statistical differences between them (Table 4). Significantly slower-growing were continental provenances (CON). The differences between them and Western Cascade provenances (CASC) were entirely negative, i.e. they had a lower average height. The statistical significance of this assertion was high $p = 0.0027$ i.e. $p < 0.01$. The differences between the continental and coastal provenances groups were also negative for the most part. The continental provenances fall back to height on the coastal ones, with the probability of this assertion $p = 0.0745$ being relatively close to the threshold value $p = 0.05$.

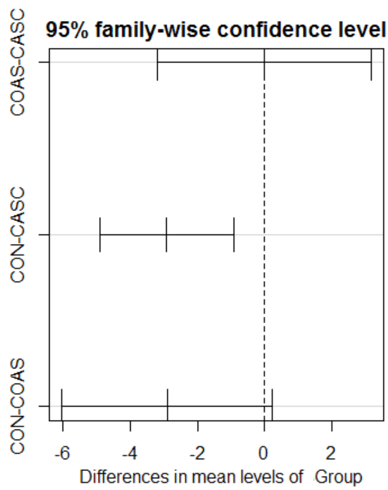



**Fig. 1. Comparison of parent groups by Tukey test.**

Table 5 presents the correlation between the different climatic variables. The established correlation between them does not exclude the specificities in the provenance responses, which were illustrated in the independent regression dependencies shown below. Parallel correlation of parameters allows their interpretation on different climatic indicators to be complementary, allowing for interpretation of the impact on the height of more than one climatic variable.

**Table 4. Statistical differences between the provenance groups.**

| Indicator | Diff | Lwr | Upr | Padj |
|---|---|---|---|---|
| COAS-CASC | -0.007575758 | -3.197051 | 3.1818990 | 0.9999819 |
| CON-CASC | -2.913986014 | -4.920073 | -0.9078992 | 0.0027076 |
| CON-COAS | -2.906410256 | -6.042871 | 0.2300501 | 0.0745497 |

Note: Diff – difference between the mean values of the two groups concerned; Lwr/Upr – lower and upper confidence interval of this difference (the 95 % confidence interval of that difference is between); Padj – the p-value adjusted for multiple comparisons.

**Table 5. Correlation between the climatic variables.**

| Variables | Variables | Cor. coef. | P-value |
|---|---|---|---|
| MAT | MTD | -1 | 0 |
| MAT | CTD | -0.779 | 0 |
| MTD | CTD | 0.781 | 0 |
| MAT | WTD | -0.731 | 0 |
| MTD | WTD | 0.728 | 0 |
| CTD | DIc | -0.75 | 0 |
| WTD | DIc | 0.54 | 0 |
| CTD | DMAP | 0.402 | 0.003 |
| WTD | DMAP | -0.678 | 0 |
| DIc | DMAP | -0.797 | 0 |

Note: MAT – mean annual temperature, MTD – difference between average annual temperature, CTD – difference between the mean coldest month temperatures, WTD – difference between mean warmest month temperatures, DIc – difference between the continentality index, DMAP – difference between mean annual precipitations.

Fig. 2 presents a regression model for the relationship between the relative height of the provenances at the age of 24 (HD) and the difference between the mean annual minimum temperature of the seed source and the planting site (TD). According to Carter (1996), when the peak of the regression curve is at the point where TD = 0, this indicates that the provenances are optimally adapted for growth at locations where the average minimum temperature matches that of the original seed source location. At a peak at the point where TD is a negative number, the provenances grow best in warmer locations with a corresponding deviation of 0 °C, and at a peak at the point where TD is a positive number, the provenances grow best at sites cooler than their original locations. The model obtained in the present study is identical to that used by Carter (1996). Here the peak of the regression curve (parabola) for the Douglas-fir provenance test is at TD = -1.66 °C, which shows that the optimal growth of Douglas-fir in the studied provenance test is observed for provenances transferred

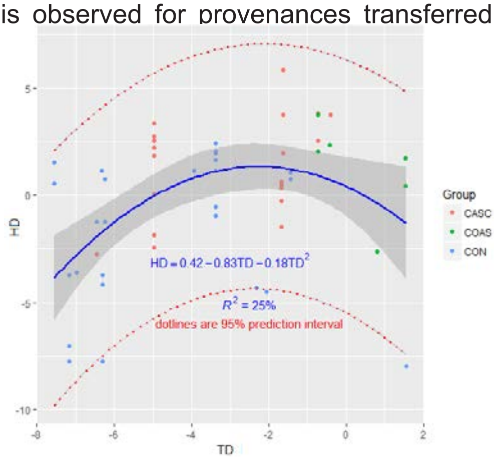



**Fig. 2. Correlation between the relative height at the age of 24 and the difference in the mean annual minimum temperature between the seed source and the provenance test (TD).**

from cooler places with 1.66 °C compared to provenance test (Fig. 2). All provenances, the relative heights of which are greater than the ordinate's value 0, are higher than the 'local' provenance.

For the continental group (CON), the moving in the provenance test was to a warmer climate, with the difference in the mean minimum temperature of the seed source and the planting site being a negative number. The only exception was the provenance Alamogordo from New Mexico, for which the relocation to Bulgaria is with about 10 ° to the north and in a cooler climate (Tables 1 and 2). For 14 of the continental provenances their height growth in provenance test conditions is slower than that of 'local' provenances. The other 12 provenances had a better growth than them. For all Western Cascade provenances (CASC), the moving was to a warmer climate. Under these conditions, most were taller than the 'local' provenance. For half of the coastal provenances (COAS), the transfer is to warmer climate and for the other – to a cooler climate than the seed source. There were taller than the 'local' provenance, with the exception of the provenance 34 Toledo, which retreats on this indicator to the 'local' provenance (Table 2).

A regression relationship, represented by a parabolic model (Fig. 3), was established regarding the difference between the temperature of the coldest month of the provenance test and the seed source (CTD). The model is statistically significant with a value of $R^2$ = 0.28 and p-value = 0.0002196 i.e. p <0.001. The peak of the regression curve of the parabolic model is at CTD = -5.5 °C, i.e. the optimal height growth is observed for provenances for which the winters in the provenance test are colder than 5.5 °C from the point of origin. This condition corresponds to coastal provenances 10 and 11 Bremerton and the continental provenances from Southern Oregon 50 and 51 Medford. Similar is the transfer distance (-5.6 °C) for the provenances of Western Cascades 40–46 Oakridge (Table 2). For all Western Cascades provenances (CASC) and for the coastal (COAS) provenances, relocation is to colder winters. For most of the continental provenances, the transfer to North-Western Bulgaria is to a colder winter, and only for a part of it to a warmer winter. The shifted provenances to a colder winter have better growth on height than the 'local' provenance compared to those for which the relocation is to a warmer winter (Fig. 3, Table 2). Such a conclusion is made by Leites et al. (2012), who investigate the height growth response of Douglas-fir continental provenances to climate change using the mean temperature of the coldest month and identifying it as the most sensitive climatic indicator.

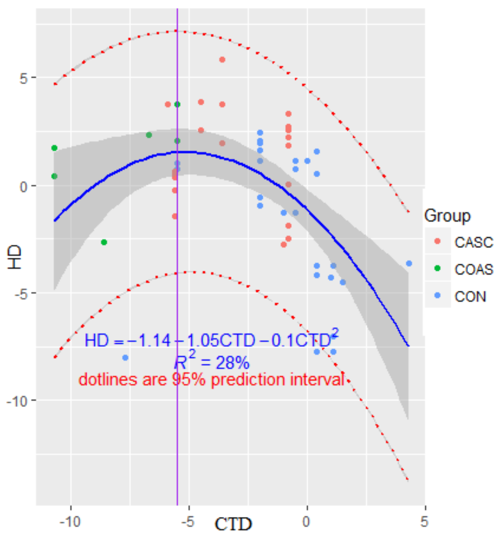



**Fig. 3. Correlation between the provenances relative height at the age of 24 (HD) and the difference in the coldest month temperatures between provenance test and seed source (CTD, °C)**

The correlation between the relative height and the difference in the continentality index is presented in Fig. 4 with two regression models – linear (Fig. 4a) and parabolic (Fig. 4b), the statistical significance of the linear is respectively $R^2 = 0.22$ and p-value = 0.0003765 and for parabolic $R^2 = 0.31$ and p-value = 0.00006. The continentality index (Ic) of the provenances varies from 7.1 (extreme hyperoceanic climate, typical for coastal provenances 52 and 53 Brookings – Table 2) to 25.5 (moderate continental for provenance Greenwood) – Rivas-Martinez et al. (2017). Moderate continental (Ic = 23.4) is the provenance test climate, as well. With increasing the difference in the continentality index (DIc) and the relative height (HD) when the transfer is to more continental climate, the provenances are taller than the 'local' one. Particularly great were the differences in the moving of the coastal provenances (COAS) but this does not negatively affect their growth. The optimum in height growth was observed when the continentality index increases by 12.7 towards the seed sources. Chakraborty et al. (2015) point out the continentality as one of the most important climatic indicators that influence the Douglas-fir provenances growth in provenance tests in Austria and Germany.

A regression correlation between the relative height and the difference in the mean annual precipitation (DMAP) between the planting site and seed source was presented by a linear model (Fig. 5). The model is statistically significant with values of $R^2 = 0.24$ and p-value = 0.0002. Positive DMAP values indicate that the provenances are transferred to more humid conditions, i.e. the annual precipitations of the provenance test is bigger than that of the corresponded provenance. It is clearly seen from Fig. 5, that the all continental provenances (CON) were transferred to more humid climate, while coastal (COAS) and Western Cascade provenances (CASC) were moved to significantly more dry conditions. The figure shows clear clustering of provenances with most continental provenances having a lower height than 'local' provenance. It seems illogical when increasing the precipitations in the new location, the provenances do not take advantage of better humidity conditions, which should have a positive effect

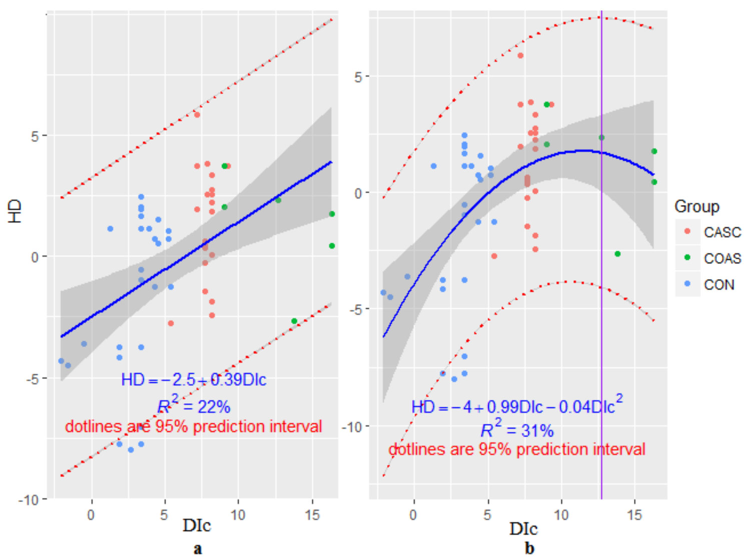



**Fig. 4. Correlations (a – linear and b – parabolic) between the relative height at the age of 24 (HD) and the difference in the continentality index of the provenance test and the seed source (DIc).**

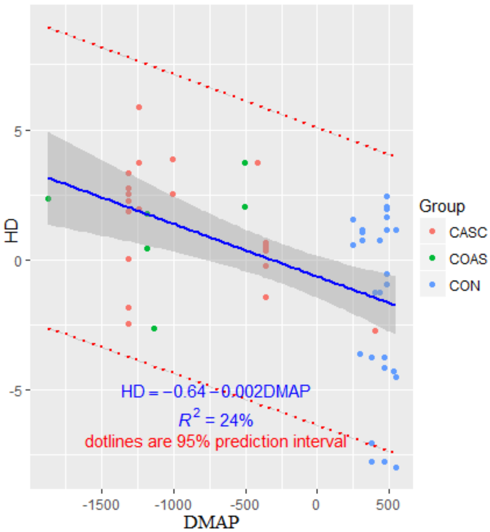



**Fig. 5. Correlation of the relative height at the age of 24 (HD) and the difference in the average annual precipitations (DMAP, mm).**

on their height growth. Here, on the one hand, the genetic features of provenances are interfered. Part of the continental provenances refer most likely to *Pseudotsuga menziesii* var. *glauca*, which is characterized by significantly poorer growth than *Pseudotsuga menziesii* var. *menziesii.* Another factor influencing the growth of the continental provenances was their susceptibility to the fungal pathogens *Phaeocryptopus gaeumannii* (Rohde) Petrak and to *Rhabdocline pseudotsugae* Syd., which are also found in the studied provenance test, a prerequisite for the development of which are the more humid conditions of this location. The continental provenances Greenwood and Keremeos from Washington, Whitefish from Montana, Bates and Canyon City from Eastern Oregon and Alamogordo from New Mexico have the poorest growth and highest sensitivity to the above mentioned fungal pathogens (Petkova et al. 2014). Kimberley et al. (2011) in New Zealand also determined decline of Douglas-fir growth due to fungal pathogen *Phaeocryptopus gaeumannii* (Rohde) Petrak.

Regression correlation was also found in the mean annual temperature (MAT) and the difference in the mean warmest month temperature (WTD), but the established correlations are poor (with $R^2 < 0.15$). However, the obtained models are presented because the results correspond to those obtained by other authors.

For example, a strong correlation was established between MAT and MTD (Table 5), which means that the studied model correlations for MAT are also expected for MTD. However, the search for regression correlations between HD and MTD did not lead to adequate models, and testing of the correlation between HD and MAT was done using the $y = a + bx + cx^4$ model due to the presence of a strongly divergent value of MAT (provenance Alamogordo 55 – Table 2). The regression correlation between HD and MAT is presented in Fig. 6. The resulting parabolic model shows that the optimal height growth is characterized by the provenances of sites with an average annual temperature of 9.4 °C. This condition corresponds to the provenances of Darrington by Western Cascade Mountains in Washington State. This result is consistent with the conclusion of Chakraborty et al. 2016, according to data for 290 origins of Douglas-fir in 50 provenance tests in Austria and Germany, that the best growth is the provenances of Western Cascades and the coastal areas of Washington, Oregon and British Columbia, for which the average annual temperature is from 6 to 9.5 °C. The provenance 7 Darrington is one of the tallest provenance and in another Douglas-fir prove-

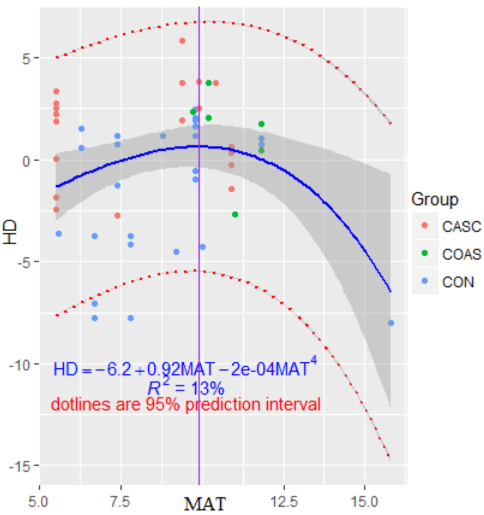



**Fig. 6. Correlation between the relative height of the provenances at the age of 24 (HD) and the mean annual temperature (MAT) of the seed sources.**

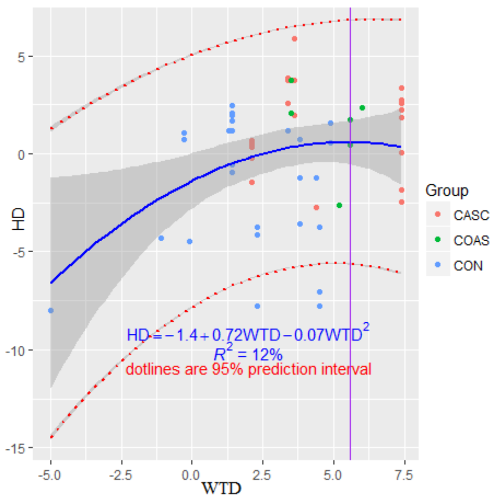



**Fig. 7. Correlation between the relative height at the age of 24 (HD) and the difference in mean warmest month temperatures of provenance test and seed source (WTD, ℃).**

nance test, established in South-Western Bulgaria (Popov 2011).

The correlation between height and mean warmest month temperatures was also presented with parabolic model (Fig. 7). The transfer for most provenances (except continental Alamogordo, Greenwood, Keremeos and Medford) was for a warmer summer compared to the seed source. The peak of the parabolic model is at WTD = 5.6 °C, i.e. the growth optimum is for provenances that have been moved from a cooler summer to 5.6 °C compared to this of the provenance test (Fig. 7). Under these conditions, almost half of the provenances have better growth than the 'local' provenance. Correlation of the growth rate of 8 Douglas-fir provenances on mean warmest month temperature is also found by Montwé et al. (2015) in provenance test in British Columbia (Canada).

## Conclusions

The climatic conditions in the studies provenance test (North-Western Bulgaria) differ from those in the natural range of the Douglas-fir, from where the seeds were imported.

For continental provenances, the transfer is to more humid and warmer climate, but they do not response with better growth, on the contrary, their height growth is poor. An explanation for this is their genetic features and their infection with the fungal pathogens *Phaeocryptopus gaeumannii* (Rohde) Petrak and *Rhabdocline pseudotsugae* Syd., to which they are susceptible.

Coastal and West Cascade Mountains provenances are found on more prominent continental and drier climate, but they grow well. Thus Oakridge's provenances from the Western Cascades in the provenance test in North-Western Bulgaria at the age of 24 have an average height of 12.7 to 14.8 m or 0.52 – 0.62 m average annual height increment, and in provenance tests in their natural range – British Columbia (Canada) and Oregon (USA) at the age of 48 have an average height of 25.17 m or 0.52 m mean annual height increment (Ye and Jayawickrama 2014), i.e. the values of the increment are similar. These provenances were transferred to North-Western Bulgaria in a more continental climate with lower annual precipitations, cooler winter and warmer but more humid summer. So far, their height growth is not negatively affected by the changed climate conditions. It can be assumed that such an assertion will be valid for the other provenances from these two groups, but requires confirmation by facts about their growth in their maternal climate.

## Acknowledgments

The author would like to thank Assoc. Prof. Dr. Emil Molle from the University of Forestry – Sofia for his help for the statistical procedures and deduced regression dependencies.

## References

Andalo C., Beaulieua J. Bousquet J. 2005. The impact of climate change on growth of local white spruce populations in Quebec, Canada, Forest Ecology and Management 205: 169–182.

Anonimous 2018. CLIMATE-DATA.ORG. Available at: https://en.climate-data.org/continent/north-america/

Carter K.K. 1996. Provenance tests as indicators of growth response to climate change in 10 north temperate tree species. Canadian Journal of Forest Research 26: 1089–1095.

Chakraborty D, Wang T, Andre K, Konnert, M, Lexer, M.J., Matulla, C., Schueler, S. 2015. Selecting populations for non-analogous climate conditions using universal response functions: the case of Douglas-fir in Central Europe. PloS One 10:e0136357

Chakraborty D., Wang T., Andre K., Konnert M., Lexer MJ, Matulla C., Weissenbacher L., Schueler S. 2016. Adapting Douglas-fir woods in Central Europe: evaluation, application and uncertainty analysis of a genetically based model. European Journal of Forest Research 135(5): 919–936.

Isaac-Renton M.G, Roberts,D. R., Hamann, A., Spiecker H. 2014. Douglas-fir plantations in Europe: a retrospective test of assisted migration to address climate change. Global Change Biology 20: 2607–2617.

Kimberley M.O., Hood I.A., Knowles R.L. 2011. Impact of Swiss needle-cast on growth of Douglas-fir. Phytopathology 101: 583–593.

Koleva E., Peneva R. 1990. Climatic reference book – Rainfalls in Bulgaria, BAS, Institute of Meteorology and Hydrology, Sofia. 169 p. (in Bulgarian).

Kyuchukova M. (Ed.), Moraliiski E., Koleva E., Stoychev St., Blaskova D., Ivanov P., Lingova St. 1983. Climatic reference book of Bulgaria. Vol. 3: Air temperature, soil temperature, frost. Nauka i izkustvo. 440 p. (in Bulgarian).

Lamy J.-B., Delzon S., Kremer A. 2013. Adaptive potential – a partial insurance against climate change risks, In.: Fitzgerald, J. and Lindner, M. (eds.) (2013) Adapting to climate change in European forests – Results of the MOTIVE project. Pensoft Publishers, Sofia: 22–27.

Leites L., Robinson A., Rehfeldt G., Marshall J., Crookston N. 2012. Height-growth response to climatic changes differs among populations of Douglas-fir: a novel analysis of historic data. Ecological Applications 22: 154–165

Messaoud Y, Chen H.Y.H. 2011. The Influence of Recent Climate Change on Tree Height

Growth Differs with Species and Spatial Environment. PloS ONE 6(2): e14691. doi:10.1371/journal.pone.0014691

Montwé D, Spiecker H., Hamann A. 2015 Five decades of growth in a genetic field trial of Douglas-fir reveal trade-offs between productivity and drought tolerance Tree Genetics & Genomes 11:29, DOI 10.1007/s11295-015-0854-1

O'Neill G.A., Nigh G. 2011. Linking population genetics and tree height growth models to predict impacts of climate change on forest production. Global Change Biology 17: 3208–3217.

Oke O.A., Wang J.R. 2013. Assessing effects of seed source and transfer potential of white birch populations using transfer functions. Open Journal of Ecology 3(5): 359–369.

Pedlar J.H., McKenney D.W. 2017. Assessing the anticipated growth response of northern conifer populations to a warming climate. Scientific Reports 7: 43881. DOI: 10.1038/srep43881

Petkova K., Georgieva M., Uzunov M. 2014. Investigation of Douglas-fir provenance test in North-Western Bulgaria at age 24. Journal of Forest Science 60(7): 288–296.

Popov E. 1990. The influence of Douglas Fir (*Pseudotsuga menziezii* (Mirb.) Franco) seed provenances on the growth in the height, terminal but formation and the frost resistance of one year old seedlings. – Nauka za gorata (Forest science) 3: 3–17 (in Bulgarian).

Popov E. 1991. Study on the results from the introduction of the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Bulgaria. PhD thesis, Bulgarian Academy of Sciences, Forest Research Institute, Sofia: 1–162 (in Bulgarian).

Popov E. 2011. Height and coefficient of stability of trees in Douglas-fir provenance trial plantation in Kostenets region. Plant Studies I: 94–99. (in Bulgarian with English abstract).

R Core Team 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org/

Reich P.B., Oleksyn J. 2008. Climate warming will reduce growth and survival of Scots pine except in the far north. Ecology Letters 11: 588–597.

Restaino C.M., Peterson D.L., Little J. 2016. Increased water deficit decreases Douglas-fir growth throughout western US forests. PNAS 113(34): 9557–9562. Available at: https://doi.org/10.1073/pnas.1602384113

Rivas-Martínez S., Penas A., del Rio S., Diaz Gonzalez T.E., Rivaz-Sáenz S. 2017. Bioclimatology of the Iberian Peninsula and the Balearic Islands. In: Loidi J (Ed.) The Vegetation of the Iberian Peninsula. Springer International Publishing, vol. 1: 29–81.

Schmidtling R.C. 1994. Use of provenance tests to predict response to climate change: loblolly pine and Norway spruce. Tree Physiology 14: 805–817.

Spittlehouse D.L. 2003. Water Availability, Climate Change and the Growth of Douglas-Fir in the Georgia Basin, Canadian Water Resources Journal 28(4): 673–688. DOI: 10.4296/cwrj2804673

Ye T.Z, Jayawickrama K.J.S. 2014. Geographic Variation and Local Growth Superiority for Coastal Douglas-fir – Rotation-age Growth Performance in a Douglas-fir Provenance Test. Silvae Genetica 63(3): 116–125.

Wang T., Hamann A., Spittlehouse D.L., Aitken S.N. 2006. Development of scale-free climate data for Western Canada for use in resource management. International Journal of Climatology 26: 383–397.

Wang T., Hamann A, Spittlehouse D, Carroll C. 2016. Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America. PLoS ONE 11(6):e0156720. doi:10.1371/journal.pone.0156720.

Wickham H. 2009. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York. 107 p.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 121–130

# PHYTODIVERSITY AND STAND CHARACTERS OF SIX OAK (*QUERCUS LEUCOTRICHOPHORA* A. CAMUS) FORESTS IN GARHWAL HIMALAYA, UTTARAKHAND, INDIA

Vikaspal Singh[1*], Sunil Prasad[2], and Dhanpal Singh Chauhan[3]

[1]Dolphin PG Institute of Biomedical and Natural Sciences, Department of Forestry, Manduwala, Dehradun, Uttarakhand, India. [*]E-mail: vikaspals@gmail.com
[2]Ecology and Biodiversity Services, Dehradun, Uttarakhand, India.
E-mail: bhat.sunil.for@gmail.com
[3]Department of Forestry and Natural Resources, HNBGU, Srinagar, Uttarakhand, India.
E-mail: dschauhan2008@gmail.com

Received: 21 March 2018 Accepted: 26 October 2018

## Abstract

A plant quantitative investigation was carried out at six oak (*Quercus leucotrichophora* A. Camus) dominated stands in different locations of Gahrwal Himalaya. A total of 28 tree species with 17 families, 41 shrub species with 21 families and 50 herb species with 22 families were observed in all studied oak stands. In tree layer maximum 15 genera were recorded in Chaurangikhal oak stand and minimum number of genera (11) was found in Chadrabadani, Diwalikhal and Ghuttu oak stand. For shrub layer highest number of genera (25) was observed in Ghuttu oak stand and lowest (18) – for Chadrabadani, Chaurangikhal and Makku oak stands. Herb layer showed maximum 32 genera, found at Ghuttu oak stand and minimum genera (15) – at Chandrabadani oak stand. Comparatively *Quercus leucotrichophora* have greater values of density, basal area and Important Value Index (IVI) among all studied oak stands to the rest of associated dominant tree species. Highest density (823.6 plant·ha$^{-1}$) and IVI (170.8) for *Quercus leucotrichophora* was observed at Diwalikhal oak stand, while, lowest density (176.7 plants·ha$^{-1}$) and IVI (126.3) was found at Makku and Chaurangikhal oak stands, respectively.

**Key words:** altitudinal range, basal area, density, Important Value Index, sapling, seedling.

## Introduction

Plant diversity analysis is an important part for determining the quantitative information, species composition, regeneration, species richness, etc., of a forest stand. Forest diversity is the main source of livelihood of rural mass with different needs as well as various ecosystem services. Oaks in the Himalayan region are intimately linked with subsistence hill agriculture as they protect soil fertility, watershed and local biodiversity. They also supply fodder, leaf litter, firewood and timber. They are also one of the most over-exploited species and fail to regenerate adequately either in disturbed or undisturbed natural habitat (Shrestha 2003). Oaks dominate the canopy in many temperate forests of the Himalayan region. In comparison to other forests such as pine, oak forests are characterized by higher species diversity, stratification, litter production and soil fertility (Shrestha 2003). Various studies and informative literature in Garhwal Himalalya have been conducted regarding oak forests. Recently Prasad et al. (2017) analyzed the relationship of disturbance with aspect and altitudes in oak belt of Garhwal Himalaya. Some other studies have been also done along altitudinal gradients for population structure, vegetation status and diversity by Chauhan et al. (2014), Pokhriyal et al. (2012) and Singh et al. (2015) in Garhwal region. Six forest types of Uttarakhand have been explored by Ram et al. (2004) for plant diversity analysis in *Quercus leucotrichophora* A. Camus and *Pinus roxburghii* Sarg. forests and advocated for the conservation and management of these forests.

Structural characteristics of the Himalayan oak forests have been studied by various workers (Upreti et al. 1985; Singh and Singh, 1986, 1987, 1992; Singh et al. 1994, Rathore et al. 1997, Kumar et al. 2009, Uniyal et al. 2010, Chauhan et al. 2014, Singh et al. 2015). A well-known multiple use value of *Quercus leucotrichophora* makes this species preferable at research front by the researchers and scientists from various parts of the world. Present study focuses not only oak species but emphasiz on associate tree species, as well. Therefore present study is an effort to investigate oak forest stands of different locations and altitudinal difference with the following objectives: i) phytodiversity and stand characters of oak stands, ii) diversity of associate species, and iii) status of sapling and seedling density of major dominant species.

## Methodology

### Study area and sample plots

This study was conducted in Garhwal (West Himalaya) in six oak stands at different altitudinal ranges: Chandarabadani 1700–2100 m, Ghuttu 1800–2300 m, Dewalikhal 1500–2200 m, Makku 1800–2300 m, Chaurangkhal 2100–2500 m, Khirsoo 1600–2100 m from Tehri, Chamoli, Rudraprayag, Uttarakashi and Pauri districts of Uttarakhand, respectively (Fig. 1). Systematic random sampling was done, two sample plots (0.1 ha each) in each site were randomly identified and 10 quadrats 10 × 10 m for tree sampling were placed at random on each plot. In each 10 × 10 m quadrat, nested quadrat of 5 × 5 m was used for shrub and sapling sampling and 1 × 1 m quadrats – for herb and seedling sampling. All six oak forest stands were explored for vegetation analysis, sapling and seedling density and diversity parameters (Table 1).

**Table 1. Studied oak stands with their geographical locations.**

| Stand No | Oak stands | District | Altitudinal range, m | Latitude | Longitude |
|---|---|---|---|---|---|
| 1 | Chandrabadani | Tehri | 1700–2100 | 30°18’58.1’’ N | 78°36’18.4’’ E |
| 2 | Chaurangikhal | Uttarkashi | 2100–2500 | 30°38’30.7’’ N | 78°28’59.2’’ E |
| 3 | Diwalikhal | Chamoli | 1500–2200 | 30°05’29.9’’ N | 79°14’30.4’’ E |
| 4 | Ghuttu | Tehri | 1800–2100 | 30°32’02.6’’ N | 78°49’15.2’’ E |
| 5 | Khirsoo | Pauri | 1600–2100 | 30°08’17.4’’ N | 78°50’47.4’’ E |
| 6 | Makku | Rudraprayag | 1800–2300 | 30°29’11.4’’ N | 79°07’32.0’’ E |

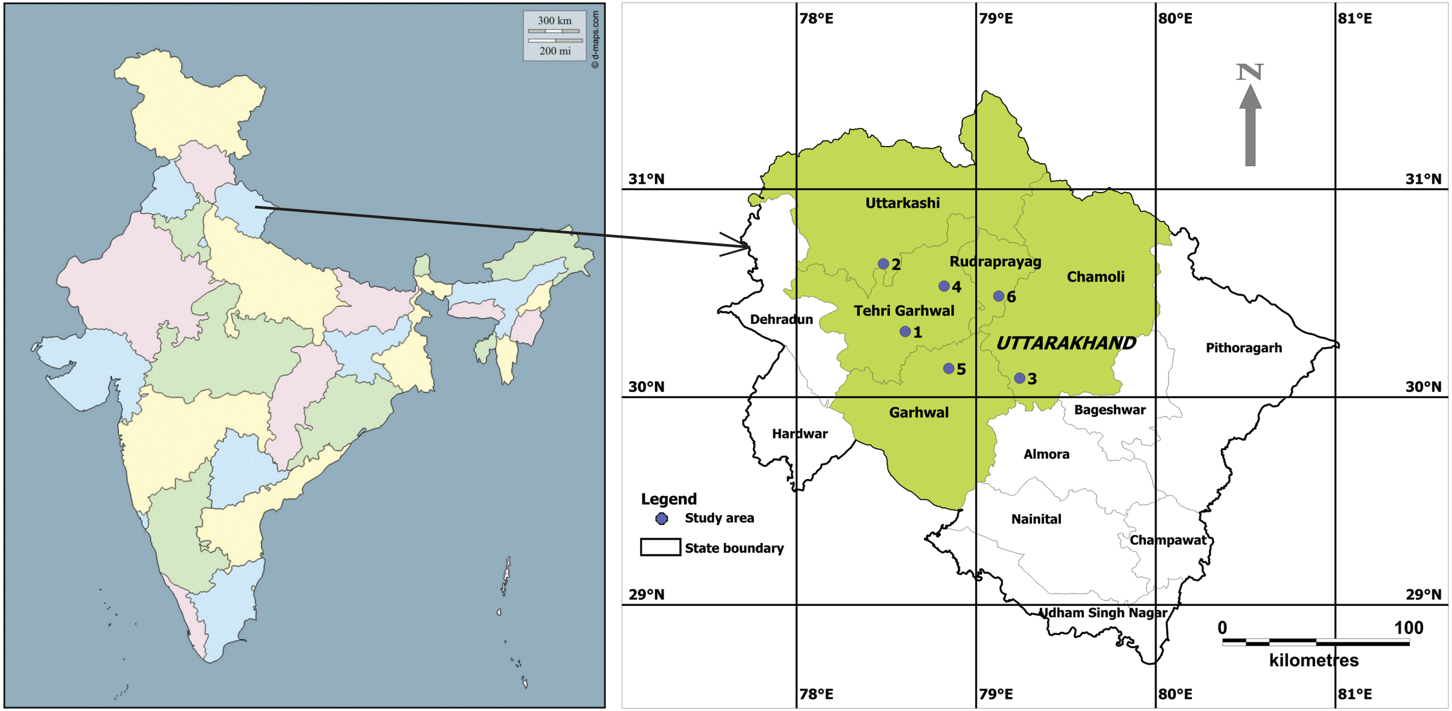



**Fig. 1. Location map of study area.**
Studied oak stand by numeric: 1 – Chandrabadani (Tehri district), 2 – Chaurangikhal (Uttarkashi district), 3 – Diwalikhal (Chamoli district), 4 – Ghuttu (Tehri district), 5 – Khirsoo (Pauri district), 6 – Makku (Rudraprayag district).

**Phytosociological analysis**

The phytosociological status was determined as per Mueller-Dombois and Ellenberg (1974) and Mishra (1968). The frequency, density, dominance and relative values for each species of the community were calculated. Different diversity indices were calculated using the following equations of Shannon Index (Shannon and Wiener 1963) (eq. 1), Simpson's index (Simpson 1949) (eq. 2), Margalef Index (Margalef 1968) (eq. 3):

$$H^{'} = -\sum p_i \cdot I_n \cdot p_i \qquad (1),$$

$$CD = \sum (n_i / n) \cdot 2 \qquad (2),$$

$$SR = S - 1 / I_n(N) \qquad (3),$$

where: $H'$ – the Shannon-Weaver index; $p_i$ – the proportion of individuals belonging to species; $I_n$ – the natural log; $CD$ – the Simpson's index; $n_i$ – total sum of an individual species; $n$ – total sum of all species; $SR$ – the Margalef index of species richness; $S$ – the number of species; $N$ – the total number of individuals.

## Results

**Vegetation composition**

Vegetation composition of the all six oak stands is present in Table 2. A total of 28 species of trees, 42 species of shrubs and 50 species of herbs were recorded belong to 17, 21 and 22 families respectively. Maximum tree species (17) were found at Chaurangikhal oak stand and minimum number (11) of tree species were recorded at Ghuttu oak stand. *Quercus leucotrichophora, Rhododendron arboreum* Sm., *Lyonia ovalifolia* (Wall.) Drude and *Myrica esculenta* Buch.-Ham. ex D. Don were dominant species among all oak stands. In shrub strata, Ghuttu and Khirsoo oak stand recorded highest (27) species while, lowest (19) species were found in Chandrabadani oak tand. Dominant shrub species included *Eupatorium adenophoram* (Spreng.) King & H. Rob. and *Berberis aristata* DC. Herb strata was composed of 50 species represented by 22 families, of which maximum 37 species were found at Ghuttu oak stand and minimum 16 species were observed at Chandrabadani oak stand. The dominant herb species in all stands were observed as *Andropogon munroi* C. B. Clarke, *Cynodon dactylon* (L.) Pers. and *Fragaria nubicola* Lindl. ex Lacaita. Large number of genera in a plant community may have an important role in plant diversity. In tree strata, stands of Ghuttu, Khirsoo and Makku have greater number of genera of respective species, however shrub strata consisted of less number of genera of respective species. In herb strata greater number of gernera was counted for Chaurangikhal, Diwalikhal and Makku oak stands.

**Diversity**

Shannon, Simpson and Margalef indices were calculated for all sampled species recorded in all oak stands. For tree layer, the highest Shannon diversity (1.23) was obtained in Chaurngikhal oak stand and lowest (1.04) at Ghuttu oak stand. Simpson index of tree strata was found within the range of 0.25–0.45. As far as the Margalef index was concerned, Chaurangikhal oak stand showed the highest value of 1.665, followed by 1.522 at Makku, 1.294 at Chandrabadani and 1.273 at Diwalikhal oak stand. Shrub strata achieved maximum Shannon diversity (1.43) at Ghuttu oak stand, while its minimum (1.13) was found at the Diwalikhal oak stand. Highest value of Simpson di-

**Table 2. Vegetation composition of tree, shrub and herb layer in studied oak stands.**

| | Chandrabadani (1700–2100 m) | Chauragikhal (2100–2500 m) | Diwalikhal (1500–2200 m) | Ghuttu (1800–2300 m) | Khirsoo (1600–2100 m) | Makku (1800–2300 m) |
|---|---|---|---|---|---|---|
| Tree strata (28 species, 17 family) | | | | | | |
| Species | 12 | 17 | 12 | 11 | 14 | 12 |
| Genera | 11 | 15 | 11 | 11 | 14 | 12 |
| Dominant species | *Quercus leucotrichophora*<br>*Rhododendron arboreum*<br>*Lyonia ovalifolia*<br>*Myrica esculenta* | *Quercus leucotrichophora*<br>*Rhododendron arboreum*<br>*Lyonia ovalifolia* | *Quercus leucotrichophora*<br>*Rhododendron arboreum*<br>*Lyonia ovalifolia*<br>*Myrica esculenta* | *Quercus leucotrichophora*<br>*Rhododendron arboreum*<br>*Lyonia ovalifolia* | *Quercus leucotrichophora*<br>*Rhododendron arboreum*<br>*Lyonia ovalifolia*<br>*Myrica esculenta* | *Quercus leucotrichophora*<br>*Rhododendron arboreum*<br>*Lyonia ovalifolia*<br>*Myrica esculenta* |
| Shrub strata (42 species, 21 family) | | | | | | |
| Species | 19 | 20 | 20 | 27 | 27 | 20 |
| Genera | 18 | 18 | 19 | 25 | 24 | 18 |
| Dominant species | *Eupatorium adenophoram*<br>*Myrisinea fricana*<br>*Caryopteris foetida* | *Eupatorium adenophoram*<br>*Berberis aristata*<br>*Rosa macrophylla* | *Eupatorium adenophoram*<br>*Berberis aristata*<br>*Myrisinea fricana* | *Eupatorium adenophoram*<br>*Berberis aristata*<br>*Leptodermis lanceolata*<br>*Rubus foliolosus* | *Berberis aristata*<br>*Caryopteris foetida*<br>*Eupatorium adenophoram* | *Berberis aristata*<br>*Eupatorium adenophoram*<br>*Rosa macrophylla* |
| Herb strata (50 species, 22 family) | | | | | | |
| Species | 16 | 25 | 21 | 37 | 21 | 19 |
| Genera | 15 | 25 | 21 | 32 | 20 | 19 |
| Dominant species | *Andropogon munroi*<br>*Cynadon dactylon*<br>*Fragaria nubicola* | *Andropogon munroi*<br>*Chrysopogon gryllus*<br>*Cynadon dactylon*<br>*Fragaria nubicola* | *Anaphalis adnata*<br>*Andropogon munroi*<br>*Cynadon dactylon*<br>*Fragaria nubicola*<br>*Galium asperifolium*<br>*Herteropogon contortus* | *Andropogon munroi*<br>*Cynadon dactylon*<br>*Fragaria nubicola*<br>*Valeriana jatamansi* | *Anaphalis adnata*<br>*Andropogon munroi*<br>*Cynadon dactylon*<br>*Micromaria biflora*<br>*Valeriana jatamansii* | *Andropogon munroi*<br>*Cynadon dactylon*<br>*Fragaria nubicola*<br>*Valeriana jatamansii*<br>*Vicia tenera* |

versity (0.19) was found at Chandrabadani oak stand, followed by Makku (0.15) and Khirsoo oak stands (0.14). In the context of Margalef diversity of shrub strata, the values were recorded within the range of 2.497–3.237. In the herb strata, highest Shanon diversity (1.57) was observed at Ghuttu oak stand and lowest (1.20) – at Chandrabadani oak stand. Chandrabadani and Ghuttu oak stands showed maximum and minimum values of Simpson diversity – 0.21 and 0.08, respectively, in herb strata. Margalef index was observed between the ranges of 1.637–2.085 in all studied oak stands (Table 3).

## Stand characters

The dominant species recorded in addition to *Quercus leucotrichophora* were *Rhododendron arboreum, Lyonia ovalifolia* and *Myrica esculenta.* Comparatively *Quercus leucotrichophora* have greater values of density, basal area and IVI among all studied oak stands to the rest of associated tree species. Highest density (823.6 plant·ha$^{-1}$) and IVI (170.8) for *Quercus leucotrichophora* was observed at Diwalikhal oak stand, while lowest density (176.7 plants·ha$^{-1}$) and IVI (126.3) was found at Makku and Chaurangikhal oak stands, respectively. *Rhododendron arboreum* was observed as second most dominant species having maximum tree density (160.0 plants·ha$^{-1}$), basal area (0.24) and IVI (50.4) in Makku oak stand. Least density (41.37 plants·ha$^{-1}$) of *Rhododendron arboreum* was found at Chandrabadani oak forest. Diwalikhal oak stand showed minimum basal area (0.13) and IVI (31.4) for *Rhododendron arboreum. Lyonia ovalifolia* exhibited as next dominant tree species in all studied oak stands, which achieved its maximum density (149.1 plants·ha$^{-1}$), basal area (0.26) and IVI (50.6) at Ghuttu oak stand. Minimum density (12.5 plants·ha$^{-1}$), basal area (0.07) and IVI (23.0) were recorded at Chandrabadani, Diwalikhal and Chaurangikhal oak stands, respectively. *Myrica esculenta* was only found at four oak stands out of six. Khirsoo oak stand is considered most suit-

**Table 3. Diversity attributes of tree, shrub and herb layer in studied oak stands.**

| Oak stands | Tree layer | | | Shrub layer | | | Herb layer | | |
|---|---|---|---|---|---|---|---|---|---|
| | Shannon | Simpson | Margalef | Shannon | Simpson | Margalef | Shannon | Simpson | Margalef |
| Chandrabadani | 1.08 | 0.35 | 1.294 | 1.28 | 0.19 | 2.871 | 1.20 | 0.21 | 1.637 |
| Chaurangikhal | 1.23 | 0.25 | 1.665 | 1.30 | 0.08 | 2.918 | 1.40 | 0.17 | 2.017 |
| Diwalikhal | 1.08 | 0.45 | 1.273 | 1.13 | 0.09 | 3.237 | 1.32 | 0.12 | 2.085 |
| Ghuttu | 1.04 | 0.31 | 1.233 | 1.43 | 0.07 | 2.595 | 1.57 | 0.08 | 1.925 |
| Khirsoo | 1.15 | 0.44 | 1.170 | 1.18 | 0.14 | 3.112 | 1.32 | 0.15 | 1.858 |
| Makku | 1.06 | 0.30 | 1.522 | 1.30 | 0.15 | 2.497 | 1.28 | 0.18 | 1.930 |

able for *Myrica esculenta* having highest values of density (165.4 plants·ha$^{-1}$), basal area (0.17) and IVI (45.5). The lowest density (67.5 plants·ha$^{-1}$) of *Myrica esculenta* was found at Chandrabadani oak stand but basal area and IVI was lowest recorded at Diwalikhal oak stand as 0.06 and 28.5 (Table 4).

Sapling and seedling occurrence shows the regeneration potential of species present in a forest stand. Higher sapling and seedling density of *Quercus leucotrichophora* was recorded as 2.93 plants/25 m$^2$ and 1.85 plants·m$^{-2}$, respectively, at Khirsoo oak stand, followed by Chandrabadani oak stand for sapling density and Chaurangikhal oak stand for the seedling density. *Rhododendron arboreum* displayed maximum sapling density (0.58 plants/25 m$^2$) again at Khirsoo oak stand, followed by Ghuttu (0.55 plants/25 m$^2$) and Chaurangikhal oak stands. Higher seedling density of this species was recorded at Chaurngikhal, Diwalikhal and Khirsoo oak stands. *Lyonia ovalifolia* showed greater density at Khirsoo oak stand and was recorded least at Chaurngikhal oak forest stand, while density at seedling stage of this species was found within the range 0.11 plants·m$^{-2}$ – 0.47 plants·m$^{-2}$. *Myrica esculenta* was absent at Chaurangikhal and Ghuttu oak stands and showed higher sapling (0.58 plants/25 m$^2$) and seedling density (0.33 plans·m$^{-2}$) at Khirsoo oak stand (Table 5).

Statistical analysis was carried out using Gen Stat Version-32 and analyzed applying 2-way ANOVA. The analysis of density, basal area and IVI of *Quercus leucotrichophora* and its associate species revealed that species differ highly significantly at the level *P = 0.001 of* probability. The analysis for all the character is shown on Table 6.

**Table 4.** Tree density (plants/ha), basal area (m$^2$/ha) and IVI (Important Value Index) of dominant tree species in studied oak stands.

| Studied oak | *Quercus leucotrichophora* | | | *Rhododendron arboreum* | | | *Lyonia ovalifolia* | | | *Myrica esculanta* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| stands | Density | Basal area | IVI | Density | Basal area | IVI | Density | Basal area | IVI | Density | Basal area | IVI |
| Chandrabadani | 522.5 | 1.14 | 144.7 | 41.3 | 0.21 | 44.6 | 12.5 | 0.13 | 43.2 | 67.5 | 0.07 | 29.1 |
| Chaurangikhal | 564.0 | 1.24 | 126.3 | 136.0 | 0.21 | 38.1 | 106.0 | 0.17 | 23.0 | - | - | - |
| Diwalikhal | 823.6 | 1.13 | 170.8 | 103.6 | 0.13 | 31.4 | 121.8 | 0.07 | 31.6 | 85.5 | 0.06 | 28.5 |
| Ghuttu | 512.7 | 1.00 | 138.7 | 138.2 | 0.22 | 46.5 | 149.1 | 0.26 | 50.6 | - | - | - |
| Khirsoo | 798.2 | 1.17 | 156.2 | 123.6 | 0.21 | 40.2 | 58.2 | 0.17 | 24.5 | 165.4 | 0.17 | 45.5 |
| Makku | 167.7 | 1.08 | 135.7 | 160.0 | 0.24 | 50.4 | 106.7 | 0.17 | 38.1 | 83.3 | 0.11 | 28.6 |

**Table 5. Sapling density (plants/25m²) and seedling density (plants/m²) of major dominant tree species in studied oak stands.**

| Studied oak | *Quercus leucotricophora* | | *Rhododendron arboreum* | | *Lyonia ovalifolia* | | *Myrica esculanta* | |
|---|---|---|---|---|---|---|---|---|
| stands | Sapling | Seedling | Sapling | Seedling | Sapling | Seedling | Sapling | Seedling |
| Chandrabadani | 1.83 | 1.13 | 0.49 | 0.23 | 0.70 | 0.28 | 0.43 | 0.08 |
| Chaurangikhal | 1.20 | 1.36 | 0.52 | 0.50 | 0.20 | 0.26 | - | - |
| Diwalikhal | 1.02 | 1.11 | 0.38 | 0.48 | 0.30 | 0.40 | 0.40 | 0.28 |
| Ghuttu | 1.09 | 0.64 | 0.55 | 0.37 | 0.42 | 0.23 | - | - |
| Khirsoo | 2.93 | 1.85 | 0.58 | 0.42 | 1.05 | 0.11 | 0.58 | 0.33 |
| Makku | 1.23 | 1.27 | 0.47 | 0.30 | 0.47 | 0.47 | 0.43 | 0.33 |

**Table 6. Statistical analysis of density, basal area and IVI.**

| Variables | Mean density | Mean basal area | Mean IVI |
|---|---|---|---|
| *Quercus leucotrichophora* | 685.9 | 1.345 | 149.4 |
| *Rhododendron arboreum* | 144.4 | 0.202 | 38.6 |
| *Lyonia ovalifolia* | 129.4 | 0.136 | 35.5 |
| *Myrica esculanta* | 63.6 | 0.041 | 18.4 |
| Level of significance | $p$<0.001 | $p$<0.001 | $p$<0.001 |
| CD (LSD) | 46.12 | 0.166 | 9.26 |

## Discussion

Phytodiversity analysis has been observed by various workers with respect to different environmental factors, altitudinal gradients, disturbance gradients and regeneration status, as well as aspect wise in Garhwal Himalayas. Singh et al. (2015), Sharma et al. (2010), Uniyal et al. (2010) and Pokhriyal et al. (2010) analyzed plant diversity with respect to disturbance and altitudinal gradients particularly of the oak dominated forest in Gahrhwal Himalaya. In present study *Quercus leucotrichophora* was associated with *Rhododendron arboreum, Lyonia ovalifolia* and *Myrica esculenta*, which were also reported earlier by Kumar et al. (2009), Singh et al. (2015), Chauhan et al. (2014) in different parts of Garhwal Himalayas. Absence of *Myrica esculenta* at Chaurangikhal and Ghuttu oak stands may be due to their higher altitudinal ranges, which were beyond of its limited habitat distribution altitudes (1500–2000 m). The distribution range of *Myrica esculenta* was recorded between 1850–2250 m a.s.l., as reported by Sharma et el. (2009). The dominant shrub and herb species, as *Myrsine africana* L. and *Valeriana jatamansi* Jones ex Roxb., were recorded in restricted distribution.

Richness of shrub and herb species is greater at higher altitudinal ranges, particularly from 2000 m up to 2500 m. Giri et al. (2008) recorded the Shannon diversity in the range of 0.27–2.22 in an oak dominated forest, which was more or less similar to present investigation (1.04–1.57). As far as the Simpson diversity was concerned, present study yielded almost similar values as reported by Sharma et al. (2010) during their study in seven temperate forest types of Garhwal Himalaya. The diversity index of Margalef was found in similar pattern as reported by Sharma et al. (2009) in a moist temperate forest of Garhwal Himalaya. In context of the density, basal area and IVI of dominant tree species of the studied oak stands were concerned; the greater values were yielded for *Quercus leucotrichophora.* Present study showed that *Quercus leucotrichophora* density range from 166.7 to 823.6 plants·ha$^{-1}$ is more or less similar to earlier reported by Chauhan et al. (2014) at two oak forest stands of Garhwal Himalaya.

## Conclusion

In a natural forest stand, the associated or companions of a dominant species can also play an important role for the establishment and sustainability of a particular species/group of species. The broadleaved character of *Quercus leucotrichophora* and its major associates *Rhododendron arboreum, Lyonia ovalifolia* and *Myrica esculenta* have been reported capable of conserving the moisture at larger amount in hilly areas and also beneficial in erosion control. Study concluded that these species may also be considered for research as same preference of *Quercus leucotrichophora.* Associate species, particularly *Myrica esculenta* and *Rhododendron arboreum,* are extracted for edible products at considerable scale and therefore may be investigated for their conservation point of view. Therefore, a conservative approach for *Quercus leucotrichophora*, as well as its associates, needed research front in the Garhwal Himalayan region.

## References

Chauhan D.S., Prasad S., Singh V., Todaria N.P. 2014. Community Composition, Tree population structure in a temperate broadleaved evergreen Oak forest along a disturbance gradient in Garhwal Himalaya. Indian Forester 140(4): 395–406.

Giri D., Tewari A., Rawat Y.S. 2008. Vegetational analysis in mixed Banj (*Quercusleucotrichophora* A. Camus) and Tilonj oak (*Quercus floribunda* Lindl.) forests in Nainital Catchment. Indian Journal of Forestry 31(2): 167–174.

Kumar M., Sharma C.M., Rajwar G.S. 2009. The effects of disturbance on forest structure and diversity at different altitudes in Grahwal Himalaya. Chinese Journal of Ecology 28(3): 424–432.

Margalef D.R. 1968. Perspective in ecological theory. University of Chicago Press, Chicago. 111 p.

Mishra R. 1968. Ecology Work Book. Oxford & IBH Publication, New Delhi. 242 p.

Mueller-Dombois D., Ellenberg H. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York. 547 p.

Pokhriyal P., Uniyal P., Chauhan D.S., Todaria N.P. 2010. Regeneration status of tree species in forest of Phakot and Pathrirao watersheds in Garhwal Himalaya. Current Science 98(2): 171–175.

Pokhriyal P., Uniyal P., Chauhan D.S., Todaria N.P. 2012. Effect of altitude and disturbance on structure and species diversity of forest vegetation in a watershed of central Himalaya. Tropical Ecology 53(3): 307–315.

Prasad S., Singh V., Chauhan D.S. 2017. Aspect and altitude modify the requirements of disturbance in oak (*Quercus leucotrichophora*) belt of Garhwal Himalaya. Acta Ecologica Sinica 37: 70–74.

Ram J., Kumar A., Bhatt J. 2004. Plant diversity in six forest types of Uttaranchal, Central Himalaya, India. Current Science 86(7):

975–978.

Rathore S.K.S., Singh S.P., Singh J.S., Tiwari A.K. 1997. Changes in forest cover in a central Himalayan catchment: inadequacy of assessment based on forest area alone. Journal of Environmental Management 49: 265–276.

Shannon C.E., Wiener W. 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana. 125 p.

Sharma C.M., Suyal S., Gairola S, Ghildiyal S.K. 2009. Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. Journal of American Science 5(5): 119–128.

Sharma C.M., Baduni N.P., Gairola S, Ghildiyal S.K., Suyal S. 2010. Effects of slope aspects on forest composition, community structures and soil properties in natural temperate forests of Garhwal Himalaya. Journal of Forestry Research 21(3): 331–337.

Simpson E.H. 1949. Measurement of diversity. Nature 163: 688. doi:10.1038/163688a0

Shrestha B.B. 2003.*Quercus semecarpifolia* Sm. In the Himalayan region: Ecology, Exploitation and Threats. Himalayan Journal of Sciences 1(2): 126–128.

Singh S.P., Singh J.S. 1986. Structure and function of the central Himalayan oak forests. Proceeding Indian Academy of Science (Plant Sciences) 96: 159–89.

Singh J.S., Singh S.P. 1987. Forest vegetation of Himalaya. Botanical Review 52(1): 82–192.

Singh J.S., Singh S.P. 1992. Forests of Himalaya. Structure, Functioning and Impact of Man. Nanital, India, GyanodayaPrakashan, and Delhi, India: Fine art press. 294 p.

Singh J.S., Adhikari B.S., Zobel D.B. 1994. Biomass productivity, leaf longevity and forest structure in Central Himalaya. Ecological Monograph 64: 401–421.

Singh V., Chauhan D.S., Dasgupta S. 2015. Vegetation status and plant diversity of Chandrabadani oak forest along anthropogenic disturbance gradient in Garhwal Himalaya. Global Journal of Agriculture and ecology 3(1): 26–37.

Upreti N., Tewari J.C., Singh S. 1985. The oak forest of Kumaun Himalaya (India): Composition, diversity and regeneration. Mountain Research and Development 5: 163–174.

Uniyal P., Pokariyal P., Dasgupta S., Bhatt D., Todaria N.P. 2010. Plant diversity in two forest types along the disturbance gradient in Dewalgarh watershed, Garhwal Himalaya. Current Science 98(7): 938–943.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 131–140

# DETECTION AND MAPPING OF CONIFEROUS FORESTS IN WESTERN BULGARIA DAMAGED BY BIOTIC AND ABIOTIC FACTORS IN THE FRAME OF THE 'CORINE LAND COVER 2018' PROJECT

Toma Tonchev, Radka Koleva*, and Youlin Tepeliev

University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria.
*E-mails: rad_koleva@abv.bg, rad.koleva@gmail.com

Received: 26 July 2018 Accepted: 29 October 2018

## Abstract

Two forest sub-regions at the western border of the country were selected as a study area because a lot of coniferous forest stands were damaged by biotic and abiotic factors in the last several years. Using the methodology, software and images of the CORINE Land Cover 2018 Project, a computer-assisted interpretation of the multitemporal satellite and aerial digital images was performed. False color compositions were used, including NIR and SWIR spectral bands. All coniferous forests in the study area (larger than 5 ha) damaged in the period 2012 – 2018 were detected and mapped. The obtained results were compared with terrestrial data from the annual reports of Forest Protection Station Sofia (FPS 2018), which are by years, by the affected areas and by the factors for the damages. The comparison proved the appropriateness of the approach and its advantages became obvious, compared to traditional ground observations, including in terms of accuracy, time and money.

**Key words:** bark beetle, computer assisted photo interpretation, CORINE Land Cover methodology, damaged coniferous forests, detection and mapping.

## Introduction

As a consequence of climate change in Europe, an increase in average annual temperatures and the frequency of extreme weather events is expected. This will lead to deterioration in the health of forest ecosystems. According to the data of the Executive Forest Agency in Bulgaria in recent years, the amount of wood obtained from salvage cuttings was significantly increased.

The poor health condition of the Bulgarian forests is due to both biotic and abiotic stressors. As the most significant factors can be mentioned the bark beetle attacks on coniferous trees, windthrows and windsnaps, snow uproots and snow breakages etc.

As a first step in the development of a strategy that aims to control the spread of bark beetle is the monitoring and mapping of the population dynamics of these pests. On the other hand, the new outbreaks of bark beetle damage are difficult to identify with terrestrial means, as well as expensive and time-consuming (Lindner et al. 2010).

The monitoring of forest ecosystems using remote sensing techniques has improved significantly in recent years, and existing technologies are suitable for use in many aspects of forest management (Lefski et al. 2001, Wang et al. 2004).

For detecting and mapping of bark beetle attacks remote sensing methods take into account the physiological and visual effects on the forest canopy leading to changes of the spectral reflectance in the red edge and near IR spectral bands. Three stages are known which take into account the color change of the leaves as a result of the attacks (Niemann and Visintini 2005). The first is the so-called ‘green stage’, in which there are no visible signs of a change in the color of the leaves and occurs during the colonization of the host, when the first generation hatches.

Generally, the ‘red’ and ‘gray’ stages occur within one to three years of the mass attack. During these stages, the crown initially gradually becomes reddish-brown in color, and in the ‘gray stage’ progressive defoliation occurs. It is possible to observe some overlap in the evolution of the ‘red’ stage and the beginning of the ‘gray’ stage, all the trees being dead.

The detection of ‘red’ and ‘gray’ stages by remote sensing techniques has been investigated over the last 30 years (Niemann and Visintini 2005), mainly aerial photographs and visual interpretation being used.

Also, change detection techniques (Collins and Woodcock 1996) and tasseled cap transformation was applied to Landsat imagery (Price and Jakubauskas 1998, Skakun et al. 2003) providing good results in the monitoring of forest disturbances and mortality as a result of insect attacks. The study by Franklin et al. (2003) is based on the automatic detection algorithm for damage during the ‘red’ stage instead of visual interpretation.

COPERNICUS is the Earth observation programme which provides accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security. COPERNICUS is the new name for the Global Monitoring for Environment and Security programme, previously known as GMES. It is headed by the European Commission (EC) in partnership with the European Space Agency (ESA) (Anonymous 2017a).

The objective of the Copernicus Land Monitoring Service is to provide land-cover information to users in the field of environmental and other terrestrial applications.

The Land Monitoring Service started its activities in 2011 as part of the GMES Initial Operations (GIO).

The current service is articulated in three components (Anonymous 2017b):

- A global component;
- A Pan-European component;
- A local component.

The CORINE Project is a part of the Pan-European component - producing land-cover and land-change maps at continental scale as well as geophysical and vegetation parameters for seasonal and annual change monitoring. CORINE Land Cover 2018 (CLC2018) is the fifth CORINE Land Cover inventory. Brief history of CLC is presented in Table 1.

The main characteristics of CLC2012 and CLC2018 are summarized in Table 2.

**Table 1. CORINE Land Cover inventories in Europe (Büttner and Kosztra 2017).**

| Name | Start year | End year |
|---|---|---|
| CLC1990 | 1986 | 1999 |
| CLC2000 | 2001 | 2006 |
| CLC2006 | 2007 | 2010 |
| CLC2012 | 2013 | 2015 |
| CLC2018 | 2017 | 2018 |

**Table 2. Main characteristics of CLC2012 and CLC2018.**

| Characteristic | CLC2012 | CLC2018 |
|---|---|---|
| Satellite data used dominantly | IRS, SPOT-4/5 and RapidEye | Sentinel-2 and Landsat-8 for gap filling |
| Time consistency | 2011–2012 | 2017–2018 |
| Geometric accuracy satellite images | ≤ 25 m | ≤ 10 m (Sentinel-2) |
| CLC mapping minimum mapped unit | 25 ha | 25 ha |
| CLC mapping minimum width | 100 m | 100 m |
| Geometric accuracy | better than 100 m | better than 100 m |
| Thematic accuracy | ≥ 85 % (probably achieved) | ≥ 85 % |
| Change mapping | boundary displacement min. 100 m;<br>all changes > 5 ha must be mapped | boundary displacement min. 100 m;<br>all changes > 5 ha must be mapped |
| Production time | 3 years | 1.5 years |
| Documentation | standard metadata | standard metadata |
| Access to the data | free access for all kind of users | free access for all kind of users |

## CORINE Land Cover Methodology

The method applied for the creating the CLC database is computer assisted visual interpretation. This is a method of recognizing, identifying and assessing of objects recorded in aerial or satellite images, which is based on analysis of interpretation elements of the recorded landscape objects (Kosztra et al. 2017). The standard CLC nomenclature includes 44 land cover classes. These are grouped in a three-level hierarchy. The five main (level-one) categories are: 1) artificial surfaces, 2) agricultural areas, 3) forests and semi-natural areas, 4) wetlands, 5) water bodies (Heymann et al. 1994).

Raw satellite images first have to be pre-processed and enhanced to a geometrically correct document in national projection.

CORINE Land Cover Changes (CLC Changes) are mapped first in the 2nd CLC inventory, CLC2000. It was a policy requirement to map changes smaller than the 25 ha, minimum mapped unit (MMU) size of CLC. Starting from CLC2006, mapping CLC Changes has been standardised: all CLC changes larger than

5 ha have to be mapped.

CLC Change$_{2012\text{-}2018}$ is the primary product of the CLC2018 Project. The aim is to produce European coverage of real land cover changes that are:

- larger than 5 ha;
- wider than 100 m;
- occurred between 2012 and 2018;
- detectable on satellite images, regardless of their position.

## CLC2018 Satellite Images

To map CLC changes between 2012 and 2018 two sets of satellite images should be used: the ones used to derive CLC2012 (IMAGE2012) as well as the ones depicting the 2018 status (IMAGE2018).

## IMAGE2012

Two coverages of pan-European multi-temporal ortho-rectified satellite imagery covering all 39 participating countries with 12 nautical miles' sea buffer was provided by ESA for the period of 2011-2012, with all spectral bands and cloud masking. The main parameters of IMAGE2012 satellite imagery are shown in Table 3 (Büttner and Kosztra 2017).

**Table 3. The main parameters of IMAGE2012 satellite imagery.**

| Parameter | IRS LISS-III | RapidEye | SPOT-4 and SPOT-5 |
|---|---|---|---|
| Swath width (km) | 141 | 20 | 60–80 (depending on looking angle) |
| Number of bands | 4 | 5 | 4 |
| Spectral bands | Green, Red, NIR, SWIR | Blue, Green, Red, Red-edge, NIR | Green, Red, NIR, SWIR |
| Ground sampling distance (m) | 23.5 | 6.5 | 20 and 10 |
| Bit depth | 7 | 12 | 8 |
| Delivered resolution (m) | 20 | 20 | 20 |
| Projection | national | national | national |

## IMAGE2018

Sentinel-2 mission is a European earth polar-orbiting satellite constellation (Sentinel-2A and 2B) designed to feed the Copernicus system with continuous and operational high-resolution imagery for the global and sustained monitoring of Earth land and coastal areas (Anonymous 2017c).

The Sentinel-2 system is based on the concurrent operations of two identical satellites flying on a single orbit plane but phased at 180º, each hosting a Multi-Spectral Instrument (MSI) covering from the visible to the shortwave infrared spectral range and delivering high spatial resolution imagery at global scale and with a high revisit frequency (Table 4) (Gatti and Naud 2017).

The multispectral imager Sentinel-2 is the most advanced of its kind – in fact it is the first optical Earth observation mission to include four bands in the 'red edge', which provide key information on vegetation state. Spectral bands of Sentinel-2 are compared with bands of main satellite sensors used in previous CLC projects in Table 5 (Büttner and Kosztra 2017).

**Table 4. The main parameters of IMAGE2018 satellite imagery.**

| Parameter | Sentinel-2 Multispectral Imager (MSI) |
|---|---|
| Swath width (km) | 290 |
| Number of bands | 13 (altogether)<br>4 in VIS<br>6 in NIR<br>3 in SWIR |
| Ground sampling distance (m) | 10 – bands 2, 3, 4 (VIS) and band 8 (NIR)<br>20 – bands 5, 6, 7, 8a (NIR) and bands 11, 12 (SWIR)<br>60 – band 1 (VIS), band 9 (NIR) and band 10 (SWIR) |
| Bit depth (recording) | 12 |
| Repeat cycle at the Equator (days) | 10 (with 1 satellite)<br>5 (with 2 satellites) |
| Data access | free, full and open access |
| Delivered resolution (m) | 10/20/60 (depending on band) |

**Table 5. Comparison of spectral bands of satellite sensors.**

| No | Sentinel-2 MSI | Landsat-7 ETM | IRS LISS-III | SPOT-4 HRV | Remark |
|---|---|---|---|---|---|
| 1. | 0.433–0.453 | | | | VIS band. Main use: atmospheric correction (aerosols) |
| 2. | 0.458–0.523 | 0.45–0.52 (TM1) | | | VIS: blue band |
| 3. | 0.543–0.578 | 0.53–0.61 (TM2) | 0.52–0.59 (MS1) | 0.50–0.59 (XI1) | VIS: green band |
| 4. | 0.650–0.681 | 0.63–0.69 (TM3) | 0.62–0.68 (MS2) | 0.61–0.68 (XI2) | VIS: red band |
| 5. | 0.698–0.713 | | | | NIR: vegetation red edge band |
| 6. | 0.733–0.748 | | | | NIR: vegetation red edge band |
| 7. | 0.773–0.793 | | | | NIR: vegetation red edge band |
| 8. | 0.735–0.950 | 0.75–0.90 (TM4) | 0.77–0.86 (MS3) | 0.78–0.89 (XI3) | NIR band |
| 8a. | 0.855–0.875 | | | | NIR: vegetation red edge band |
| 9. | 0.935–0.955 | | | | NIR band. Main use: atmospheric correction (water vapor) |
| 10. | 1.365–1.395 | | | | SWIR band. Main use: atmospheric correction (cirrus clouds) |
| 11. | 1.565–1.655 | 1.55–1.75 (TM5) | 1.55–1.70 (MS4) | 1.58–1.70 (XI4) | SWIR band |
| 12. | 2.100–2.280 | 2.09–2.35 (TM7) | | | SWIR band |

The recommended standard image band combinations in order to provide similar colours on screen for interpretation are shown in Table 6.

**Table 6. Recommended standard colour band combinations.**

| Colour | IRS | SPOT-4,5 | RapidEye | Sentinel-2 |
|---|---|---|---|---|
| Red (R) | band 3 (NIR) | band 3 (NIR) | band 5 (NIR) | band 8 (NIR) |
| Green (G) | band 4 (SWIR) | band 4 (SWIR) | band 3 (Red) | band 11 (SWIR) |
| Blue (B) | band 2 (Red) | band 2 (Red) | band 2 (Green) | band 4 (Red) |

## CORINE Land Cover Software

CLC2018 Support Package is a significantly modified and improved version of CLC2012 Support Pack-age. The CLC2018 software has been developed for the Government Office of the Capital City Budapest (BFKH), legal successor of the Institute of Geodesy, Cartography and Remote Sensing (FÖMI). BFKH as consortium member of European Topic Centre Urban, Land and Soil Systems (ETC/ULS) provides assistance for the implementation of European CLC2018 project managed by the European Environment Agency (EEA) within the framework of COPERNICUS Earth Observation Programme (Taracsák 2017).

GIS software packages in general are designed primarily for viewing GIS databases, with tools for creating maps, menus for handling databases and with graphical editing tools. If the software has editing functions too, these are general tools, not specialized for any individual task. In the contrary CLC2018 Support Package offers a specialized, problem-oriented software tool, which significantly facilitates the updating, change detection, quality control and correction of CORINE Land Cover databases by means of computer-assisted visual photointerpretation. Consequently, this software is not applicable for creating, viewing or editing GIS databases in general. For these purposes one can use any common commercial (e.g. ESRI ArcGIS) or free (e.g. Quantum GIS) software.

InterChange program provides a tool for the revision of CLC2012 database and supports the interpretation of land cover changes in order to create the CLC-Change$_{2012–2018}$ database. The program provides a convenient and easy-to-use interface for editing polygons in CLC2012 and CLC-Change databases, for viewing and modification of polygons' data and for finding and correction of errors generated during interpretation and editing. InterChange program was designed especially for revision of existing land cover databases and interpretation of land cover changes. It is unsuitable for primary interpretation of satellite images and for building up an independent land cover database (Taracsák 2017).

## The Bark Beetle Problem in Bulgaria

Reducing the afforested area due to biotic and abiotic factors can lead to significant environmental and economic consequences. Biotic damage is mainly due to species of the family Scolitidae and in particular to the pine engraver beetle (*Ips acuminatus* Gyll.), which primarily attacks Scots pine (*Pinus sylvestris* L.).

Bark beetles are secondary pests. They exist naturally in nature and usually they do not create any problem. Normally, bark beetles attack almost dying old trees and play a very important role in the destruction of wood. They start to create a problem as a secondary pest when there is a significant amount of potential food – potential hosts, as the trees are in a weakened state. Exactly such are the artificial pine forests, created outside their natural habitat. In the 60s and 70s of the last century about 1 million hectares of artificial plantations were created in Bulgaria mainly of Scots pine and Austrian pine and at that not in the high mountain region, but in the middle mountain region and below it at an altitude of about 700 meters. They were created on very inappropriate dry places with less rainfall, and when these trees reached over 40 years of age and the respective size, they needed more nutrients and water, which were not available. The stands were already very dense because the lack of access to them hindered logging.

Bark beetles started to be a problem in the country because in 2014 and 2015 there were wet snow and fallen trees, and the beetles most often attack dead, fallen trees that are much weakened. In the large mass of fallen wood they rapidly multiplied (one family of the insect create a generation of 60 small larvae). Then they transfer to the already weakened trees. Normally this pest makes two generations during the year. The development of this pest is such that its maximum probably was reached in 2017. Compared to the 53,000 cubic meters of contaminated wood in 2012, only for the first 6 months of 2017 dead trees already amount to 400,000 cubic meters of wood. The peak of the damages almost coincides with the second time horizon (the first being 2012) of the CORINE Land Cover 2018 project.

## Study Area

The damages of coniferous forests due to both biotic and abiotic stressors are greatest in southern and southwestern Bulgaria, where forest officials have adopted logging plans to tackle the pest infestation. Almost all of the damaged forest stands fall into 3 forest sub-regions of Bulgaria. These are (Fig. 1) Kraishte-Ihtiman (a sub-region of the Moesian forest region), Osogovo (a sub-region of the Thracian forest region) and Ardino (a sub-region of the Sothern border forest region).

This study is carried out within the CORINE Land Cover 2018 project and concerns the first two adjacent forest sub-regions located right next to the western border of the country.

## Results and Discussion

Using the methodology, software and images of the CORINE Land Cover 2018 Project described above, a computer-assisted interpretation of the multitemporal satellite and aerial digital images was performed. False color compositions were used, including NIR and SWIR spectral bands (Table 5). All coniferous forests in the study area (larger than 5 ha) damaged in the period 2012–2018 have been detected and mapped. As far as pure coniferous forests attacked by bark beetle are concerned, depending on which of the above-mentioned 3 stages they are at, the color of the crowns in the left window (healthy trees – 2012) changes from dark brown through light brown to light gray green in the right window (already attacked trees – 2018) (Fig. 2). If the trees are already fallen or cut the dark


**Fig. 1. A map of the forest regions and sub-regions of Bulgaria (by EFA 2011).**

brown from the left window changes to light green if the grass cover is seen or to light red-brown in the presence of deciduous understory, as is the colour of broad-leaved forests.

According to the CORINE Land Cover Project nomenclature, this is a change in land cover from class 3.1.2 Coniferous forest to class 3.2.4 Transitional woodland/shrub (Fig. 2). In the same way areas with damaged conifers greater than 5 hectares, which are parts of polygons of mixed coniferous-deciduous forests – class 3.1.3 Mixed forests, are also detected and mapped. Because only real changes are given under the technology of the project, here the source code 3.1.3 is changed and the change is given again as 3.1.2 Coniferous forest to 3.2.4 Transitional woodland/shrub.

Altogether for both sub-regions, 716 polygons with damaged forests were delineated with a total area of 17,896 ha.

The obtained results are compared with data from the annual reports of Forest Protection Station Sofia (FPS 2018), which are by years, by the affected areas and by the factors for the damages (Table 7).

From these terrestrial data can be seen that the dynamics of the areas affected by bark beetle show a continuous increase over the period under review, with a maximum of 3,242.9 ha in 2017. The share of the bark beetle area compared to the total area of the damaged stands is 51.1 %.

The areas of damaged by caused abiotic factors are the largest for the stressors ice breakage, followed by snow breakage and the snow uproot – 33.3 %, the maximum value being in 2016. The areas affected by windsnap and windthrow are 9.5 %, the maximum being in 2016.

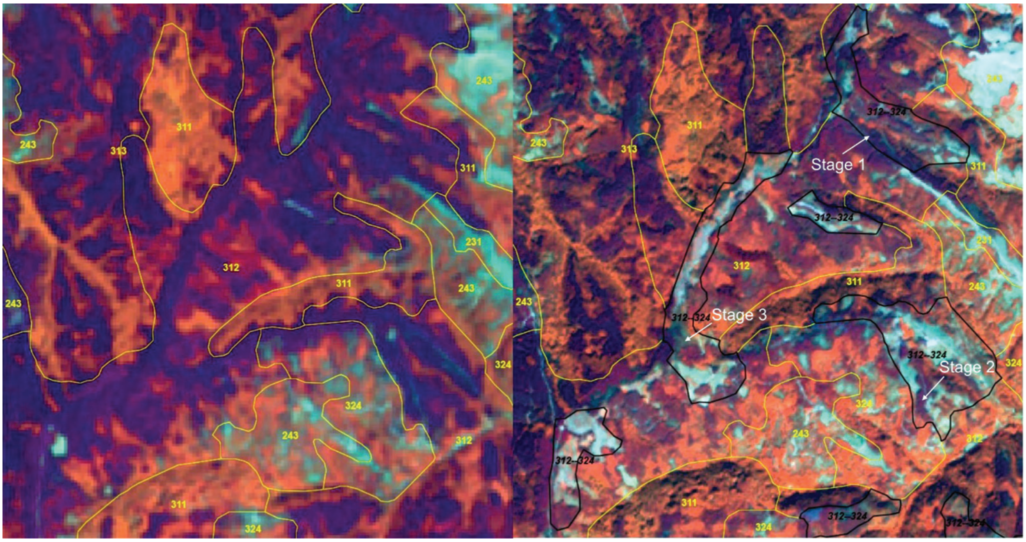



**Fig. 2. Detection and mapping of damaged coniferous forests: left window – image 2011; right window – image 2017 – change polygons (black contours).**

**Table 7. Terrestrial data for the annual distribution of affected areas by stressors.**

| **Stressor** | **Years** | | | | | | | **Sum** |
|---|---|---|---|---|---|---|---|---|
| | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018*** | |
| | **Area, ha** | | | | | | | |
| Windthrow | 16.5 | 122.7 | 1 | 0.7 | 46.2 | 71.2 | | 258.3 |
| Windsnap | 4.9 | 64.7 | | 9.5 | 54.1 | 13.3 | | 146.5 |
| Windthrow & windsnap | 0.1 | 243.4 | 157.1 | 277 | 486.8 | 103.1 | 44.7 | 1,312.2 |
| Bark beetle | 817.5 | 279.7 | 726.5 | 963.7 | 2,448.6 | 3,242.95 | 789.9 | 9,268.8 |
| Ice breakage | 86.5 | 12.1 | | 568.4 | 614.4 | 357.2 | 13.2 | 1,651.8 |
| Snow uproot | 14.5 | 3 | | 0.6 | 14.1 | 29.9 | 7.5 | 69.6 |
| Snow breakage | 403.3 | 177.2 | 7.6 | 17.2 | 50.1 | 59.6 | 13.8 | 728.8 |
| Snow uproot & breakage | 152.2 | 189.6 | 82 | 880.1 | 1908.7 | 318.8 | 47.3 | 3,578.7 |
| Defoliation of Scots pine | 44.8 | 89.7 | 168.6 | 19.4 | 18.8 | 14.4 | 7.6 | 363.3 |
| Defoliation of pine | 11.3 | 164.2 | 230.3 | 91.2 | 79.5 | 169.2 | 1.1 | 746.8 |
| Total area | 1,551.6 | 1,346.3 | 1,373.1 | 2,827.8 | 5,721.3 | 4,379.6 | 925.1 | 18,124.8 |

Note: *data for 2018 are up to June.

## Conclusions

The comparison between terrestrial data (18,124.8 ha damaged forests) and the results obtained by the CORINE technology (17,896 ha damaged forests) shows that the difference is only 228.8 ha (1.3 %) due to limitation of 5 ha minimum area of mapped changes in the latter case.

From the presented results, it can be concluded that the CORINE technology has a number of advantages compared to traditional ground observations, including in terms of accuracy, time and money.

## References


Anonymous 2017a. Copernicus Overview. Available at: https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview3

Anonymous 2017b. Land services. Available at: https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Land_services

Anonymous 2017c. Sentinel-2. Available at: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2

Büttner G., Kosztra B. 2017. CLC2018 Technical Guidelines. Wien. 61 p.

Collins J.B., Woodcock C.E. 1996. An assessment of several linear change detection techniques for mapping forest mortality using multi temporal Landsat TM data. Remote Sensing of Environment 56: 66–77.

EFA (Executive forest agency). 2011. Instruction for identification and mapping of the forest site types and determination of the composition of the dendrocoenoses. 135 p.

FPS 2018. Annual reports 2012 – 2018.

Franklin S.E.,Wulder M., Skakun R.S., Carroll A. 2003. Mountain pine beetle red-attack damage classification using stratified Landsat TM data in British Columbia, Canada. Photogrammetric Engineering & Remote Sensing 69: 283–288.

Gatti A., Naud C. 2017. Sentinel-2 Products Specification Document. 487 p. Available at: https://sentinel.esa.int/documents/247904/685211/Sentinel-2-Product-Specifications-Document

Heymann Y., Steenmans C., Croissille G., Bossard M. 1994. CORINE Land Cover. Technical Guide. EUR12585 Luxembourg, Office for Official Publications of the EC. 130 p.

Kosztra B., Büttner G., Hazeu G., Arnold S. 2017. Updated CLC illustrated nomenclature guidelines. Wien. 124 p.

Lefski M.A., Cohen W.B., Spies T.A. 2001. An evaluation of alternate remote sensing products for forest inventory, monitoring, and mapping of Douglas-fir forests in western Oregon. Canadian Journal of Forest Research 31: 78–87.

Lindner M., Maroschek M., Netherer S., Kremer A., Barbati A., Garcia J., Seidl R., Delzon S., Corona P., Kolström M., Lexer M., Marchetti M. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management 259: 698–709.

Olaf Niemann K., Visintini F. 2005. Assessment of potential for remote sensing detection of bark beetle-infested areas during green attack: a literature review. Mountain Pine Beetle Initiative Working Paper 2005 – 2. 14 p.

Price K.P., Jakubauskas M.E. 1998. Spectral retrogression and insect damage in lodgepole pine successional forests. International Journal of Remote Sensing 19: 1627–1632.

Skakun R.S., Wulder M., Franklin S.E. 2003. Sensitivity of the thematic mapper enhanced wetness difference index to detect mountain pine beetle red-attack damage. Remote Sensing of Environment 86: 433–443.

Taracsák G. 2017. InterChange 4.0 User Manual. Program development and text: Taracsák, Gábor. Revision of English text, English translation: Kosztra, Barbara. v4.0.1 – 01.10.2017.

Wang L., Gong P., Biging S.G. 2004. Individual Tree-Crown Delineation and Treetop Detection in High Spatial-Resolution Aerial Imagery. Photogrammetric Engineering & Remote Sensing 70: 351–357.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 141–162

# METHODOLOGICAL APPROACHES TO ASSESS THE AESTHETICS OF PARK ENVIRONMENT

Nadiia Oleksiichenko[1] and Nadiia Gatalska[2*]

[1]National University of Life and Environmental Sciences of Ukraine, Department of Landscape Architecture and Park-Garden Construction, 19 Heneral Rodimtsev Str., Kiev, Ukraine. E-mail: noolex@ukr.net

[2]National University of Life and Environmental Sciences of Ukraine, Department of Landscape Architecture and Park-Garden Construction, 19 Heneral Rodimtsev Str., Kiev, Ukraine. [*]E-mail: gatalska@ukr.net

Received: 13 June 2018 Accepted: 14 December 2018

## Abstract

The paper presents the spectrum of the research of aesthetic assessment of the landscape with the involvement of respondents (23 people), which was carried out during the summer-autumn period directly in the park environment and with the use of photographs. When using different methodological approaches and according to a comparative analysis of peculiarities of perception of the scenery park environment, the interconnections between aesthetic assessment of park landscape and features that affect its formation were revealed. It was discovered that while evaluating the park environment directly in the place, the estimation is reduced in comparison with the pictures, although at the same time the positive features of the landscapes noted by the respondents are similar, and the negative ones have significant differences in the summer and autumn periods, which are also present when using different methods of the research. Thus, the relationship between the assessment of the aesthetic qualities of the landscape and the frequency of references by respondents, both positive and negative features of the park environment are determined primarily rather by the season, than by the method of conducting research. Despite the significant difference in the frequency of references of the features of the park landscapes under the different conditions and methods of conducting the research, it has been discovered that the force of influence of a particular feature on the assessment of aesthetic quality of park landscape does not determine its factor weight in the assessment, but it is related to it. At the same time, the features (subliminal and compositional) are revealed and their influence on the aesthetic evaluation is significant, which can be taken into account during green space planning. It is revealed that conducting the research of park landscapes directly in the park is reasonable, first of all, if it is necessary, to determine the positive features of the park environment, which influence the formation of a subjective ‘general-landscape’ emotional reaction to a certain landscape, which is revealed in the definition of subliminal features by the respondents.

**Key words**: emotional reaction, landscape assessment methodology, park landscape perception.

## Introduction

The issue of involving the public in the assessment of the aesthetic qualities of the park environment becomes more and more relevant due to a number of factors, among which the definition of the international normative documents of expediency of the study of the landscape through the prism of human perception and parallel development of subject-oriented approaches to study aesthetics, namely – focusing the attention of scientists on man as a subject of perception. Daniel (2001) notes that the visual quality of the landscape can be determined as ′the relative aesthetic perfection of any landscape′, what can be measured on the observer's assessment. Individual scientists (Dramstad et al. 2006) do not consider expert-based methods to assessing the aesthetic quality of the landscapes as rational, considering their subjectivity. These scientists support the view that the characteristics of the landscape, taken as indicators of its aesthetic qualities by experts, may not correspond to the priorities in the visual assessment of the landscape by the public.

Currently, the spectrum of the aesthetic assessment of the landscape with the involvement of the respondents is expanding, as well as the application of the results, which focuses both on practical aspects, and is used to substantiate theoretical conceptions. In this context, it should be noted that the question of the methods and materials for studying the aesthetic preferences of the landscape by interviewing the respondents is controversial in the sources of scientific literature. The main issues of the discussion include the choice of the ways of conducting a research – on-site and through photographs.

The use of on-site study of the aesthetic qualities of the landscape includes finding the subject (person) in the environment of the object at the very moment of his perception and evaluation. During the study the environment is perceived both during motion and static reviews. Due to the multisensory perception of the environment, sensory perception and emotional evaluation prevail (Osychenko 2015). When using photographs, the object is replaced by a model, which may include plans, maps, satellite imagery, photographs, 3D models, etc. When using models, visual perception and rational assessment dominates (Dramstad et al. 2006, Osychenko 2015).

In turn, the philosophical basis of the methods of studying the aesthetics of the landscape includes distance theories and activity theories. Distance theory is based on the assertion that an aesthetic sensation is possible only from the objects that do not have a practical meaning for a person and are at a ′distance′ from him (Hrozdynskyi and Savytska 2005). Aesthetics is considered as an internal property of the objects and does not depend on individual features of the person. Landscape substitutes are used for research – models (maps, plans, satellite imagery, photographs etc.). Theory of activity is based on the philosophical and aesthetic direction, which involves knowledge of the object by ′immersion′ in it (Hrozdynskyi and Savytska 2005).

Relevance of using both methods of the landscape aesthetics study became a prerequisite for the formation of scientific works aimed at comparative analysis of the results obtained directly in the environment and under the condition of using the models. In particular, studies of Shelby and Harris (1985), aimed at identifying the priority methods for choosing evaluation data to determine the preferences of camping users, showed that photographs and written descriptions were consistent with 90 and 80 % of environmental assessment on-site (in environment). The analysis of characteristics (desirability and preference) testifies less consistency of methods (65–80 %), probably because the photos and written descriptions are limited in their ability to show background and context features.

Convincing results on the possibility of using models for studying the aesthetic qualities of the landscape, in particular the photographs, presented by Stamps (1990), are based on the conducted meta-analysis of secondary research results of several scientists (11 sources of scientific literature) devoted to the comparative analysis of the study of visual preferences in various ways. The author discovered a strong correlation ($r$ = 0.67–0.99) between preferences based on the photographs and on-site (in the environment). However, the author neither gives any specific preferences that were discovered, nor shows the details of conducting the research, the results of which are used for meta-analysis.

Later, Stamps (2010) carried out a comparative analysis of the subjective responses of the respondents resulting from the use of diapositives, photographs and in the environment and found correlation at the 0.82 level, on the basis of which the author concludes that both types of simulation generate statistically equivalent results, and therefore the choice of simulation carriers should be based on efficiency, not on the degree of their validity.

In addition, the analysis of sources of scientific literature indicates the widespread usage of various substitutes (models) to analyse the aesthetic appeal of landscapes – photographs (Polat and Akay 2015; Osychenko 2014, 2015), satellite imagery and maps (Dramstad et al. 2006), and 3-D models (Sang et al. 2008). At the same time, Dramstad et al. (2006) and Polat and Akay (2015) observe the critique of using photographs when investigating aesthetic preferences of the respondents, since they cannot fully reflect and describe real landscapes.

Summing up the results of the analysis of the sources of scientific literature, it should be noted that under the conditions of the research of the aesthetic preferences using models, the method of semantic differential is dominant, which involves the use of verbal antonyms to determine the ′general-landscape′ emotional reaction of the respondent to a particular landscape (Hofmann et al. 2012), and his assessment characterises the degree of its correspondence to the given adjective. In this way, the general psycho-emotional reaction to a particular landscape or the environment of the experimental object on the whole is determined, and the very similarity of such reactions obtained using different methods has been found by individual authors (Hershberger and Cass 1973; Shuttleworth 1980; Shelby and Harris 1985; Trent et al. 1987; Stamps 1990, 2010). However, the peculiarities of human perception of the environment are difficult physiological and psycho-emotional reaction that causes the formation of a number of issues important both in terms of applied and theoretical aspects of the research and formation of the landscape objects. Along with a large number of scientific works (Hofmann et al. 2012, Dupont et al. 2014, Polat and Akay 2015, Du et al. 2016), in which present the results of the study of the influence of the material components of the landscape on the aesthetic value of the landscapes, there are no data on the peculiarities of their influence on the formation of specific emotional reactions, which are the basis of the semantic differential. The influence of culture-historical, informational and symbolic significance, both separate material components, and mental images, associative values of individual knowledge about the environment, which are under evaluation, also occurs in the researches of the scientists of the second half of the twentieth century (Lynch 1960, Kaplan and Kaplan 1978, Kane 1981, Bell 1999, Gobster 2001, Jankovic 2017), and are the basis for the formation of semantic differential scale during the estimation of the particular landscape objects, however the strength of their influence on the formation of preferences, as well as the defined landscape locations in the semantic space by the respondent, was left without attention.

Thus, the question of analysing the research methods of the aesthetic qualities of the park environment and identifying those that will contribute to obtaining reliable results in accordance with the tasks set is relevant.

The purpose of the study is to analyse methodological approaches to assessing the aesthetics of the park environment and to identify the interrelationships between the aesthetic assessment of the park landscape and the features that influence its formation.

## Objects and Methods

The methodological basis for the study is the paradigm of the aesthetic preference (Osychenko 2015), as well as the psychophysical paradigm (Zube et al. 1982), in which the aesthetic qualities of the objects and patterns of perception are determined by the survey and evaluation of the object with the involvement of the respondents. The research is based on the studies of Thorpert and Nielsen (2014), Dupont et al. (2014), Hofmann et al. (2012), Shelby and Harris (1985), however, there are significant differences. First, it is the comparative analysis of the perception peculiarities of the park environment landscapes using different methods of the research, as well as allowing the respondents to independently determine the factors, which affect their evaluation, instead of using semantic differential scales.

Twenty three people were involved in the study. When substantiating the number of the respondents, it is worth paying attention to the data available in sources of scientific literature, where their number varies from 23 (Thorpert and Nielsen 2014, Dupont et al. 2014), 30 (Shelby and Harris 1985), 82 (Hofmann et al. 2012) to 409 (Polat and Akay 2015), and in some cases up to 836 (Osychenko 2014). The significant difference in the number of the respondents is related to the methods of the research. In particular, the largest number of the respondents is involved in surveys using models, most often photographs. In the case of conducting the research directly in the environment (Thorpert and Nielsen 2014), their number is significantly reduced due to the complexity of measuring and material costs. Stamps (1990), referring to a reasonable number of the respondents for the study, states about the number from 10 to 50 people. Hrozdynskyi and Savytska (2005) note the need to involve at least 20 respondents.

Respondents are students at the National University of Bioresources and Natural Resources of Ukraine, ′Landscape Management′ department. They are 20–22-year-old, including 9 men and 14 women. All respondents are citizens of Ukraine.

### Characteristics of the research object

The object of the research is the memorial park of garden and park art ′Mariinsky Park′, part of the Nature Preservation Fund of Ukraine, located in the central historical part of Kiev. Twenty six locations were determined within the park for the landscapes estimation (Fig. 1), which are

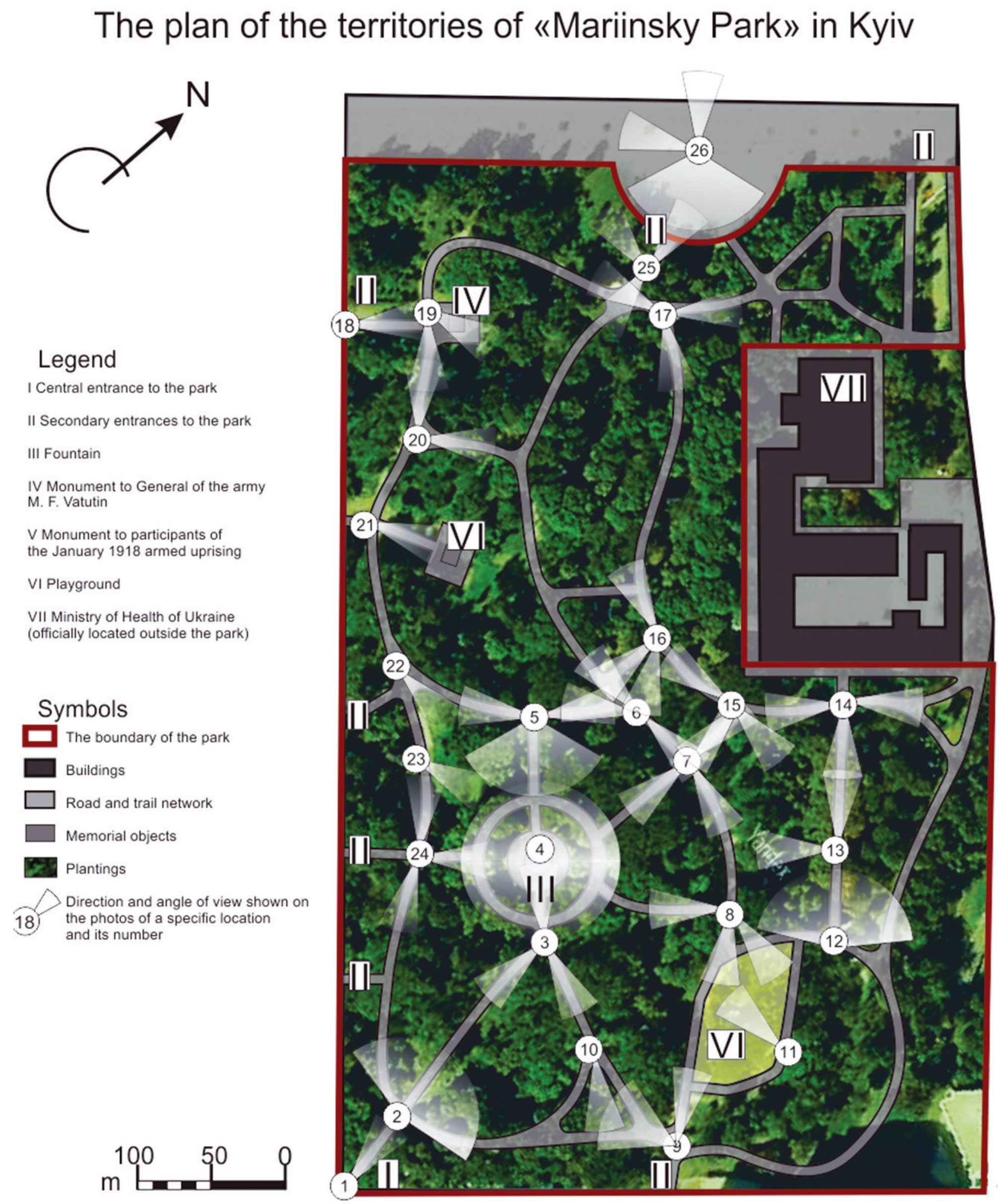



**Fig. 1. Scheme of the locations in 'Mariinsky Park' (Kyiv, Ukraine) used to assess the aesthetic appeal of the park environment and the angles shown on the photographs.**

presented in 63 pictures total.

Locations and photographs were selected in accordance with generally accepted methods of such studies (Daniel and Boster 1976), in particular those used in Hofmann et al. (2012), Polat and Akay (2015). They are based on the determination of the photo according to the purpose of the study; in this case, it is a comparative analysis of the perception and estimation of the aesthetics of the park environment while actually being present in it and using the photographs. Therefore, the main requirement for selecting the photo is the most complete reproduction of the real situation in the park environment.

The feasibility of using multiple points of view when photographing a single location is confirmed by Sang et al. (2008), who note that to provide a reasonable assessment of the landscape, rather than a particular landscape, it makes sense to take a number of the photographs that will provide the necessary information about the components of the park environment as a whole. Accordingly, the number of photos for one location was determined by the intensity of the change of the landscapes and viewing angle.

### Photographing and order of conducting the research

Since the research involves identifying features of the perception of the park landscapes during the growing season, mainly those that characterise the season, the time was determined in accordance with this requirement. In particular, taking pictures of park landscapes took place on August 31, 2017 (to illustrate the summer features of the park environment) and on October 5, 2017 (to illustrate the autumn landscape features) from 13:00 to 16:00 taking into account the human factor on the photographs. For taking pictures, a semi-professional digital camera with a resolution of 20.1 million pixels, camera lens with 26× optical zoom and panoramic mode was used. The angle of the most photos (59) was 30$^{o}$. Four photos were taken as 3-phase panoramas in such a way that they reflected all the characteristics of panoramic viewing points. The photos are printed in 10×15 format (matte paper), and panoramic in 10×29 format.

The assessment of the park landscapes directly in the environment was conducted twice – when the conditions were quite comfortable for the person, most often in the summer period and under the conditions that can worsen comfort due to lowering the temperature, presence of wind gusts, and increasing humidity (characteristic features of the autumn). Taking into consideration the aim of the study, as well as a number of objective and subjective factors, the first assessment (the main requirement of which is to conduct the study in comfortable for the person weather and colour conditions of the summer landscapes) was conducted on September 21, 2017, during 13:00–16:00, air temperature +24 °C, relative humidity during the assessment varied from 53 to 45 %, wind speed – 2 m/s and direction of wind was eastern, pressure was 742 mm, day was sunny. The estimation of the autumn landscapes was carried out on October 09, 2017, during 13–16 hours in the conditions that differed significantly – air temperature +10 °C, relative humidity varied from 83 to 59 %, wind speed – 4–5 m/s and direction of wind – north-western and western, pressure – 740 mm, the day was cloudy, which is typical for so-called ′golden autumn′. The very estimation of the landscapes in the environment was carried out after the respondents had already evaluated landscapes on the photographs.

### Questioning and processing of the results

Methods of determining the aesthetic preferences of the respondents can be divided into 2 groups. Comparative analysis of the aesthetic assessment of the landscape obtained by interviewing the respondents and analysis of the parameters of the landscape components belong to the first group. In this case, the parameterization of the components is carried out by the experts in accordance with the purpose of the study, and the photos are used as models (including panoramic (Polat and Akay 2015), satellite imagery and maps (Dramstad et al. 2006), 3-D models (Sang et al. 2008).

The second group is based on the use of semantic differential developed by Charles E. Osgood in 1952 and involves the use of verbal antonyms to determine the ′general-landscape′ emotional response of the respondent to a particular landscape (Hofmann et al. 2012). A comparative analysis of using these two methods was carried out by Kane (1981), who determined that both methods provide high scores that highly correlate with each other ($S_r$ = 0.81 at $n$ = 46).

Both of these methods were used for the personal research, however in order to carry out the given tasks the parameterisation of the components of the park environment was not done by the experts. Instead, the respondents were offered to independently substantiate the features of the landscape, which are positive and increase its aesthetics or reduce it and might be defined as negative. Characteristics could include both the material components of the landscape and associative notions and feelings that should have been indicated in the appropriate column opposite the number of the photo or location (where the evaluation of the environment was conducted) after evaluating a particular landscape on a 10-point scale, where 10 is the highest score. As a basis, the technique used by Osychenko (2015) was used to determine the aesthetic preferences of urban environment.

The analysis of the results envisaged the distribution of the above-mentioned features of landscapes into groups (Table 1) located in the Excel spreadsheet, with the parallel calculation of the average points of each individual landscape, after which the frequency of mentioning a certain feature by the respondents in the negative and positive contexts was calculated.

For a comparative analysis of the average scores, to estimate the views by means of the photos and directly in the environment, the arithmetic mean values of the photos corresponding to one location were used. For the output data analysis, the statistical methods such as probability theory were used. In particular, the Pearson correlation analysis was used to determine the relationship between the average indicator of the visual quality of each photograph (and location) and the frequency of respondents` references, as well as the interdependence of the features among themselves.

## Results

In the process of analysis of the average scores of park landscapes given by the respondents by photographs and in the environment, decrease was obtained in the estimation in the second case, which during the growing season makes 8.3 % in summer and 19.5 % in autumn. In particular, the average score for the park environment in summer according to the photographs makes 7.9, in the environment – 7.3, in autumn – 7.3 and 5.9, respectively. As a result of the correlation analysis, a significant correlation (0.539) was found between the average score of photos and locations in the environment in summer and moderate correlation (0.405) – in autumn.

**Table 1. Groups of the features that are noted in different contexts by the respondents and selected according to the results of processing the questionnaires.**

| A group of the features | Components | Elements and characteristics |
|---|---|---|
| Material components of the park environment | Spatial components | Plantings<br>Architectural elements<br>Terrain<br>Components of borrowed landscapes |
| | Elements of the planning system | Squares<br>Road network planning<br>Paving pattern |
| | Spatial characteristics | Panorama<br>Perspective<br>Visual connections |
| Colour | | Colorfull, green, monotonous, gray etc. |
| Basic features of comfort (rational level) | Convenience of travel and recreation | The junction of road and path network<br>Organization of places for rest<br>Organization of places of public service |
| | The comfort of environment | Light or dark, spacious or cluttered, clean or dirty, comfortable of uncomfortable |
| | Sanitary condition of the park environment components | Road and path covering<br>Lawn<br>Street furniture of utilitarian purpose and elements of engineering equipment |
| Emotional and associative | | Harmoniously or disharmoniously<br>Bright or monotonous<br>Interesting or boring<br>Atmospheric and etc. |

As the result of the correlation analysis between the average score and the frequency of mentioning by the respondents of the positive characteristics of the autumn landscapes on the photographs, that influenced their assessment, the correlation was identified at the 0.772 level, however between the negative ones it was inverse at the -0.703 level. Therefore, both negative and positive features of the landscapes given by the respondents are representative and determine a general aesthetic assessment. At the same time, the correlation between the similar indicators determined in the environment was at the 0.695 and -0.014 levels, which in turn suggests that there is no connection between the frequency of mentioning the characteristics that had a negative impact on the aesthetic assessment of the landscape. Comparing the results of the correlation analysis between similar indicators of the summer landscapes, it is advisable to pay attention to the similarity of the indicators obtained as a result of the photo estimation, where the correlation was 0.741 and negative – -0.85. The results obtained in the environment correlated far more closely, namely, the correlation between the assessment of the landscape and the frequency of mentioning the positive features and characteristics of the environment was 0.823, while the negative ones were 0.801. These results suggest similarity of the relationship between the environment of 'Mariinsky Park' and its aesthetic quality in the various ways of conducting the study namely in this period.

The next stage was the analysis of the features of the park environment identified by the respondents (Fig. 2) using different research methods, during which the significant correlation (0.605) between the frequency of mentioning the positive features of the summer landscapes and moderate correlation (0.444) of the autumn landscapes of 'Mariinsky Park' was found. Comparing the results with the data of the literary sources (Stamps 1990), it is worth noting the consistency with the data received in summer and the difference from the results received in less comfortable autumn conditions.

In addition, an analysis was carried out of the connection between the benefits of respondents noted in different seasons, during which a strong correlation between the positive qualities noted in summer and autumn in the environment (0.769) and significant with similar data obtained from the analysis of photos (0.604). Such

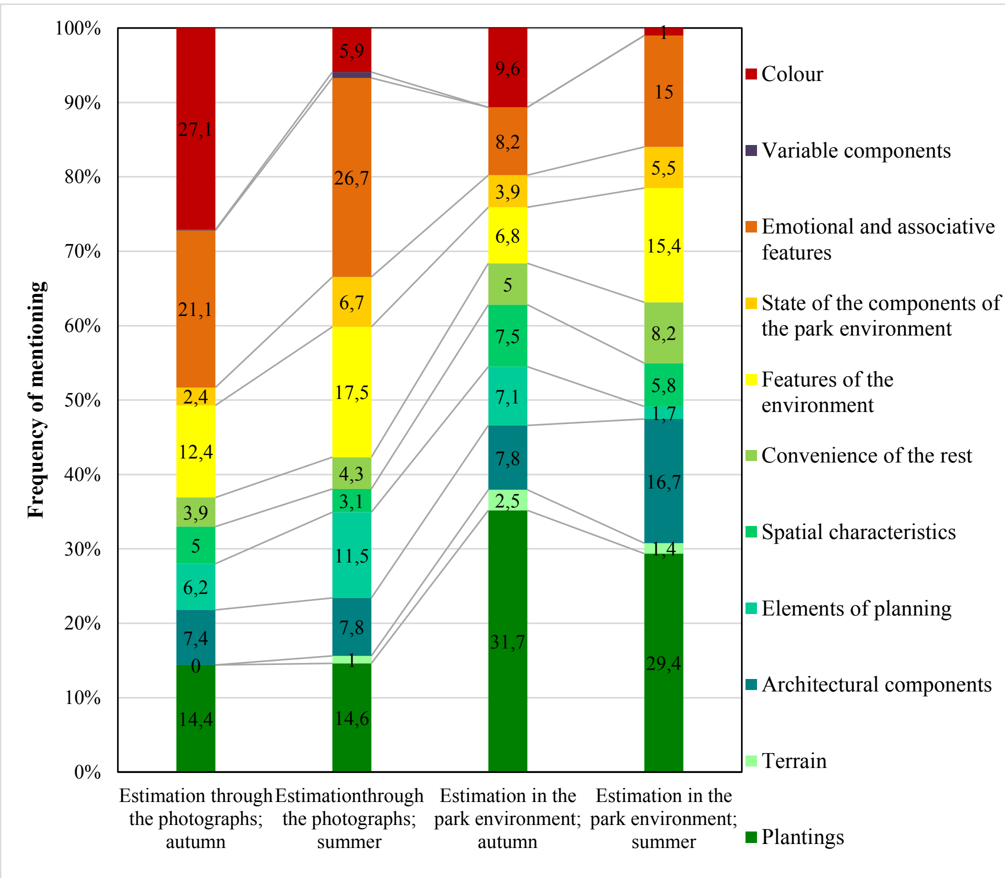



**Fig. 2. The frequency of mentioning the group of the landscape features as positive factors influencing the assessment of their aesthetic qualities.**

circumstances are a prerequisite for substantiating the hypothesis that the features and components of the Mariinsky Park landscapes, which have a positive effect on their aesthetic appeal, are similar during summer and autumn, and this connection is the closest when perceiving landscapes directly in the park environment.

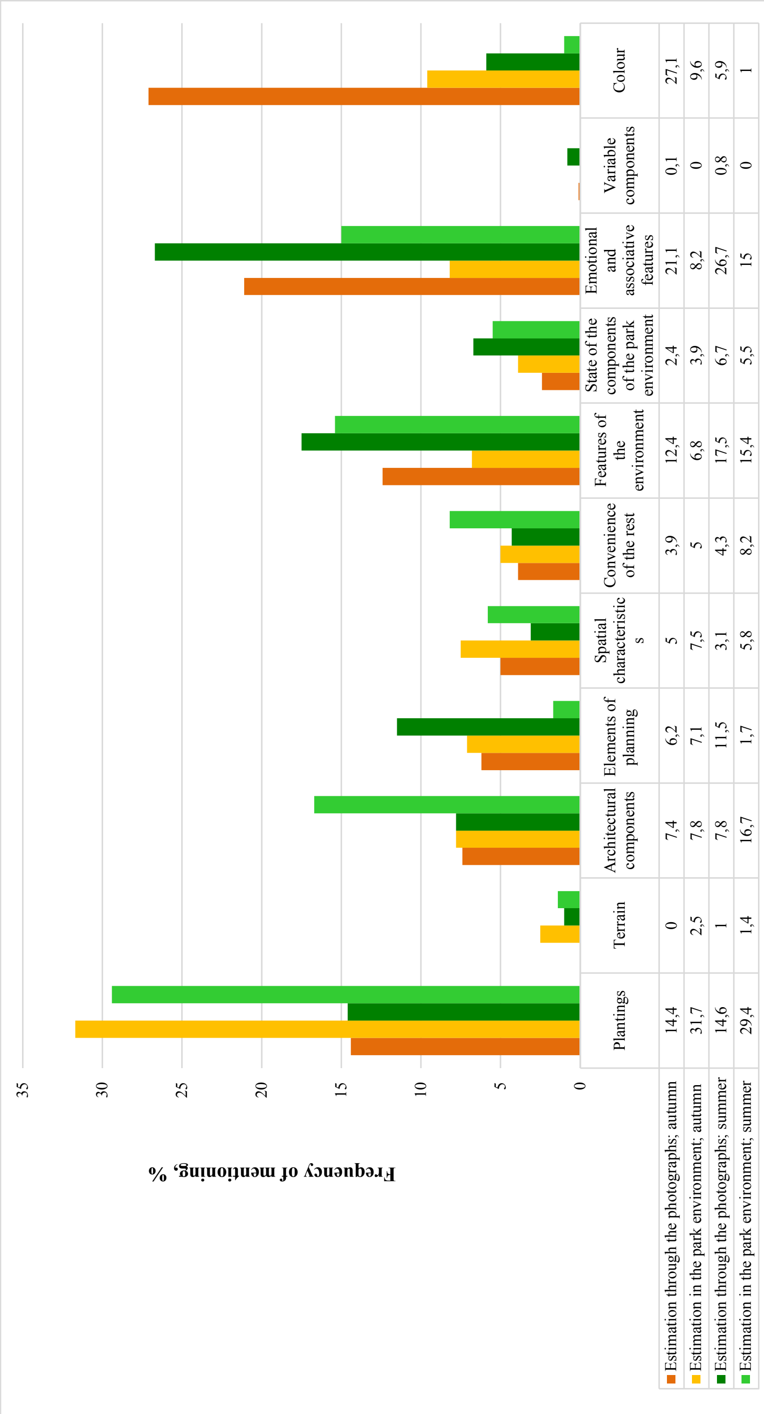
At the same time, a correlation analysis between the frequency of mentioning the features that negatively affected the aesthetic quality of the park landscapes showed quite different results. Thus, along with a very strong correlation between the mentioning the features on summer and autumn photos (0.964) and in summer in the park environment and on the photos (0.929) the lack of connection is revealed between the features noted in different conditions in the park environment, as well as in the park environment in autumn and on the photos. Such circumstances substantiate a necessity of comparative analysis of the frequency of mentioning the features and characteristics of the environment obtained in different ways during the growing season in order to identify the probable causes that influenced the results of the autumn evaluation conducted within the park.

Among the positive factors of the park landscapes, the number of mentioning of which most often fluctuate between the photographs and the environment, it is worth noting the plantings (the number of mentioning was twice bigger in the environment), emotional and associative features (far fewer in the environment than on the photos) and colour (differences are observed both between methods and the time of conducting the research) (Fig. 3). In addition, a significant (more than double) increase in the frequency of mentioning of the architectural elements, as positive features of the summer landscape, while researching in the park environment in relation to other conditions was revealed.

The results of the analysis of the negative factors are significantly different – the difference in the frequency of the mentioning is the largest in the characteristics of the environmental features in the conditions of evaluation in the park in the last decade of October and are related mainly to microclimatic features and noted by the respondents as ′windy′, ′cold′, ′wet′ and others (Fig. 4). In general, the number of mentioning related to the negative environmental features is 53.3 % of the total number of mentioning of the negative features and characteristics of the park environment during the period. At the same time, at this very time the frequency of mentioning the negative state of the components of the park environment comparing with other conditions and methods of conducting the research is the lowest.

Summing up the analysis of the frequency of mentioning the features of the park environment and the average score, it is advisable to pay attention to Osychenko (2015), who believes that the effect of the feature on the assessment of the aesthetic quality is not limited by the frequency of mentioning, but it is a process even more complicated and requires further studies. Taking into account the author's opinion based on a comprehensive analysis of the aesthetics of urban environment, an analysis of the interrelations between the groups of the features and the average score, as well as among them, was made, which became the third stage of the study.

Correlation relationship of different strengths between the numbers of the features, mostly indicated by the evaluation of the summer landscapes, was revealed. At the same time there are some




| | Plantings | Terrain | Architectural components | Elements of planning | Spatial characteristics | Convenience of the rest | Features of the environment | State of the components of the park environment | Emotional and associative features | Variable components | Colour |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimation through the photographs; autumn | 14,4 | 0 | 7,4 | 6,2 | 5 | 3,9 | 12,4 | 2,4 | 21,1 | 0,1 | 27,1 |
| Estimation in the park environment; autumn | 31,7 | 2,5 | 7,8 | 7,1 | 7,5 | 5 | 6,8 | 3,9 | 8,2 | 0 | 9,6 |
| Estimation through the photographs; summer | 14,6 | 1 | 7,8 | 11,5 | 3,1 | 4,3 | 17,5 | 6,7 | 26,7 | 0,8 | 5,9 |
| Estimation in the park environment; summer | 29,4 | 1,4 | 16,7 | 1,7 | 5,8 | 8,2 | 15,4 | 5,5 | 15 | 0 | 1 |

**Fig. 3. Structure of the frequency of mentioning the positive qualities of the landscapes under different conditions and methods of the research.**

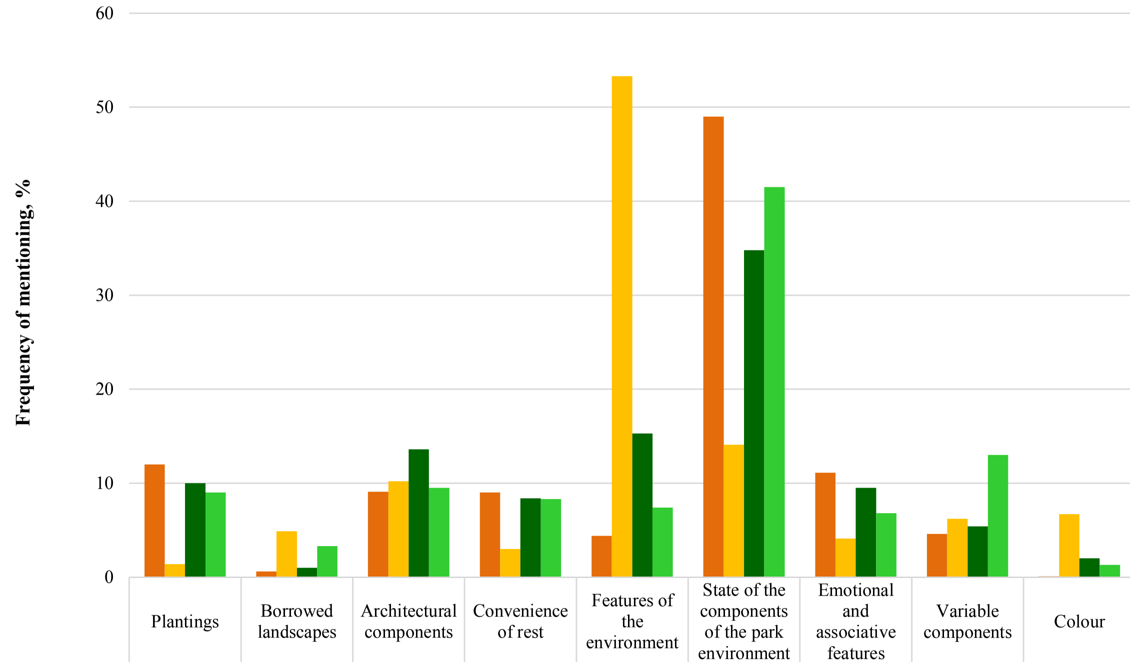
features between which and the average score the correlation relationship both direct and inverse is almost absent. First of all, it is advisable to note the negative features of the environment when assessing respondents' comments in autumn between which despite the huge number of mentioning (see Fig. 4) and an average score, correlation is at 0.054 level. It is interesting to note the presence of inverse correlation between the features of the environment (mainly related to comfort), which is negative in respondents' opinion and the average score noted in the summer landscape in the environment (-0.211) and in the photo (-0.264).

Analysing the direct correlation between the average score and the individual features of the landscapes, it is worth starting with the features, which are the emotional and associative characteristic of the park environment, and the share of their mentioning by the respondents is significant both in the summer and autumn landscapes under the different methods of conducting the research. In addition to the emotional and associative features, the significant correlation was found only between the colour of the photos of the autumn landscapes and the average score (0.502), as well as between the architectural components and the assessment of the summer landscapes, carried out directly in the park environment (0.547). In the context of the significant frequency of the plantings mentioning, as a positive feature of the evaluation in the park environment, it is worth noting that there is a moderate correlation in both seasons (summer – 0.310, autumn – 0.432).

The closest inverse correlation was found between the state of the components of the park environment and the average score in the evaluation of summer landscapes by the photo, which is on the level -0.614. Significant inverse correlation was found between the assessment of the landscape and the number of the mentioning of people and cars presence within the park – during the photo assessment it was at the -0.6 level, while in the environment it is level -0.558, which confirmed the research results of Acar et al. (2006); Arriaza et al. (2004) about the negative impact of people and artificial elements (not inherent to the park environment) in the landscapes.

The results of the analysis of the aesthetic attractiveness of individual park landscapes testify to the importance of the influence of disharmonious variable components of the park environment. Thus, it was determined that autumn landscapes estimated by photos No 26.2 and No 26.4 received the lowest score (5.0), however the same photos, with 9.2 and 9.7, respectively, and taken in summer, received the highest score (Fig. 5). The main difference between the landscapes is the presence of people and vehicles in the park in October.

The average score of the landscapes of this location (No 26) obtained by estimating photos is significantly different, namely, it is the highest among all summer photographs and the lowest among all autumn photographs. In the environment conditions, the situation is similar: the highest score (9.3) was found in the assessment of the 26$^{th}$ location in summer, and the lowest (4.1) within the 25$^{th}$ location in autumn near the 26$^{th}$ location (see Fig. 1), whose average score was 4.6. Describing the characteristics that the respondents identified as negative on the photos of the autumn landscapes, it should be noted that 91 % of the respondents indicated such variable components as cars and people on photo No 26.2 and 86 % on photo No 26.4. At the same time,




| | Plantings | Borrowed landscapes | Architectural components | Convenience of rest | Features of the environment | State of the components of the park environment | Emotional and associative features | Variable components | Colour |
|---|---|---|---|---|---|---|---|---|---|
| Estimation through the photographs; autumn | 12 | 0,6 | 9,1 | 9 | 4,4 | 49 | 11,1 | 4,6 | 0,1 |
| Estimation in the park environment; autumn | 1,4 | 4,9 | 10,2 | 3 | 53,3 | 14,1 | 4,1 | 6,2 | 6,7 |
| Estimation through the photographs; summer | 10 | 1 | 13,6 | 8,4 | 15,3 | 34,8 | 9,5 | 5,4 | 2 |
| Estimation in the park environment; summer | 9 | 3,3 | 9,5 | 8,3 | 7,4 | 41,5 | 6,8 | 13 | 1,3 |

**Fig. 4. Structure of the frequency of mentioning the negative qualities of the landscapes under the different conditions and methods of the research.**

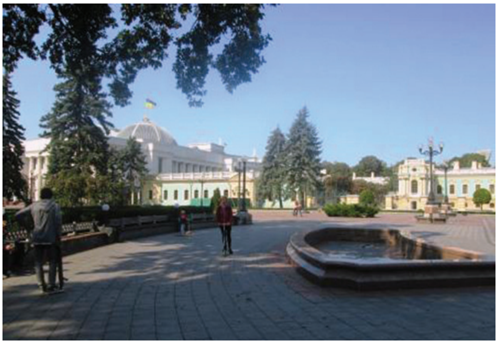


**Photo No 26.2 (31.08.2017)**

**Photo No 26.2 (05.10.2017)**

**Photo No 26.4 (31.08.2017)**

**Photo No 26.4 (05.10.2017)**

**Fig. 5. The photos that received the highest (left) and the lowest (right) average scores.**

only 10 % paid attention to the disharmony of the environment and another 10 % – to the broken fountain. In turn, far fewer respondents paid attention to the positive characteristics of the autumn landscapes – only 20 % (photo No 26.2) and 40 % (photo No 26.4), including planting composition, architecture of the palace, as well as space and illumination of the square. In the environment conditions the situation is the same – the presence of variable components that are inappropriate in this environment was noted by 57 % of the respondents on location No 25 and 54 % – on location No 26. At the same time, 19 % of the respondents (location No 25) and 14 % (location No 26) identified other negative features, including the environment – cold, noise, wind, bad smell.

In the case when the assessment of the landscapes on the 25th and 26th locations was the highest, as a positive feature the respondents highlighted the architecture of the palace – 20 % and 25 % respectively (under the conditions of the assessment in the environment) and 19 % (under the conditions of the assessment by the photos, photo No 26.4). On photo No 26.2, taken in summer, the respondents highlighted topiaries (19 %) as a positive feature of the landscape. Actually, when evaluating in the environment of the 26th location, respondents highlighted groups and regular compositions placed in niches directly on the square (30 % of the respondents in total), however the mentioning of the topiaries was absent.

The negative factors include the state of the components of the park environment – 50 % of the respondents during photo assessment and 10 % during the environmental assessment. Using the determination coefficient, it is possible to state with a probability of 99 % that the decrease of the aesthetic qualities of ′Mariinsky Park′ landscapes at the level of 31–36 % (depending on the method of research) is influenced by the variable components discovered in autumn.

The correlation analysis between several groups of the features and the average score for identifying closer interconnections of the features of the park environment and its aesthetic appeal to human being was performed (Table 2).

**Table 2. Correlation between the frequency of mentioning several groups of the features and characteristics and the average score of the landscape.**

| The characteristics and features of the environment | Correlation between the frequency of mentioning and the average score of the landscape | | | |
|---|---|---|---|---|
| | Estimation by the photographs | | Estimation in the park environment | |
| | Autumn | Summer | Autumn | Summer |
| Positive | | | | |
| Compositional features (plantings+architectural components+terrain+spatial characteristics+ elements of planning) | 0.358 | 0.518 | 0.496 | 0.607 |
| Basic features (convenience+features of the environment+state of the components of the park environment) | 0.014 | 0.290 | 0.053 | 0.499 |
| Comfort of the rest+state of the components of the park environment | 0.054 | 0.256 | 0.138 | 0.273 |
| Features of the environment+ emotional and associative features | 0.496 | 0.553 | 0.510 | 0.698 |
| Colour+plantings+architectural components | 0.589 | 0.766 | 0.617 | 0.556 |
| Negative | | | | |
| Plantings+borrowed landscapes+architectural components | -0.053 | -0.419 | -0.181 | -0.421 |
| Comfort of the rest+state of the components of the park environment | -0.196 | -0.613 | 0.383 | -0.557 |
| Features of the environment+ emotional and associative features | -0.251 | -0.449 | -0.037 | -0.238 |
| State of the components of the park environment+features of the environment | -0.293 | -0.642 | -0.191 | -0.519 |
| Variable components+state of the components of the park environment+features of the environment | -0.694 | -0.651 | -0.371 | -0.539 |
| Colour+plantings+borrowed landscapes+ architectural components | -0.123 | -0.422 | -0.194 | -0.455 |
| Variable components+features of the environment | -0.625 | -0.314 | -0.324 | -0.248 |

Taking into account the significant influence of the emotional and associative features on the assessment of the aesthetic quality of the park environment (confirmed both by the frequency of mentioning these features and by the results of the correlation analysis), the correlation analysis between these features and other characteristics of the park environment (basic and compositional) was carried out to determine those that may affect the formation of emotional and associative concepts that determine the peculiarities of the perception of the characteristic of the environment. The distribution of the park environment features was measured in accordance with their peculiarities – the basic features characterise the general, both visual and physical comfort of the park environment, and compositionally are associated with the compositional consistency of the landscapes.

According to the results of the analysis, positive basic characteristics do not affect the formation of the positive emotional and associative features, regardless of the time and method of conducting the research. Instead, the negative ones have minor negative effect, which is revealed through a moderate inverse correlation between given groups of the features, which also does not have a significant difference under the different conditions of the research (Table 3).

Specifying which groups of the basic features of the park environment can influence the formation of the emotional and associative concepts, one should pay attention to the heterogeneity of the correlation between both groups of the features, and the way of the research and seasonal peculiarities. In particular, a direct moderate correlation (0.360) is observed only between emotional and associative features and the state of the components of the park environment together with the variable parts of the landscapes in the autumn environment, and the inverse correlation is only on level -0.091. In other cases, the situation is the opposite – a direct relationship is either poor or almost absent, whereas the inverse relationship is moderate (see Table 3). In addition, the presence of a poor (both direct and inverse) correlation between the features of the environment and emotional and associative under different conditions and time of the research should be noted. The exception is the reverse moderate correlation between given features based on the results of the research conducted in the environment in early September. At the same time, the number of negative mentioning of the environmental features in this period is only 7.4 %, as opposed to 53.3 %, recorded at the end of October during research in the park environment (see Fig. 4).

The results of the correlation analysis of the compositional and emotional and associative features showed the existence of a direct poor correlation in the autumn landscapes of ′Mariinsky Park′ in terms of the research using photographs. In other cases, direct correlation are moderate, which may be the evidence of a certain influence of the positive compositional features of the park environment on the formation of psycho-emotional associations in the process of perception. At the same time, the influence of the negative compositional features, which is determined by the inverse correlation, is hardly tangible while evaluating autumn landscapes, despite the method of conducting the research, and in the summer landscapes it is moderate and poor in the conditions of the on-site method and through the photographs, respectively.

**Table 3. Correlation between the frequency of mentioning the emotional and associative features and characteristics of the material components of the park environment.**

| Features of the park environment that correlate with the subliminal features | Correlation (direct/inverse) | Method of conducting | Time of conducting |
|---|---|---|---|
| Compositional features of the components of the park environment | 0.317/-0.318 | On-site | Summer landscapes |
| | 0.306/-0.269 | Through photographs | |
| | 0.342/0.059 | On-site | Autumn landscapes |
| | 0.248/-0.046 | Through photographs | |
| Plantings+architectural components+ elements of planning | 0.567/-0.420 | On-site | Summer landscapes |
| | 0.274/-0.292 | Through photographs | |
| | 0.367/ 0.059 | On-site | Autumn landscapes |
| | 0.032/0.066 | Through photographs | |
| Plantings+architectural components+colour | 0.288/-0.305 | On-site | Summer landscapes |
| | 0.331/-0.298 | Through photographs | |
| | 0.453/0.128 | On-site | Autumn landscapes |
| | 0.265/-0.087 | Through photographs | |
| Basic features | 0.058/-0.346 | On-site | Summer landscapes |
| | 0.026/-0.378 | Through photographs | |
| | 0.026/-0.378 | On-site | Autumn landscapes |
| | 0.029/-0.419 | Through photographs | |
| State of the components of the park environment+variable components | 0.056/-0.312 | On-site | Summer landscapes |
| | 0.161/-0.349 | Through photographs | |
| | 0.360/-0.091 | On-site | Autumn landscapes |
| | 0.069/-0.426 | Through photographs | |
| Features of the landscape | 0.127/-0.346 | On-site | Summer landscapes |
| | 0.059/-0.109 | Through photographs | |
| | 0.140/-0.220 | On-site | Autumn landscapes |
| | 0.100/-0.052 | Through photographs | |

In the context of determining the relationship between the certain groups of the features with the emotional and associative characteristics, the results of the analysis of the material components of the park environment are important. Thus, as a result, a significant direct correlation (0.567) was found between the emotional and associative features and the material components of the summer landscape (plantings, architectural components and planning elements), determined directly in the park environment. At the same time, under the conditions of using the photographs during the research, the correlation is greatly reduced. A similar situation is observed when comparing the correlation between the negative features of the above mentioned components. From methodological point of view, it is worth paying attention to reducing the correlation between these features in autumn, when using the on-site method of research and its significant reduction when using photographs.

At the same time, in the case of inclusion of the colour to the features of the plantings and architecture and exclusion of the mentioning of the planning elements, the situation is changing – the correlation between the features of the autumn landscapes and emotional and associative increases (especially when evaluated in the environment), and between the features of the summer landscapes this indicator decreases. Such circumstances can be an evidence of the significant influence of colour on the perception of the park environment namely in the autumn period, as evidenced by the presence of a moderate positive correlation (0.4) between the emotional and associative features and colour on the photos of October landscapes. This pattern can be an evidence of the difference in the influence of the components of the park environment on the formation of associations in its perception in different research conditions. In particular, the evaluation of the photos does not give us a clear idea about the needed features of 'Mariinsky Park', which determine the location of its landscapes in the semantic space, unlike the environment.

## Discussion

As a result of the conducted researches, it was discovered that in the conditions of the park environment evaluation on-site (in the environment), the assessment is reduced in comparison with the photographs, while the positive features of the landscapes are similar, as mentioned in the literature (Stamps 1990, 2010). However, the negative features of the summer and autumn landscapes have significant differences that are also present under the conditions of using different research methods in the last decade of October, which can be the evidence of the impact of weather conditions and reduced environmental comfort, especially taking into account the frequency of mentioning these characteristics by the respondents.

As a result of the correlation analysis between the frequency of mentioning the features of the park landscapes and the average score given by the respondents, it was found that the effect of the attribute on the assessment of the aesthetic quality does not directly determine its factor weight in the assessment, but it is related to it, as evidenced by the study of Osychenko (2015). In particular, the positive influence of the plantings on the perception of the park landscapes is much more highlighted by the respondents in the conditions of observation in the park environment than when looking at the photos, but the correlation between the positive characteristic of this feature and the average score is similar regardless of the conditions and method of conducting the research.

Among the features that influence the aesthetic value of the landscapes, it is useful to note the emotional and associative features that characterise the psycho-emotional impact of the park environment on the person and correlate with the average score irrespective of the vegetation season and the methods of conducting the research, and therefore, the results can be considered reliable. In addition, this is confirmed by the data available in the sources of scientific literature. At the same time, the widest range of the associative notions, which make it possible to determine the place of the park landscapes in semantic space, is found in the conditions of the landscape evaluation by the photographs.

Regardless of the research method, the disharmoniously variable components of the park environment, which negatively affected the aesthetics of the landscapes, as well as the state of the components of the park environment, can be attributed to the features which reveal reliable results. In particular, an analysis of the interrelation of the variable parts of the park space (vehicles, significant number of people, including the police) with an assessment of the aesthetic appeal of the Mariinsky Park landscapes negatively affected the aesthetics of the park environment, regardless of the method of research. A similar situation is observed in the relatively unsatisfactory state of the components of the park space. In particular, the frequency of mentioning the features varies in the summer and autumn landscapes and under the different conditions of the studies, but it is the highest in the evaluation of the autumn landscapes in the conditions of the park environment. However, the correlation with the average score in the autumn period is poor under the different ways of carrying out the research.

The only one group of the park environment, the perception of which has significant differences in the evaluation in the environment and on the photos, are positive characteristics of the architectural components highlighted in the summer landscapes, which is confirmed by both the frequency of mentioning this feature and the significant correlation relationship (0.547). However, the negative characteristics of this feature do not have significant differences in the use of the different methods of the research. Such circumstances are the basis for making a conclusion about the possibility of underestimating the influence of the architectural components of ′Mariinsky Park′ during the photograph evaluation.

Significant influence on the perception of the landscapes of ′Mariinsky Park′ is observed according to the colour of the autumn landscapes evaluated on the photographs, which is confirmed by the frequency of mentioning this feature (27.7 %) and the correlation with the average score of 0.502. The frequency of mentioning the autumn colour of the park landscapes as a positive feature under the condition of the assessment in the environment is also greater than in the summer, but the correlation with the average score is moderate. Respondents noted that the colour as a positive feature in the park environment has the least effect on the respondents' preferences in the summer, which may be due to the perception of mainly green colour as the background of other components of the park space, especially the architectural elements. At the same time a moderate inverse correlation connection at the -0.305 level, between the frequency of mentioning the colour as the feature, that negatively affects the aesthetics of the landscape during the summer period in the environment, and the average score was revealed.

During the analysis of the interconnection of several groups of the features with the average score, it was found that the closest direct correlation are observed between the total number of positive mentioning of the colour, plantings and architecture and aesthetic assessment of park landscapes. The tightness of the relationship has minor differences depending on the conditions of the research method, which testifies in favour of the similarity of their perception, as well as the impact on the aesthetic qualities of the landscapes during the summer-autumn period. Focusing on the correlation analysis of the interconnection of the several groups of the features with the average score, it is reasonable to note that the significant differences are observed, mainly, between the results obtained at different times, rather than using different methods (see Table 2).

It is reasonable to conduct the study of the park landscapes directly in the park, in the first place, in case of necessity to determine the positive features of the park environment that influence the formation of the subjective ′general-landscape′ emotional reaction to a particular landscape. This is shown in the definition of the emotional and associative features by the respondents, because according to the results of the analysis of the relationship between the compositional and basic features with emotional and associative, the increase of the direct correlation between the results obtained in the environment in comparison with the photos (see Table 3) has been received. In the conditions of conducting the research though photographs, the correlation between the features that characterises the compositional features of the park environment is muchpoorer, which complicates the process of understanding which one influence the emotional and associative perception of the landscapes of the researched park object largely. The results of the analysis of the influence of the negative characteristics of the material components of the park environment on the definition of the emotional and associative features are also important. In particular, it is a poorer inverse correlation while estimating the autumn landscapes and the presence of moderate and poor while estimating the summer landscapes (on-site and through photographs, respectively). The given results are the reason for forming the statement that the compositional imperfection of the material components of the park environment has no pronounced effect on the emotional and associative perception of the environment of ′Mariinsky Park′ in autumn, and in summer, it is poorly expressed.

## Conclusions

When applying various methodological approaches and according to the results of comparative analysis of the peculiarities of the perception of landscapes of the park environment, interrelations between the aesthetic assessment of the park landscape and the features influencing its formation are revealed. The relationship between the assessment of the aesthetic qualities of the landscape and the frequency of mentioning by respondents to both positive and negative signs and characteristics of the park environment is primarily determined by the season of conducting the research, and not by the way of conducting them. It is established that the force of influence of a specific feature (or group of features) on the assessment of aesthetic quality does not directly determine its factor weight in the assessment, but is related to it. Along with that the revealed features (emotional and associative and compositional), the influence of which on aesthetic assessment are significant regardless of the season or method of their determination.

The results obtained in the autumn period, where, along with the strong positive correlation between the estimation and the positive characteristics of the landscape, the inverse correlation between the negative characteristics and the estimation is almost absent.

It is determined that conducting the research of the park landscapes directly in the park is relevant, first of all, if it is necessary to determine the positive features of the park environment, which influence the formation of the subjective ′general-landscape′ emotional reaction to a certain landscape by the respondents, which can be taken into account in the study of existing park objects and the development of reconstructive measures.

Further scientific researches may be aimed at studying the peculiarities of the influence of cultural-historical, informational and symbolic significance, both as certain material components and mental images, associative values, which may arise in the perception of the park environment and influence the formation of the preferences of the respondent.

## References


Acar C., Kurdoglu B.C., Kurdoglu O., Acar H. 2006. Public preferences for visual quality and management in the Kackar Mountains National Park (Turkey). International Journal of Sustainable Development and World Ecology 13(6): 499–512.

Arriaza M., Canas-Ortega J.F., Canas-Madueno J.A., Ruiz-Aviles P. 2004. Assessing the visual quality of rural landscapes. Landscape and Urban Planning 69(1): 115–125.

Bell S. 1999. Landscape: Pattern, Perception and Process (London: Spon). 344 p.

Daniel T.C. 2001. Whither scenic beauty? Visual landscape quality assessment in the 21st century. Landscape and Urban Planning 54(1–4): 267–281.

Daniel T.C., Boster R.S. 1976. Measuring landscape esthetics: the scenic beauty estimation method. In: USDA Forest Service Research Paper, RM-167. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. 66 p.

Dramstad W.E., Tveit M.S., Fjellstad W.J., Fry G.L.A. 2006. Relationships between visual landscape preferences and map-based indicators of landscape structure. Landscape and Urban Planning 78(4): 465–474.

Du H.Y., Jiang H., Song X.J., Zhan D.F., Bao Z.Y. 2016. Assessing the Visual Aesthetic Quality of Vegetation Landscape in Urban Green Space from a Visitor's Perspective. Journal of Urban Planning and Development 142(3).

Dupont L., Antrop M., Van Eetvelde V. 2014. Eye-tracking Analysis in Landscape Perception Research: Influence of Photograph Properties and Landscape Characteristics. Landscape Research 39(4): 417–432.

Gobster P.H. 2001. Visions of nature: conflict and compatibility in urban park restoration. Landscape and Urban Planning 56(1–2): 35–51.

Hershberger R.G., Cass R.C. 1973. The adequacy of various media as representations of the designed environment. Man-Environment Systems 3: 371–372.

Hofmann M., Westermann J.R., Kowarik I., van der Meer E. 2012. Perceptions of parks and urban derelict land by landscape planners and residents. Urban Forestry & Urban Greening 11(3): 303–312.

Hrozdynskyi M.D., Savytska O.V. 2005. Estetyka landshaftu [Aesthetics to the landscape]. Polihraftsentr ′Kyivskyi universytet′. 183 p. (in Ukrainian).

Jankovic N. 2017. Architectural Terri(s)tories: Jajinci Memorial Park in Belgrade. AM Joutnal 12: 81–88.

Kane P.S. 1981. Assessing Landscape Attractiveness: a comparative test of two new method. Applied geography 1: 77–96.

Kaplan S., Kaplan R. 1978. Humanscape – environments for people. North Scituate, Mass: Duxbury Press. 480 p.

Lynch K. 1960. The Image of the City. Cambridge, MA: MIT Press & Harvard University Press. 194 p.

Osychenko H.O. 2014. Classification of the aesthetic qualities of the urban environment. New University (3–4): 28–34.

Osychenko H.O. 2015. Metodolohichni osnovy formuvannia estetyky miskoho seredovyshcha [Methodological basis for the formation of the urban environment aesthetics]. DSc thesis (doctor in architecture), National University of Construction and Architecture Kyiv. 330 p. (in Ukrainian).

Polat A.T., Akay A. 2015. Relationships between the visual preferences of urban recreation area users and various landscape design elements. Urban Forestry & Urban Greening 14(3): 573–582.

Sang N., Miller D., Ode A. 2008. Landscape metrics and visual topology in the analysis of landscape preference. Environment and Planning B-Planning & Design 35(3): 504–520.

Shelby B., Harris R. 1985. Comparing methods for determining visitor evaluations of ecological impacts – site visits, photographs, and written descriptions. Journal of Leisure Research 17(1): 57–67.

Shuttleworth S. 1980. The use of photographs as an environment presentation medium in landscape studies. Journal of Environmental Management 11(1): 61–76.

Stamps A.E. 1990. Use of photographs to simulate environments – a meta-analysis. Perceptual and Motor Skills 71(3): 907–913.

Stamps A.E. III 2010. Use of static and dynamic media to simulate environments a meta-analysis. Perceptual and Motor Skills 111(2): 355–364.

Thorpert P., Nielsen A.B. 2014. Experience of vegetation-borne colours. Journal of Landscape Architecture 9(1): 60–69.

Trent R.B., Neumann E., Kvashny A. 1987. Presentation mode and question format artifacts in visual assessment research. Landscape and Urban Planning 14(3): 225–235.

Zube E.H., Sell J.L., Taylor J.G. 1982. Landscape perception – research, application and theory. Landscape Planning 9(1): 1–33.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 163–170

# MORPHO-ANATOMICAL DIFFERENTIATION WITHIN POPULATIONS OF *CALLUNA VULGARIS* L. (HULL) ON THE SUBMERIDIONAL TRANSECT MURMANSK – BATUMI

Olga E. Cherepanova*, Irina V. Petrova, and Nelly S. Sannikova

Botanical Garden of the Ural Branch of Russian Academy of Sciences, 202a, 8 Marta Str. Ekaterinburg, 620144, Russia. *E-mail: botgarden.olga@gmail.com

Received: 09 October 2018 Accepted: 19 December 2018

## Abstract

*Calluna vulgaris* is an ornamental bush widespread from the Kola Peninsula in the north to the Georgian ridges (Batumi) in the south. Today it is in considerable use for pharmacopoeial purposes as it has a lot of bioactive substances in different parts (leaves, roots, shoots, flowers, etc.). Having a wide habitat, the heather demonstrates minor range of morpho-anatomic feature variability that is represented by its systematical characteristics. Heather is a monotype of *Calluna*. This article presents brief results from morphological and anatomical analysis of four *Calluna vulgaris* populations growing on the submeridional transect Murmansk – Batumi. The main aim of the study was to investigate and clarify the mechanism of adaptive variation to the contrast environment conditions. The discriminant analysis was performed using the complex of 22 morpho-anatomic leaf characters. As a result it was found out that *Calluna vulgaris* populations growing at the habitat boundary had some common features that led to growth of plant xeromorphism (decrease of stomata number, trichome number increase, cuticle height rise). *Calluna vulgaris* populations growing in the central part of the habitat on the Russian Plain, despite their sharp isolation, also had one important similar feature – significantly smaller size of chlorenchyma cells which is probably connected with growing of plants beyond the canopy.

**Key words:** adaptive radiation, isolation, leaf anatomy, xeromorphism.

## Introduction

Today the molecular-genetic methods are successfully used to study the microevolutionary processes in the plant populations. On the other hand, the traditional morpho-anatomical methods, which reflect phenotypic selection trend and degree as well as population adaptive radiation under influence of heterogeneous environment, geographical and ecological habitat (Sannikov et al. 2014), are also informative and used for this purpose.

*Calluna vulgaris* L. (Hull) was chosen as an object to study the processes within the insular marginal populations of the habitat. Following the taxonomists' assumption the populations of this species, which belongs to monotypic genus *Calluna,* do not undergo the morpho-phenotypical adaptive radiation within wide and ecological-geographical heterogeneous habitat – from Transatlantic in Europe to

Trans-Urals in Western Siberia and from the Kola Peninsula (Murmansk) to Colchis (Batumi) (Rayner 1913, Hagerup 1953, Sannikov et al. 2016). However, this hypothesis was not proved with quantitative genetic and phenotypic researches.

At the same time our researches revealed reliable differentiation (on complex of lamina anatomical features) between marginal western (London, England) and eastern (Zavodouspenskoe, Sverdlovsk region) populations (Cherepanova et al. 2015).

The purpose of the article is to perform the comparative analysis of geographic variation and differentiation of some morpho-anatomical features of Central European, southern (Batumi) and northern (Murmansk) marginal populations of *C. vulgaris*.

## Materials and Methods

The comparative analysis of seed morphological variation and morpho-anatomical variation of annual sprout of *C. vulgaris* was carried out on the geographical transect going from north to south of the habitat: Murmansk – Luga – Bryansk – Batumi (Fig. 1). The first three populations grew under the canopy of vicariant stands of pine forests and cowberry-heather-moss forests of Russian Plain and the last one – on the south-east coast of the Black Sea.

The structure of *C. vulgaris* annual sprouts were studied using about 11–40 fresh and soaked samples taken from each population. The seed capsules were gathered in August and September. For each sample we measured the length and thickness of 5 leaves taken from the

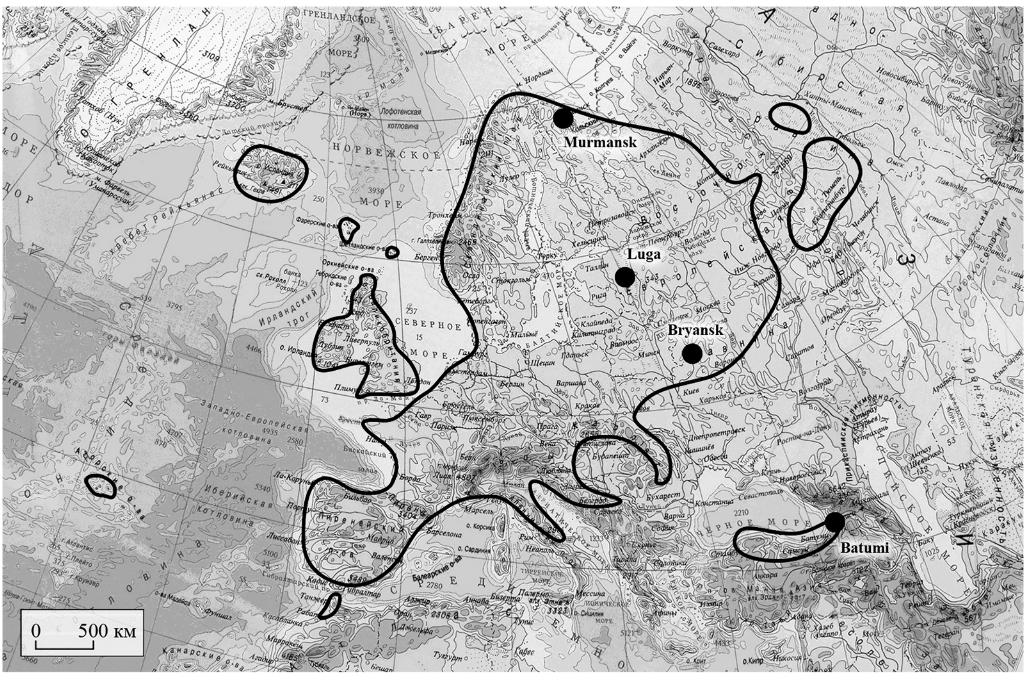



**Fig. 1. Schematic map showing the range of *C. vulgaris* and location of population sampling on the submeridional geographic transect Murmansk – Batumi.**
Note: The *C. vulgaris* range is marked with the line.

middle part of each of three terminal annual sprouts. The samples of leaves were soaked in a mixture of ethanol and glycerin (3:1). The cross-sections were cut manually with a razor (Fig. 2). Five sections were cut for each leaf and the tissue samples were taken for epidermis maceration, which was performed using the material previously soaked in water solution of NaOH (10 %).

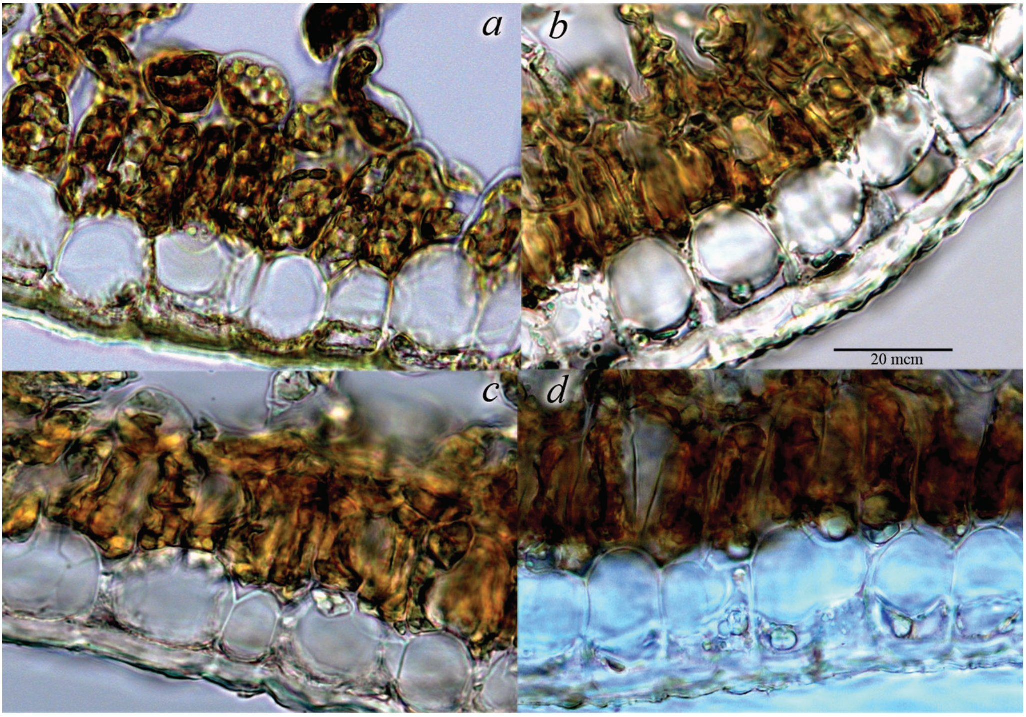



**Fig. 2. Sheet of *C. vulgaris* cross-sections: *a* – Murmansk, *b* – Luga, *c* – Bryansk, *d* – Batumi.**

Twenty six morpho-anatomical parameters' characters of annual sprout were analyzed (Table 1). The parameters' dimensions of morpho-anatomical structure of leaves were measured with threefold and fivefold replication applying the binocular loupe Carl Zeiss Stemi 2000-C and light microscope Carl Zeiss, as well as software AxioVision Rel. 4.8.

The statistical analysis was carried out on the basis of 26 morpho-anatomical characters of annual sprout (internode length, thickness and length of the leaf, linear parameters of chlorenchyma cells and epidermis cells, number of stomata and trichomes, vascular bundle). For statistical processing (discriminant analysis, ANOVA – Kruskal-Wallis one-way analysis of variance), statistical software package Statistica 8.0 was used.

## Results and Discussions

The minimal number of stomata was observed in hot and wet climate in Batumi (12.10±0.57 pcs for 10 μm), and maximal number – in cool and wet climate in Luga

**Table 1. Average morpho-anatomical parameters of leaf in *C. vulgaris* populations ($p \leq 0.001$).**

| Parameters | | Murmansk | Luga | Bryansk | Batumi |
|---|---|---|---|---|---|
| | | $N$=20 | $N$=14 | $N$=16 | $N$=12 |
| | | $M \pm m_M$ | $M \pm m_M$ | $M \pm m_M$ | $M \pm m_M$ |
| Cuticle thickness, μm | | 3.86±0.18 | 3.97±0.28 | 2.9±0.14* | 4.36±0.22* |
| Stomata number, pcs. | | 18.24±0.39 | 19.69±1.14 | 16.95±0.88 | 12.10±0.57** |
| Trichome number, pcs. | | 14.76±0.5 | 15.65±0.75 | 14.20±1.17 | 17.63±0.99 |
| Upper epidermis cells | height, μm | 28.68±1.39 | 26.61±1.44 | 26.27±1.23 | 31.76±5.05** |
| | length, μm | 58.89±2.55 | 58.78±2.4 | 65.32±1.47 | 59.74±3.05 |
| | thickness, μm | 27.26±1.58 | 29.39±4.46 | 25.39±1.09 | 25.34±1.45 |
| | area, μm$^2$ | 1377.65 ±111.87 | 1195.19 ±56.37 | 1395.47 ±102.76 | 1309.33 ±101.38 |
| | perimeter, μm | 175.95±8.25 | 180.48±5.02 | 200.19±9.25 | 177.48±9.2 |
| | elongation | 0.47±0.02 | 0.49±0.06 | 0.40±0.02 | 0.43±0.03 |
| Palisade tissue cells | length, μm | 34.31±1.21 | 26.19±1.14 | 31.51±1.07 | 35.50±2.88 |
| | thickness, μm | 14.53±0.26 | 11.82±0.55** | 14.87±0.96 | 14.53±0.37 |
| | area, μm$^2$ | 453.58±22.81 | 290.85 ±19.87* | 353.40±17.60 | 465.65±20.85 |
| | perimeter, μm | 89.19±2.56 | 67.99±4.98** | 81.08±2.38 | 90.62±2.62 |
| | elongation | 0.43±0.02 | 0.46±0.03 | 0.47±0.03 | 0.43±0.03 |
| Spongy parenchyma cells | length, μm | 19.80±0.58 | 16.76±1.06* | 19.07±0.47 | 21.18±1.08 |
| | thickness, μm | 20.56±4.68 | 13.29±1.48* | 14.40±0.47 | 15.52±0.93 |
| | area, μm$^2$ | 269.18±15.60 | 192.74±17.48 | 228.41±10.18 | 285.81±28.05 |
| | perimeter, μm | 62.56±1.64 | 54.99±3.25 | 58.29±0.99 | 64.86±3.07 |
| | elongation | 1.05±0.24 | 0.86±0.15 | 0.76±0.02 | 0.74±0.04 |
| Vascular bundle | length, μm | 82.18±2.93 | 60.33±3.22 | 59.29±1.75 | 68.18±2.38 |
| | thickness, μm | 79.79±3.14 | 77.65±3.46 | 60.35±1.47 | 79.98±3.79 |
| | elongation | 0.98±0.04 | 1.30±0.04 | 1.03±0.03 | 1.18±0.06 |
| Leaf | length, mm | 1.23±0.08 | 1.26±0.03 | 1.31±0.05 | 1.22±0.07 |
| | thickness, mm | 0.54±0.02 | 0.37±0.03* | 0.44±0.03 | 0.50±0.03 |
| | elongation | 0.42±0.02 | 0.30±0.02 | 0.34±0.03 | 0.43±0.04 |

Note: $p \leq 0.05$ – *, $p \leq 0.001$ – ** (Kruskal-Wallis one-way analysis of variance), $N$ – number of specimens in the analyzed sample, $M$ – mean, $mM$ – standard error.

(19.69±1.14 pcs for 10 μm). Together with smaller number of stomas the maximal number of trichomes (17.63±0.99 pcs for 10 μm) was found out here (see Table 1).

The number of stomata decrease and trichomes number increase occurring from west to east of heather habitat (Oslo, Norway – Zavodouspenskoe) along with climate dryness increase have been already mentioned before (Fig. 2). The overall trend decrease of stomata number from west to east and from south to north of the habitat was observed. Together with stoma number decrease occurring from west to east, the trichome number increase took place in the same direction. Probably the heather responded to the climate humidity reduction with the trichome number increase and stoma number decrease to avoid excessive transpiration (Zvereva 2010, Blagushka and Sozinov 2014).

The tendency of general reduction in linear parameters of epidermis cells occurring from the habitat boarders to its central part, previously observed in a row west-east, was preserved. In marginal southern population the epidermis cell height grew sharply (Table 1), while in the central part the values of this parameters were minimal (Bryansk – 26.27±1.23 μm) (Fig. 2).

The cuticular layer thickness grew along with the epidermis cell height from the center to the periphery of the habitat and reached its maximal value in the south 4.36±0.22 mcm. According to several authors, the strong cuticle development prevents the plans from excessive transpiration during daylight hours (Yakovleva and Barmicheva 2005, Dommee 1969, Grant and Hunter 1962, Mohamed and Gimingham 1970). The main function of cuticle, as well as of epidermis, is to avert the moisture loss in conditions of its deficiency (Zvereva 2010). Matching of epidermis height and cuticular layer thickness can demonstrate that the *C. vulgaris* population growing in Batumi was adapted to the dry climate best of all (Fig. 2).

The comparative analysis of sizes of palisade tissue cells and spongy parenchyma cells represented similar tendencies of linear increase of these parameters occurring from the center to the periphery of the habitat. The maximal linear dimensions of palisade tissue cells were found out in Batumi (35.50±2.88 μm – length, 465.65±20.85 μm$^2$ – area), and minimal – in Luga (26.19±1.14 μm – length, 11.82±0.55 μm – thickness, 290.85±19.87 μm$^2$ – area). The heather growing near the forest-tundra on the northern border of the habitat (Murmansk) was characterized with almost maximal linear dimensions of palisade tissue cells and spongy parenchyma cells (Table 1).

We did not found out any variability pattern for leaf conduction system linear parameters – vascular bundle – occurring from north to south of the habitat (Table 1).

The result of the step-by-step analysis was the inclusion of 19 parameters in the discriminant analysis model (Table 2).

The parameters characterizing the anatomical structure of the leaf were the most significant (Table 2). Those describing leaf morphology were included in the discriminant analysis model in the minimum number (leaf elongation, leaf thickness, mm).

The most determined population were Murmansk and Bryansk (distance between groups – 8.23, $p \leq 0.001$), Murmansk and Luga (distance between groups – 6.41, $p \leq 0.001$). The closest of leaf parameters are Batumi and Murmansk (distance between groups – 3.92, $p \leq 0.001$), Luga and Bryansk (distance between groups – 4.79, $p \leq 0.001$) populations.

The value of the vectors for the first two factors, describing the discriminant model, amounted to 5.17, 2.50 accordingly. The discriminant analysis (Fig. 3) of *C. vulgaris* populations growing in Luga and Bryansk revealed their differentiation.

**Table 2. A summary analysis of the discriminant functions calculated for leaf parameters included in model (*p*≤0.001).**

| Parameters | Wilks' Lambda | Partial Lambda | *F*-remove (3.35) | *p*-level | Tolerance | 1-Tolerance |
|---|---|---|---|---|---|---|
| Vascular bundle length, μm | 0.023 | 0.641 | 6.542 | 0.001 | 0.036 | 0.964 |
| Stomata number, pcs. | 0.031 | 0.478 | 12.752 | 0.000 | 0.472 | 0.528 |
| Vascular bundle elongation, μm | 0.021 | 0.716 | 4.621 | 0.008 | 0.045 | 0.955 |
| Palisade tissue cells area, $\mu m^2$ | 0.024 | 0.631 | 6.818 | 0.001 | 0.253 | 0.747 |
| Cuticle thickness, μm | 0.020 | 0.747 | 3.945 | 0.016 | 0.637 | 0.363 |
| Upper epidermis cells elongation | 0.020 | 0.764 | 3.609 | 0.023 | 0.008 | 0.992 |
| Spongy parenchyma cells elongation | 0.019 | 0.806 | 2.807 | 0.054 | 0.038 | 0.962 |
| Spongy parenchyma cells thickness, μm | 0.018 | 0.831 | 2.370 | 0.087 | 0.037 | 0.963 |
| Leaf elongation | 0.018 | 0.823 | 2.507 | 0.075 | 0.209 | 0.791 |
| Palisade tissue cells thickness, μm | 0.019 | 0.794 | 3.036 | 0.042 | 0.562 | 0.438 |
| Spongy parenchyma cells area, $\mu m^2$ | 0.016 | 0.941 | 0.738 | 0.537 | 0.365 | 0.635 |
| Upper epidermis cells area, $\mu m^2$ | 0.017 | 0.888 | 1.472 | 0.239 | 0.212 | 0.788 |
| Upper epidermis cells perimeter, μm | 0.023 | 0.655 | 6.154 | 0.002 | 0.091 | 0.909 |
| Upper epidermis cells height, μm | 0.020 | 0.750 | 3.899 | 0.017 | 0.023 | 0.977 |
| Vascular bundle thickness, μm | 0.019 | 0.794 | 3.029 | 0.042 | 0.040 | 0.960 |
| Upper epidermis cells thickness, μm | 0.019 | 0.783 | 3.232 | 0.034 | 0.008 | 0.992 |
| Trichome number, pcs. | 0.019 | 0.780 | 3.296 | 0.032 | 0.428 | 0.572 |
| Palisade tissue cells length, μm | 0.018 | 0.839 | 2.245 | 0.100 | 0.318 | 0.682 |
| Leaf thickness, mm | 0.017 | 0.895 | 1.367 | 0.269 | 0.194 | 0.806 |

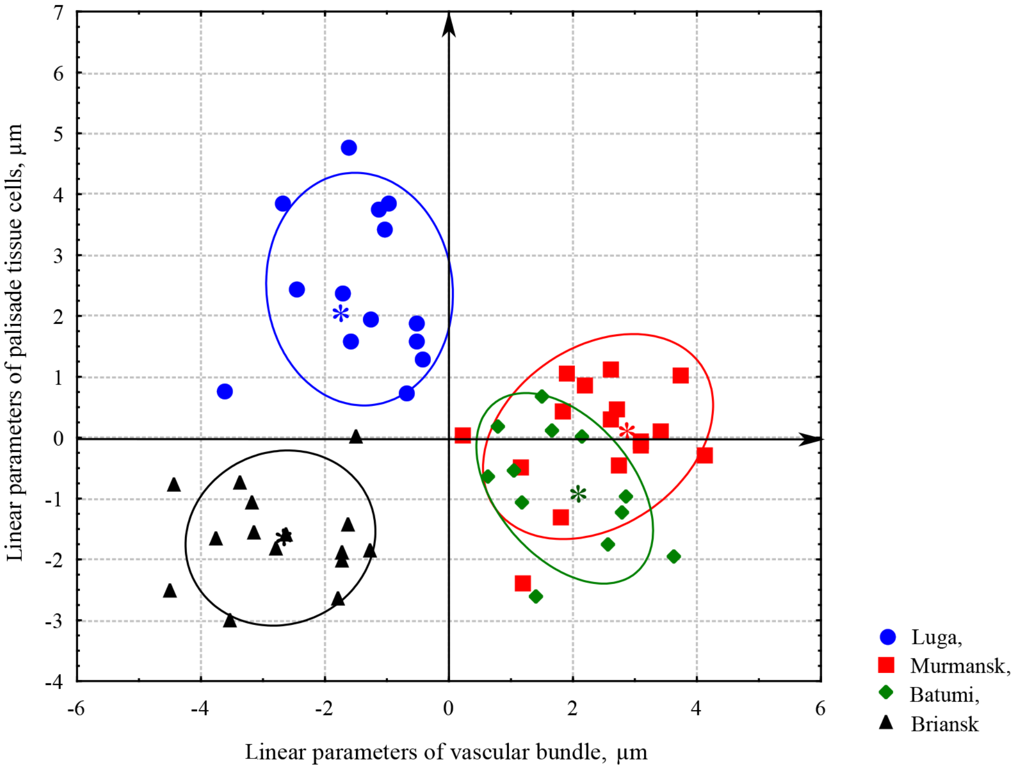



**Fig. 3. Graphical representation of discriminant analysis results of morpho-anatomical parameters of leaves.**
Note: * – Means of canonical variables.

At the same time the allocation areas populations growing in Murmansk and Batumi overlapped which evidenced for the resemblance of their leaf blade structure. The most significant features for that were the height, thickness of palisade tissue and length vascular bundle (Table 2).

## Conclusion

As a result of comparative study of morpho-anatomical characters of leaf in vicariant populations of *C. vulgaris* growing on submeridional transect Murmansk – Batumi, we found out an increase in linear parameters of heather leaf cells (epidermis, chlorenchyma), as well as in xerophytism parameters (stomata number decrease, trichome number increase, growth of cuticle height) along with reduction of leaf blade overall dimensions occurring from periphery to habitat borders, that was previously revealed on the transect going from west to east of the habitat (London – Zavodouspenskoe) (Cherepanova 2015). Along with that the heathers growing in open space were characterized with more xeromorphic structure, which was represented by chlorenchyma cells reduction.

## Acknowledgements

Study was supported by Russian Foundation for Basic Research, grant No 18-34-00506.

## References

Blagushka M.M., Sozinov O.V. 2014. Ecological-and-cenotic and resource characteristics of cenopopulations *Calluna vulgaris* L. (Hull). [Ekologo-tsenoticheskaya i resursnaya kharakteristika tsenopopulyatsiy *Calluna vulgaris* L. (Hull)] Medicinal plants: biodiversity, technologies, application: collected articles including materials of I international research and practice conference. Hrodna: GGAU: 16–18. Available at: https://elib.grsu.by/doc/9924 (in Belarussian).

Cherepanova O.E., Petrova I.V., Mishchikhina Yu.D. 2015. Leaf morphology and anatomy in marginal populations of common heather, *Calluna vulgaris* (L.) Hull from West Siberia and Atlantic Europe. Skvortsovia. Russian Academy of Sciences 2(1): 35–44. Available at: http://skvortsovia.uran.ru/2015/2104.pdf

Dommee B. 1969. Expériences sur le régime de la reproduction et sur la structure génetique des populations de *Calluna vulgaris*. Comptes Rendus de Académie royale des sciences de Paris 268: 2582–2584.

Grant S.A., Hunter R.F. 1962. Ecotypic differentiation of *Calluna vulgaris* (L.) in relation to altitude. New Phytologist 61: 44–55. Available at: https://doi.org/10.1111/j.1469-8137.1962.tb06272.x

Hagerup O. 1953. The morphology and systematics of the leaves in Ericales. Phytomorphology 3(4): 459–465.

Mohamed B.F., Gimingham C.H. 1970. The morphology of vegetative regeneration in *Calluna vulgaris*. New Phytologist 69: 743–750. Available at: https://doi.org/10.1111/j.1469-8137.1970.tb02459.x

Rayner M.C. 1913. The ecology of *Calluna vulgaris*. New Phytologist 12: 59–78.

Sannikov S.N., Petrova I.V., Cherepanova O.E. 2016. Alternative hypotheses of the origin of heather *Calluna vulgaris* (L.) Hull. [Alternativnyye gipotezy proiskhozhdeniya vereska *Calluna vulgaris* (L.) Hull ]. Eko-potential 2(14): 28–40 (in Russian).

Sannikov S.N., Petrova I.V., Dymshakova O.S., Cherepanova O.E. 2014. Genetic and phenotypic differentiation of European and Pritobolian populations of *Calluna vulgaris* (L.) Hull. Genetika 50(9): 1050–1055. DOI: 10.1134/S1022795414090129

Yakovleva O.V., Barmicheva E.M. 2005. Features of abaxial epidermis structure at different stages of leaf formation in some Ericaceae species. [Osobennosti stroeniya i razvitiya abaksialnojj epidermy lista u predstavitelejj semejjstva Ericaceae]. Moscow – Leningrad. Botanicheskij zhurnal 90(9): 1421–1428 (in Russian).

Zvereva G.K. 2010. Comparative anatomic study of the leaf mesophyll structure in *Festuca* L. species. [Sravnitelno-anatomicheskoye issledovaniye stroyeniya mezofilla listyev u vidov roda *Festuca* L.]. The Flora of Asian Russia 1(5): 79–86 (in Russian).

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 171–181

# DECLINE MODELLING OF OAK TREES UNDER EFFECTS OF PHYSIOGRAPHIC FACTORS IN SEMI-ARID FORESTS OF IRAN

Mehrdad Mirzaei[1*], Amir Eslam Bonyad[1], Reza Akhavan[2], and Ramin Naghdi[1]

[1]Deparment of Forestry, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, Iran.
[*]E-mail: mehrdadmirzaei28@gmail.com
[2]Forest Research Division, Research Institute of Forests and Rangelands, Tehran, Iran.

Received: 11 September 2018 Accepted: 05 December 2018

## Abstract

Recent dust and droughts caused stress to physiological weakness of oak trees, so that insect outbreaks and pathogens lead to decline of oak trees in the Zagros forests. In addition to evaluate the effects of physiographic factors (elevation, slope and aspect) on the amount and distribution of decline, the objective of present study was to make a model of decline of *Quercus brantii* species in semi-arid forests of Iran. For this purpose, 509 hectares of Zagros forests, known as Dalab forests in Ilam province, were selected. Based on systematic-random sampling method, 100 circular plots (2000 m$^2$) were measured in grid inventory of 200×250 m dimensions. In each plot, physiography factors and percentage of decline were measured. ANOVA and Duncan tests were used to compare the decline of oak trees in different physiography factors. Then, an individual tree decline models were developed with a data set from a total of 1370 oak trees. To evaluate the effects of physiographic factors on the decline of oak trees, a logistic regression model was used. Omnibus test, log-likelihood, and pseudo r-square coefficients were used to evaluate the logistic regression model. The results showed that physiography factors had significant effects on the decline of oak trees. Also, the results showed that with increasing slope and elevation, the decline of oak trees was increased. Lowest and highest declines belonged to east and south aspects, respectively. Values of both statistics related to the pseudo determination coefficient are acceptable (0.395 and 0.584), and these values indicated that the three independent variables of this study had the power of a relatively high explanation of the variance and changes in the dependent variable of trees decline. The results of this study can be effective in the oak decline area conservation.

**Key words:** logistic regression, oak decline, physiography factors, Zagros forests.

## Introduction

Zagros forests are located in the west of Iran and cover five million hectares. These forests are one of the most important and sensitive habitats for oak species that are classified as semi-arid and consist 40 % of Iran's forests. These forests provide various non-timber products, services and have multiple socio-economic and ecological functions. Due to uncontrolled cutting and overgrazing, Zagros forests have become degraded and have very low density. Natural regeneration is nearly non-existent, and severe soil erosion exposes the basic rock (Azizi et al. 2008, Marvi-Mohajer 2007). One of the main problems of Zagros forests is the decline of oak trees. Oak decline is characterized by crown thinning, foliar necrosis and progressive death of primary leaf-bearing branches and the emergence and subsequent decline of foliage. The condition of tree crowns is an important indicator of tree and forest health. A range of biotic and abiotic factors has been shown to contribute to the decline. However, no satisfactory investigation has been established to explain the distribution. The decline of Zagros forest ecosystem is a multidimensional phenomenon that various factors such as climate change, dust, lack of tree regeneration due to agriculture in the understorey, soil impaction due to livestock movement and oak pest and diseases are involved (Hamzehpour et al. 2011). Quantification and modelling of stand changes are important to the management of forest ecosystems. Therefore, forest modelling has been an intrinsic part of forest management planning and research for more than two centuries (Burnham 2002, Zheng and Zhou 2010, Lu et al. 2003). The majority of models operate at the stand-level and predict stand-level changes such as mortality and decline to provide information needed to estimate conservation costs, expected the yield and the financial result (Sheykholeslami et al. 2011). The key ingredient for obtaining a good decline model is a data set that is both large and representatives of the population under study. In many studies, linear and nonlinear regression was used for modelling of different tree variables in forests. Nonlinear regression including logistic, exponential and Chapman-Richard was used in different studies for modelling of the crown ratio of different species (Popoola and Adesoye 2012, Fu et al. 2015). Individual tree mortality models were developed for the six major forest species of Austria: European beech (*Fagus sylvatica* L.), European larch (*Larix decidua* Mill.), Norway spruce (*Picea abies* (L.) H. Karst.), Silver fir (*Abies alba* Mill.), Scots pine (*Pinus sylvestris* L.) and oak (*Quercus spp*.) by Monserud and Sterba (1999). Shifley et al. (2006) studied the oak mortality risk factors and mortality estimation in eastern North America and showed that mortality rates for trees in the red oak group were four to six times greater than mortality rates for associated trees in the white oak group. Also found that red oak group mortality was significantly related to tree crown class, tree diameter, and basal area of larger competitors. Kabrick et al. (2008) investigated the role of environmental factors in oak decline and mortality in the Ozark Highlands and showed that red oak mortality is more prevalent on droughty and nutrient-deficient sites because red oak group species are more abundant there. Fan et al. (2008) used logistic regression to study the oak mortality associated with crown dieback in the Ozark Highlands of Missouri and results of logistic regression showed that oak mortality was mainly related to crown width and dieback, and failed to detect any significant link with the number of oak borer emergence holes. The objectives of present study were to evaluate the effect of physiographic factors (elevation, slope and aspect) on the amount and distribution of oak decline trees and decline modelling of oak trees under effects of physiographic factors for *Quercus brantii* Lindl. species in semi-arid forests of Iran.

## Material and Methods

### Study area

The study area covered 509 ha in Dalab forests at 46°22'07″ E to 46°24'24″ E and 33°41'56″ N to 33°43'32″ N (Fig. 1). There was no permanent residential land in the study area, but dairy farmers and locals generally used the area for animal husbandry for about 2-4 months during spring and summer every year. The forests were under heavy pressure of livestock grazing, excessive cutting of trees and shrubs to supply fuel wood. The original vegetation of the study area was an uneven-aged mixed forest dominated by *Quercus brantii*, mixed *Quercus brantii – Pistacia atlantica – Acer cinerascens*, and mixed *Daphne mucronata – Amygdalus orientalis*. This area has a semi-arid climate based on the Emberger climate classification. Elevation ranges from 1450 to 1750 m a.s.l. and mean annual precipitation and temperature are 571.5 mm and 16.7 °C, respectively. In the main types division of lands, the study area was located in the mountain type and based on soil properties and their classification by

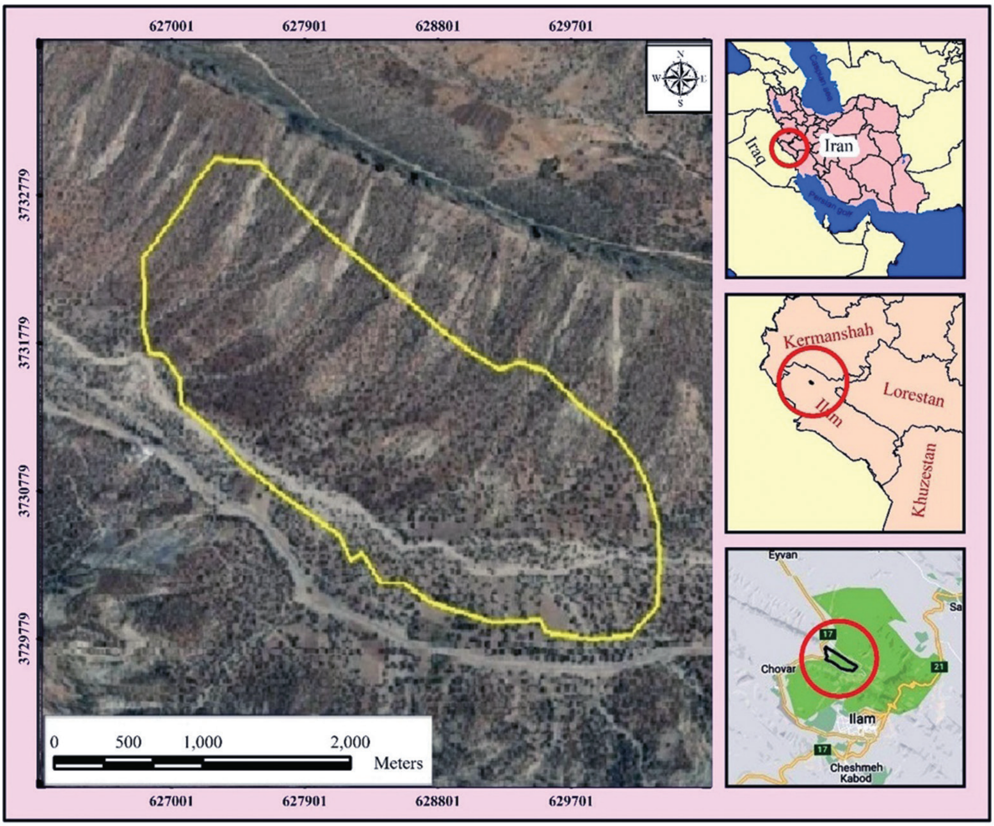



**Fig. 1. Location of study area.**

FAO, its soils are classified as lithosols (Rostami and Heidari 2009, Mirzaei and Bonyad 2016).

## Methods

In order to collect data, 100 circular plots (2000 $m^2$) were measured in inventory grid of 200×250 m. In each plot, physiographic factors including elevation (1450–1550, 1550–1650 and >1650 m a.s.l.), slope (0–25, 25–50 and >50 %) and aspect (North, South, East and West) were measured and recorded. Also the existence or non-existence of decline in oak trees was recorded. In total, 1370 oak trees were measured.

Logistic regression was used in order to modelling individual tree decline for oak trees. Logistic regression is a statistical method for analysing a dataset in which there are one or more independent variables. The equation of logistic regression (Long 1997, Pampel 2000, Hosmer and Lemshow 2000) is the following (Equation 1):

$$P_{(decline)} = \frac{1}{1 - e^{-\alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n}} \qquad (1),$$

where: α is intercept, *e* is Naperian constant, $\beta_1$ to $\beta_n$ is set of regression coefficients and $X_1$ to $X_n$ is the independent variables.

ANOVA and Duncan tests were used to compare tree decline in different classes of physiographic factors. Logistic regression was used to investigate the relationship between oak decline and physiographic factors. Omnibus test, log-likelihood and pseudo *r*-square coefficients (including of Cox & Snell *R* square and Nagelkerke *R* square) were used for evaluation of the logistic regression model (Hosmer and Lemeshow 2000, Heydari et al. 2015). The values of the pseudo *r*-square coefficient stats are between 0 and 1, and the more these statistics are closer to 1, it shows that the role of independent variables is high in the explanation of the variance of dependent variable. Also, Hosmer and Lemeshow test was performed fitting of the predicted changes in the dependent variable (Hosmer and Lemeshow 2000, Heydari et al. 2015). Excel ver. 2013 (Microsoft Office) and IBM SPSS Statistics ver. 22 software were used for analysis of data.

## Results

Descriptive statistics of the oak decline showed that 34.69 % of Dalab forests were decline in the study area. These statistics related to the oak decline are shown in Table 1.

The ANOVA test showed that there was a significant difference between oak decline in different slope classes (Table 2). According to Table 3, by increasing the percentage of slope factor, the oak decline was increased. Duncan test showed that the slope factor had significant effects on the decline of oak trees (Table 3).

The results showed that there was a significant difference between oak decline in the geographic aspects (tables 4 and 5). According to Table 5, the lowest and highest values of oak decline belonged to the east and south aspects, respectively. Also Duncan test showed that all geographic aspects had a significant difference in the oak decline values (Table 5).

**Table 1. Descriptive statistics of oak trees decline in study area.**

| Variable | Mean, % | SD | CV, % | SE, % |
|---|---|---|---|---|
| Decline | 34.69 | 9.22 | 26.57 | 5.31 |

Note: SD is standard deviation, CV is coefficient variation, SE is sampling error.

**Table 2. ANOVA test of tree decline in different slope classes.**

| Indicator | Sum of squares | d.f. | Mean square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 7230.48 | 2 | 3615.24 | 187.01 | 0.000* |
| Within Groups | 1875.13 | 97 | 19.33 | | |
| Total | 9105.615 | 99 | | | |

Note: d.f. is number degrees of freedom, * is significant difference at the 0.05 level probability.

**Table 3. Comparison mean of decline in different slope classes.**

| Slope classes, % | N | Subset alpha = 0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 0–25 | 29 | 23.99 | | |
| 25–50 | 42 | | 34.48 | |
| > 50 | 29 | | | 46.30 |

**Table 4. ANOVA test of tree decline in different aspect.**

| Indicator | Sum of squares | d.f. | Mean square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 7538.981 | 3 | 2512.994 | 153.991 | 0.000* |
| Within Groups | 1566.634 | 96 | 16.319 | | |
| Total | 9105.615 | 99 | | | |

Note: * is significant difference at the 0.05 level probability.

**Table 5. Comparison mean of decline in different aspect.**

| Aspect | N | Subset alpha = 0.05 | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| North | 11 | 26.54 | | | |
| South | 18 | | 46.30 | | |
| West | 42 | | | 34.48 | |
| East | 29 | | | | 19.82 |

The results of ANOVA showed that elevation had significant effects on the oak decline (Table 6), so that by increasing of elevation, the oak decline was increased (Table 7).

**Table 6. ANOVA test of decline in different elevation.**

| Indicator | Sum of squares | d.f. | Mean square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 1161.97 | 2 | 580.98 | 7.09 | 0.001* |
| Within Groups | 7943.64 | 97 | 81.89 | | |
| Total | 9105.615 | 99 | | | |

Note: * is significant difference at the 0.05 level probability.

**Table 7. Comparison mean of decline in different elevation.**

| Elevation classes, m | N | Subset alpha = 0.05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 1450–1550 | 41 | 31.07 | | |
| 1550–1650 | 26 | | 35.67 | |
| 1650–1750 | 33 | | | 38-96 |

According to the results of the Omnibus test, the fit of the model was acceptable and at a level of error less than 0.01 was significant. The results of Omnibus test are shown in Table 8.

**Table 8. Omnibus test of model coefficients.**

| Indicator | Chi-square | d.f. | Sig. |
|---|---|---|---|
| Step | 36.638 | 2 | 0.000 |
| Block | 688.716 | 7 | 0.000 |
| Model | 688.716 | 7 | 0.000 |

The values of both statistics related to the pseudo determination coefficient were acceptable (0.395 and 0.584), and these values indicated that the three independent variables of this study had the power of a relatively high explanation of the variance and changes in the dependent variable of oak decline. In fact, these three variables have been able to explain between 39.5 % and 58.4 % of the variations in the oak decline (Table 9). Also, the results of Hosmer and Lemeshow test showed that the research model was appropriate and has the necessary fit (Table 10).

**Table 9. Results of model summary.**

| -2 Log likelihood | Cox & Snell *R* square | Nagelkerke *R* square |
|---|---|---|
| 855.369 | 0.395 | 0.584 |

**Table 10. Hosmer and Lemeshow test of model.**

| Chi-square | d.f. | Sig. |
|---|---|---|
| 360.579 | 6 | 0.000 |

Results of variables entered on the model are shown in Table 11. The results of Wald statistic showed that all independent variables entered in the regression analysis were capable of predicting changes of dependent variable and their predictive ability at the probability level of 0.01 was significant. Also, the results of Exp (B) statistic showed that among the variables entered on the model, the slope variable has the highest ability to predict the impoverishment of trees, and the lowest ability was related to the elevation variable.

**Table 11. Results of variables entered on model.**

| Variable | B | S.E. | Wald | Sig. | Exp (B) |
|---|---|---|---|---|---|
| $E$ | | | 110.073 | 0.000 | |
| $E_1$ | 2.894 | 0.443 | 42.685 | 0.000 | 18.062 |
| $S$ | | | 35.621 | 0.000 | |
| $S_1$ | -1.159 | 0.343 | 11.428 | 0.001 | 0.314 |
| $S_2$ | -1.830 | 0.311 | 34.675 | 0.000 | 0.160 |
| $A$ | | | 77.246 | 0.000 | |
| $A_2$ | -1.577 | 0.426 | 13.702 | 0.000 | 0.207 |
| $A_3$ | 1.874 | 0.423 | 19.659 | 0.000 | 6.512 |
| Constant | -0.505 | 0.237 | 4.538 | 0.033 | 0.603 |

Note: $E$ is elevation, $E_1$ is elevation in 1450–1550 m a.s.l., $S$ is slope, $S_1$ and $S_2$ are slope in 0–25 and 25–50 % respectively, $A$ is aspect, $A_2$ and $A_3$ are aspect in south and east respectively.

According to the results of Table 8, logistic regression model for oak decline trees is as follows (Equation 2):

$$P_{(decline)} = 1/(1 + \exp(– 0.505 + 2.894\ E_1 – 1.159\ S_1 -1.830\ S_2 – 1.577\ A_2 + 1.874\ A_3)) \qquad (2),$$

where: $E_1$ is elevation in 1450–1550 class, $S_1$ and $S_2$ are slope in 0–25 and 25–50 % respectively, $A_2$ and $A_3$ are aspect in south and east, respectively.

## Discussion

The finding of present study showed that 34.69 per cent of Dalab forests were affected by the decline phenomenon (Table 1), which indicates that management operations should be taken as soon as possible to control and prevent the spread of oak decline in these forests. Evidences revealed that most of oak decline were located in areas that are classified as rain-fed agriculture and were affected by severe human intervention and exploitation in the region. In fact, the interaction of severe climate stresses, interferences and the presence of humans in the region has provided the necessary ground for increasing the decline of forest trees. The irregular distribution of rainfall and dry season length have more significant effect on the oak decline (Hamzehpour et al. 2011). In the present study, by increasing of slope and elevation factors, the rate of decline was increased (tables 3 and 7). Also, the lowest (23.99 %) and the highest (47.57 %) values of oak decline were in the slope classes 0–25 and >50 % (Table 3). Hosseini (2009) and Hosseinzadeh et al. (2015) reported that with increasing of elevation classes, rate of oak mortality was increased, which is in accordance with the results of the present study. Drohan et al. (2002) in their studies in Pennsylvania found that decline of maple trees occur at higher elevation. The effects of slope percentage on the oak decline were in accordance with the results of Lawrence et al. (2002), Kabrick et al. (2008), Kane and Kolb (2011) and Worrall et al. (2008) studies. By increasing the percentage of slope factor, the density of oak decline trees was increased and the density of healthy trees was decreased. In fact, by increasing the percentage of slope, moisture, soil depth and litter thickness decreases and these factors cause physiological weakness of the trees (Momeni Moghaddam et al. 2012). As the results show, the highest value of oak decline was in the southern and western aspects (tables 4 and 5). Sunlight intensity is higher in the western and southern aspects, providing more direct light and heat energy, which causes increasing the temperature, evapotranspiration and loses moisture. While the northern and eastern aspects receive low energy, so these aspects are cooler. Trees that are more restricted in the water condition (sun-directed) are more susceptible to drought (Suarez et al. 2004). Hosseinzadeh et al. (2015) showed that the rate of oak decline was higher in the southern than in the northern aspect, which is in accordance with the results of present study. Also, the results of this study are based on the results of Eckhardt and Menard (2008), which found physiographic factors of slope and aspect affecting pine (*Pinus taeda* L.) mortality in Central Alabama. Gerardin and Ducruc (1990) showed that the steep slopes in the sunshine directions in case of low rainfall are prone to soil drought and propagation drought stress for forest species. Extensive oak mortality and unprecedented abundance of oak borer populations are significant threats to forest health and economic value of timber. Regionally, there is a need to (1) identify trees and stands that are at high risk for oak decline, (2) forecast the mortality risk for individual trees within declining stands, and (3) select silvicultural treatments to mitigate decline.

The fitting and evaluation of models are an important part of modelling. According to the results of the Pseudo determination coefficient and Log-likelihood statistics (Table 9), it can be concluded that the logistic regression model of the study consists of three independent variables (elevation, slope and aspect) and dependent variable (decline) is a good model and the set of independent variables is capable of explaining the changes of decline. In other words, the set of independent variables have been able to explain 39.5 % to 58.4 % of the variations of decline variable (Table 9). Leites et al. (2009) showed that the logistic regression model has a high accuracy in estimation of the crown ratio for conifer forests in the United States that is in accordance with the results of this study. Mahdavi et al. (2015) using the logistic regression model and geographic information system showed that with increasing elevation in the western and southern aspects, forest cover density was increased and in areas with shallow soils and steep terrain the amount and distribution of dead standing oak trees were increased. Oak decline is widespread in the west of Iran that few studies have been done in this area, and consequently, specific causes for the phenomenon remain elusive. In general, physiographic factors are one of the most important sources of change in forest ecosystems (Bale et al. 1998). Although understanding their effects are complex due to the interaction of various factors, but an important part of it is due to light regulation and moisture regime (Kaufmann and Ryan 1986, Griffiths et al. 2009). Therefore, due to differences in the factors mentioned in different ecosystems, the comparison of the results of the present study with the results of other studies is not correct, but according to the results of this study and other researchers, it can be stated that the physiographic factors are very important in the estimation of quantitative characteristics of forest.

## Conclusion

Oaks are major component of the Zagros forests but due to decline phenomenon, vast area of these forests has been lost. Slope, aspect and elevation of physiographic factors affected the decline of oak trees. By increasing slope and elevation, percentage of the oak decline was increased. Determining the effects of these factors helps to identify areas that are in this situation or are at risk of developing a phenomenon of decline. It should be stated that quantitative and qualitative characteristics of each forest are a function of physiographic factors, the microclimate of the region, management and operation of the forest, geographical location, environmental and soil factors, species types and other factors. Also, logistic regression model that was used through our analyses can be used to estimate decline from knowledge of slope, aspect and elevation, information that is routinely collected during forest inventories. These models can be used to guide marking prescriptions during thinning and harvesting operations.

## Acknowledgments

This paper presents results from a research project entitled 'Estimation and mapping of decline forest stands in Ilam province using geostatistics and deterministic methods'. The research was sponsored by the Presidential Office, Department of Science and Technology, Iran National Science Foundation (95818244). The authors are grateful to the Iran National Science Foundation.

## References

Azizi Z., Najafi A., Sohrabi H. 2008. Forest canopy density estimating, using satellite images. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVIII. Part B8. Beijing 2008: 1127–1130.

Bale C.L., Williams J.B., Charley J.L. 1998. The impact of aspect on forest structure and floristics in some Eastern Australian sites. Forest Ecology and Management 110: 363–377.

Burnham R.N. 2002. Dominance, diversity and distribution of lianas in Yasuni Ecuador: Who is on top? Journal of Tropical Ecology 18: 845–864.

Drohan P.J., Stout S.L., Petersen G.W. 2002. Sugar maple (*Acer saccharum* Marsh.) decline during 1979–1989 in northern Pennsylvania. Forest Ecology and Management 170: 1–17.

Eckhardt L.G., Menard R.D. 2008. Topographic features associated with *loblolly pine* decline in central Alabama. Forest Ecology and Management 255: 1735–1739.

Fan Z., Kabrick J.M., Spetich M.A., Shifley S.R., Jensen R.G. 2008. Oak mortality associated with crown dieback and oak borer attack in the Ozark Highlands. Forest Ecology and Management 255: 2297–2305.

Fu L., Zhang H., Lu J., Zang H., Lou M., Wang G. 2015. Multilevel Nonlinear Mixed-Effect Crown Ratio Models for Individual Trees of Mongolian Oak (*Quercus mongolica*) in Northeast China. Plos One 10(8): e0133294.

Gerardin V., Ducruc J.P. 1990. An objective approach to evaluating natural drainage of forest mineral soils for non-specialists. Vegetatio 87: 127–133.

Griffiths R.P., Madritch M.D., Swansona A.K. 2009. The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): Implications for the effects of climate change on soil properties. Forest Ecology and Management 257: 1–7.

Hamzehpour M., Kia-daliri H., Bordbar K. 2011. Preliminary study of manna oak (*Quercus brantii* Lindl.) tree decline in Dashte-Barm of Kazeroon, Fars province. Iranian Journal of Forest and Poplar Research 19(2): 352–363.

Heydari M., Poorbabaei H., Esmailzadeh O., Salehi A., Eshaghi Rad J. 2015. Indicator plant species in monitorin forest soil conditions using logistic regression model in Zagros oak (*Quercus brantii* var. *persica*) forest ecosystems, Ilam city. Journal of Plant Researches 27(5): 818–828.

Hosmer D.W., Lemeshow S. 2000. Applied Logistic Regression. Third Edition. New Jersey: John Wiley & Sons. 528 p.

Hosseini A. 2009. Investigation the affection rate of oak trees to mistletoe, *Loranthus europaeus*, in forests of Zagros area (A case study of Southern slope of Manesht Mountain in Ilam Province). Iranian Journal of Forest and Range Protection Research 7(1): 26–35.

Hosseinzadeh J., Aazami A., Mohammadpour M. 2015. Influence of topography on Brant`s oak decline in Meleh-Siah Forest, Ilam Province. Iranian Journal of Forest and Poplar Research 23(1): 190–197.

Kabrick M., Dey J., Daniel C., Randy G., Wallendrof J. 2008. The role of environmental factors in Oak decline and mortality in the Ozark Highlands. Forest Ecology and Management 255: 1409–1417.

Kane J.M., Kolb T.E. 2011. Site and species differences in tree mortality within mixed-conifer forests of northern Arizona. 96th Ecological Society of America Conference, Austin, TX. August 7–11, 2011.

Kaufmann R.M., Ryan G.M. 1986. Physiographic, stand, and environmental effects on individual tree growth and growth efficiency in subalpine forests. Tree Physiology 2: 47–59.

Lawrence R., Moltzan B., Moser K. 2002. Oak decline and the future of Missouri s Forests. Missori Conservationist 63: 11–18.

Leites L.P., Robinson A.P., Crookston N.L. 2009. Accuracy and equivalence testing of crown ratio models and assessment of their impact on diameter growth and basal area increment predictions of two variants of the forest vegetation simulator. Canadian Journal of Forest Research 39: 655–665.

Long J.S. 1997. Regression Models for categorical and limited dependent variables. Thousand Oaks, CA: Sage Publications. 328 p.

Lu Y.C., Lei X.D., Jian D.L. 2003. A new function for modeling diameter frequency distribution in the tropical rain forest of Xishuangbanna, Southwest of China. Forestry Studies in China 5(2): 1–6.

Mahdavi A., Mirzaei Zadeh V., Niknezhad M., Karami O. 2015. Assessment and prediction of oak trees decline using logistic regression model (Case study: Bivareh forest, Malekshahi-Ilam). Iranian Journal of Forest and Range Protection Research 13(1): 20–33.

Marvi-Mohajer M.R. 2007. Silviculture. University of Tehran. 387 p.

Mirzaei M., Bonyad A.E. 2016. Comparison of fixed area and distance sampling methods in open forests: case study of Zagros Forest, Iran. Journal of Forestry Research 27(5): 1121–1126.

Momeni Moghaddam T., Sagheb-Talebi K., Akbarinia M., Akhavan R., Hosseini S.M. 2012. Impact of some physiographic and edaphic factors on quantitative and qualitative characteristics of Juniper forest (Case study: Layen region – Khorasan). Iranian Journal of Forest 4(2): 143–156.

Monserud R.A., Sterba H. 1999. Modeling individual tree mortality for Austrian forest species. Forest Ecology and Management 113: 109–123.

Pampel F.C. 2000. Logistic regression: A primer. Sage University Papers Series on Quantitative Applications in the Social Sciences, 07-132. Thousand Oaks, CA: Sage Publications.

Popoola F.S., Adesoye P.O. 2012. Crown ratio models for *Tectonia grandis* (Linn. f) stands in Osho forest reserve, Oyo state, Niġeria. Journal of Forest Science 28(2): 63–67.

Rostami A., Heidari H. 2009. Typology of forest stands and evaluation of their overall status in natural forest of Dalab region, Ilam province. Journal of Agricultural Sciences and Natural Resources 15(6): 274–277.

Sheykholeslami A., Kia Pasha Kh., Kia Lashaki A. 2011. A study of tree distribution in diameter classes in natural forests of Iran (Case study: Liresara forest). Annals of Biological Research 2(5): 283–290.

Shifley S.R., Fan Z., Kabrick J.M., Jensen R.G. 2006. Oak mortality risk factors and mortality estimation. Forest Ecology and Management 229: 16–26.

Suarez M., Ghermandi L., Kitzberger T. 2004. Factors predisposing episodic drought-induced tree mortality in Nothofagus site, climatic sensitivity and growth trends. Journal of Ecology 92: 954–966.

Worrall J., Egeland L., Eager T., Roy A., Erik W., Johanson P., Wayne A., Shepperd D. 2008. Rapid mortality of populous tremuloides in southwestern Colorado, USA. Forest Ecology and Management 255: 686–696.

Zheng L., Zhou X. 2010. Diameter distribution of trees in natural stands managed on polycyclic cutting system. Forestry Studies in China 12(1): 21–25.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 182–193

# WILLINGNESS TO PAY ESTIMATION FOR RIVERS BIODIVERSITY CONSERVATION, CASE STUDY OF GUILAN PROVINCE, NORTH IRAN

Tooba Abedi[1], Ladan Kazemi Rad[1], Nazi Avani[2*], and Behnam Yusefi[3]

[1]Academic Centre for Education, Culture and Research. Environmental Research Institute, Rasht, Guilan, Iran. E-mails: t.abedi@acecr.ir, L_Kazemi@erijd.ir
[2]Teaching Fellow, School of Distance Education, Universiti Sains Malaysia.
[*]E-mail: avani.nazi@yahoo.com
[3]Graduate Student of Forestry, Faculty of Natural Resources, Guilan University, Iran.
E-mail: behnamyousefi67@gmail.com

Received: 24 August 2018 Accepted: 06 January 2019

## Abstract

This study attempts to value the biodiversity and landscape services provided by four river spots: Khalkaei, Ghaleeroodkhan, Pasikhan and Shemroud of the North region of Iran, Guilan. The Contingent Valuation Method were used for estimation willingness to pay (*WTP*) for conserving these areas. This method tries to define the individual's *WTP* of given hypothetical market. It was estimated with a logit model for which indices were obtained based on a maximum precision criterion. The results show that 79.45 % of people were willing to pay for the landscape and biodiversity value of the rivers. Among the variables of the model presented, monthly expenditure and gender had a negative impact and age, education, environmental opinion and income had a positive impact on the *WTP* at 1 % level. The average monthly *WTP* per visitors was calculated as 21,913 Rials (0.74 $). The annual landscape and biodiversity value in terms of *WTP* for the landscape and biodiversity was estimated for Khalkaei, Ghaleeroodkhan, Pasikhan and Shemroud as 2 milliard, 15 milliard, 2 milliard and 8 million Rials, respectively. One unit change in descriptive variables (Education and Environmental opinion) showed the highest change in the probability of a positive response to the *WTP* among individuals. Therefore, in order to facilitate individual's involvement in public decision-making policies, improvement in perceptions of environmental awareness and educational level would seem desirable.

**Key words:** bid amount, Contingent Valuation Method, education, environmental opinion, logit model.

## Introduction

Human beings can receive many ecosystem services from rivers which provide benefits to them, including water supply for municipal, industrial and agricultural consumption, fish habitat and recreation (Loomis et al. 2000). When considering all ecosystem service values, instead of solely focusing on the economic value of the landscape and biodiversity, a more complete perspective is obtained.

Rivers have been interfered by humans for millennia by diverting water for cropland irrigation (Gopal 2016). According to Millennium Ecosystem Assessment (2005), more than half of the major rivers of the world are seriously polluted. The presence of these pollutants depletes the capacity of rivers and associated inland and coastal ecosystems to provide clean water for social and economic uses.

Millennium Ecosystem Assessment (MEA) is one of the frameworks that try to highlight the relationship between human and nature and advance a powerful vision for the future (Daily et al. 2009). It's vision is to highlight the central roles of ecosystems and environmental resources in supporting human wellbeing and thus incorporate their values into decision making (Farr et al. 2016).

For many years, economists and environmentalists have tried to develop valuation techniques to estimate the benefits of non-market services associated with the environmental resources in monetary terms (Farr et al. 2016). One of the methods is Contingent Valuation Method (CVM). It is the most commonly used among researchers around the world. CVM was proposed for first time by Ciriacy-Wantrup (1947) who believed that the soil erosion prevention generates some ′extra market benefits′ which define as public goods in nature, and one way to estimate the benefit is to elicit the willingness to pay of individuals by a survey method. The first person who used this method was Robert Kenneth Davis when he investigated the benefits of goose hunting through a survey among the goose-hunters (Venkatachalam 2004).

This obviously showed that biodiversity conservation benefits can be assessed through CVM (Abdullah et al. 2015). It's construction is based on hypothetical markets where individuals are ask to detect their willingness to pay for non-market products such as improve water quality to enjoy swimming or diving (Farr et al. 2016).

CVM has been applied by many researchers around the world to estimate the economic values of forests and other environmental services. Jain et al. (2017) used CVM to assess the *WTP* of respondents for benefits derived from forests in India. The results showed the average *WTP* was 2.1 € per respondent per month for all five intangible benefits with more than 43 % of total *WTP* for the intangible benefits ‘soil conservation and remediation’ and ‘improvement in underground water level’. Kerna (2012) obtained the median WTP per entry per car for Hrady and Morelos river sides in Colorado with 13 $ and 7 $ respectively. Lehtonen et al. (2003) also showed that 74 % of respondents are willing to pay for biodiversity conservation of forests in southern of Finland with the mean of *WTP* ranged from 60 $ to 223 $ per household per year. Abdullah et al. (2015) assess the biodiversity value of forest research institute in Malaysia with CVM and they found the mean *WTP* ranges from 53.24 RM to 67.22 RM, which could contribute annual revenue ranged from 66.3 million RM to 83.8 million RM.

Tao et al. (2012) evaluated the forest ecosystem services economic value in three counties in Anfu, Yongxin and Lianhua in China using CVM. Analysis resulted from 170 valid questionnaire out of 200, showed that respondents would pay for forest restoration and protection 238 yuan per year. It is shown that social-economic variables such as income, education level, household population and off-farm work members had the significant influence on individuals WTP.

Recently, in Iran, CVM is the environmental tool to assess non-market goods and services with WTP of individuals for conservation value of biodiversity of forests, recreational values of parks, preservation and reclamation of desert areas and economic valuation of forests animal species (Kolahi et al. 2013; Mansouri et al. 2014; Haghjou et al. 2015a, 2015b; Eslamian et al. 2016). Haghjou et al. (2016) applied CVM to assess the total economic value of Arasbaran forest in Iran. They found the significant positive relation between WTP of respondents and the level of education, income, number of annual visits to the forests, and their friendly attitudes towards Arasbaran forests. Haghjou et al. (2015b) mentioned that variables such as demographic, economic and social influence willingness to pay of respondents for different features of environmental resources. Amiri et al. (2015) also using CVM method estimating the annual conservation value of myrtle (Myrtus communis L.) in Dooreh forest in Iran and estimated average monthly WTP per family as 0.79 $ and 102.525 $ for annual conservation of myrtle forest. They found that education had a positive effect on WTP while family size and bid amount had a negative.

In the other study, Karimzadegan et al. (2007)and the extent to which the human race is vitally dependent on them. Without a firm understanding of the value of these systems we are unlikely to make many of the hard choices and compromises needed to protect them. In this study the least marginal monetary value of eleven forests and rangelands ecosystem services including gas regulation, plants genetic reverse diversity, pollination, soil formation, biological control, flood control, hydrological current control, water erosion control, wind erosion control, and ecotourism in fivefold vegetative regions of Khazar, Arasbaran, Zagros, Iran-toran and Khalij-e Omani (Oman gulf estimate non-market values of fivefold vegetation regions in Iran (Khazar, Arasbaran, Zagros, Iran-Toran and Khalij-e Omani (Oman gulf) with surface area of about 65,624.4 ha equal to 47.9 billion $ per year.

Although many studies have been tried to estimate the conservation value of forest resources in Iran, studies on the conservation value of biodiversity of rivers, similar to this study, are very limited. Our investigation deal with four rivers in the North of Iran, Guilan province which are one of the tourism attraction areas in the north of Iran.

The purpose of this study is to estimate the conservation value of biodiversity of four rivers in Iran in order to provide evidence for policy makers and managers by quantifying the economic values of biodiversity conservation of rivers to support and prevent any further destruction.

## Material and Method

### Study area

The rivers have been destroyed in recent years in Iran. Large projects are running in Guilan province simultaneously which leads significant problems such as rivers contamination and overexploitation of sand and gravel. It causes loss of the river landscape and tourist attraction.

Khalkaei, Ghaleeroodkhan, Pasikhan and Shemroud rivers are the main tourists' attraction and rivers in Guilan province which face contamination problems recently due to overexploitation of sand and gravel for construction purposes (Nezami Balochi et al. 2007).

In order to assess the willingness of visitors to protect the landscape and diversity of main rivers in Guilan province, four rivers – Khalkaei, Ghaleeroodkhan, Pasikhan and Shemroud were studied (Fig. 1). The source of Khalkaei River is from the mountains of Masal city, locat-

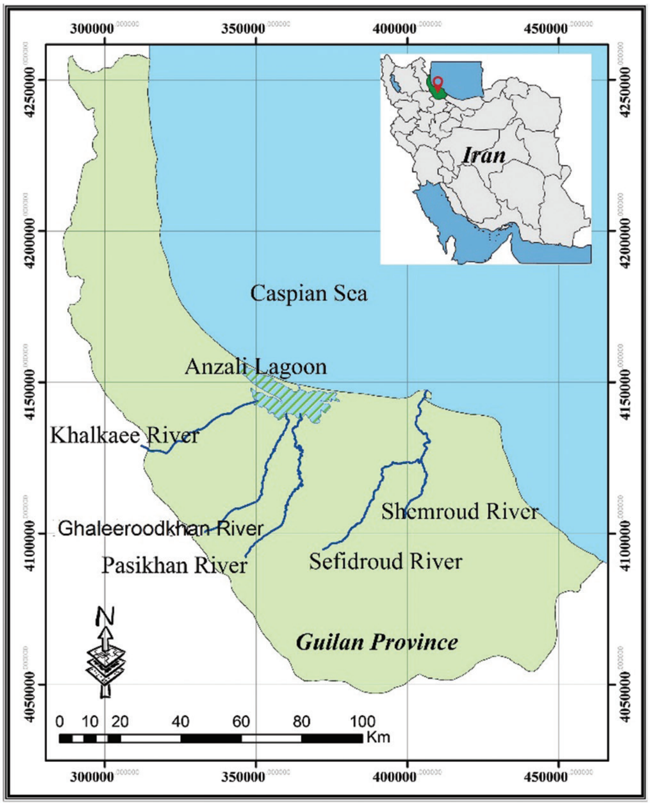



**Fig. 1. The map of the study area.**

ed in Guilan province. The river length is 40 km and the average annual discharge is 4.77 $m^3/s$. Ghaleeroodkhan and Pasikhan rivers origin from Fouman city and the average annual discharge are 0.93 and 22.6 $m^3/s$, respectively. The source of Shemroud river is from the mountains of Siyahkal city, located in the Guilan province. The river length is 101.72 km and the average annual discharge is 4.05 $m^3/s$.

## Methodology

In this paper, CVM was used to estimate the economic value of conserving biodiversity of rivers.

Therefore, the well-known CVM with logit model are used to evaluate the conservation purpose (Loomis 1989, Jain et al. 2017). The identified intangible benefits of biodiversity and landscape of four rivers were surveyed by asking questions of tourists who visited rivers annually whether they are willing to pay for rivers conservation or not.

In early application of CVM, the respondents usually were asked an open-ended questions about their *WTP*, whether they would be willing to pay for the services they receive or not. The respondents were ask if they are interested to contribute biodiversity conservation of rivers by choosing ’Yes‘ or ’No‘ with respect to a proposed price in a hypothetical market in a double bounded dichotomous choice approaches.

Dichotomous choice format is the most widely sued approach to eliciting respondents *WTP*. The amount in questions depends on the regular market where usually people purchase or decline to purchase. The questionnaire used in this study were taken from Amiri et al. (2015).

Regards to the question whether the individuals willing to pay for biodiversity conservation of rivers and to find the proper charge, a pilot study with forty questionnaire (open questions) without a proposed price were distributed randomly among individuals. In the pilot study on 40 respondents, the lowest *WTP* given by respondents was 10,000 Rials, the highest *WTP* was 40,000 Rials and the main bid was 20,000 Rials.

According to Cultural Heritage, Handicrafts and Tourism Organization (2013) the number of tourists who visited Khalkaei, Ghaleeroodkhan, Pasikhan and Shemroud rivers in 2013 were 9,074, 58,245, 10,000 and 320, respectively. In order to analyse the visitors *WTF*, questionnaires were distributed among visitors.

To estimate the landscape and biodiversity value of the rivers, tourists were asked to participate as part of our sample population. The required sample size for simple random sampling was calculated according to Cochran (1977) (Equation 1).

$$n = \frac{\frac{z^2 \cdot p \cdot q^2}{d^2}}{1 + \frac{1}{N}\left[\frac{z^2 \cdot p \cdot q}{d^2} - 1\right]} = 380 \quad (1),$$

where: $N$ is population; $p$ is the acceptance (0.5); $q$ is the rejection (0.5); $z$ = 1.96; $d$ is error part.

Therefore, for each river, 95 questionnaires were distributed among visitors, 370 accepted and were surveyed in the analysis.

SHAZAM and Excel were used to calculate the logit model parameters.

## Results

Socioeconomic aspects of individual respondents is one of the most important part in the questionnaire, therefore the first section contained questions regarding age, gender, marital status, education, occupation, family size, place of residence, income, monthly expenditure and environmental opinion (Table 1).

**Table 1. Definition of variables.**

| Variable | Definition |
|---|---|
| Age | Scale variable |
| Gender | 0: Female, 1: Male (Nominal scale) |
| Marital status | 0: Single, 1: Married (Nominal scale) |
| Education | Years of the education from illiterate, to PhD (Ordinal scale) |
| Occupation | Level of occupation from Expert to no job (Ordinal scale) |
| Family size | Number of family members (Scale factor) |
| Place of residence | Size of the household (Scale variable) |
| Income | Average monthly income in Rial (Scale variable) |
| Monthly expenditure | Average monthly expenditure in Rial (Scale variable) |
| Environmental opinion | Whether the respondent feeling responsibility towards natural resource protection or not (Nominal scale) |

The statistical result of socioeconomic characteristics of respondents are presented in Table 2. The average age of about 40.64 represents the high average age between visitors. It is showed that 88 % of visitors were married and 85 % were male and the average education years were 13.05. 54 % of respondents showed their environmental opinion and responsibility towards natural resource protection which showed the importance of environment among visitors. The average monthly expenditure was almost 10 million Rials and the average monthly income was about 13 million Rials.

**Table 2. Statistical Results of Socioeconomic Characteristics.**

| Variable | Mean | Standard deviation | Max | Min |
|---|---|---|---|---|
| Age, years | 46.64 | 12.2 | 91 | 20 |
| Education | 13.05 | 3.12 | 22 | 0 |
| Household size | 2.95 | 1.47 | 6 | 1 |
| Monthly expenditure, million Rials | 10 | 6 | 40 | 1 |
| Monthly income, million Rials | 13 | 8 | 70 | 2 |

Out of 370 respondents, 294 (79.45 %) were willing to pay something for the landscape and biodiversity of the rivers, while the other 76 (20.55 %) respondents were not interested to pay anything. Out of the 88 persons, who were asked to pay 20,000 Rials, only 12 people were willing to pay less than 10,000 Rials and the remaining 76 individuals were not willing to pay anything. Out of the 282 people who accepted the first offer of 20,000 Rials, 113 people agree to pay the amount less than 40,000 Rials bid and the rest agreed to pay 40,000 Rials (Table 3).

**Table 3. Response to three proposed bids for the purpose of rivers landscape and biodiversity.**

| Response | Indicator | Bid 1, 20,000 Rials | Bid 2, 10,000 Rials | Bid 3, 40,000 Rials |
|---|---|---|---|---|
| Yes | Frequency | 282 | 12 | 169 |
| | Percent | 76 | 3 | 46 |
| No | Frequency | 88 | 76 | 113 |
| | Percent | 24 | 21 | 30 |
| Total | Frequency | 370 | 88 | 282 |
| | Percent | 100 | 24 | 76 |

The logit regression method provided the following model for the landscape and biodiversity value of the rivers (Equation 2):

$$WTP_i = \alpha_0 + \alpha_1 \cdot x_1 + \alpha_2 \cdot x_2 + \\ + \alpha_3 \cdot x_3 + \alpha_4 \cdot x_4 + e_i \quad (2),$$

where: $WTP_i$ is the willingness of respondent *i* to pay; $x_1$ represents education; $x_2$ is household size, $x_3$ is household income in million Rials; and $x_4$ represents the bids in Rials (0, 10,000, 20,000 and 40,000 Rials).

Table 4 shows the estimated coefficients, levels of statistical significance and the effect of descriptive variables of the logit model on the dependent variable (based on maximum likelihood estimation).

**Table 4. Estimated regression coefficient of the most effective variables of logit model.**

| Variable | Estimated coefficient | *t*-value | Elasticity | Marginal effect |
|---|---|---|---|---|
| Constant | -1.6772 | -1.8858 | -0.6004 | - |
| Age | 0.25408E-01*** | 2.9083 | 0.36963 | 0.58394E-02 |
| Gender | -0.70411*** | -2.5201 | -0.22071 | -0.16182 |
| Education | 0.88215E-01*** | 2.8174 | 0.41197 | 0.20274E-01 |
| Environmental opinion | 0.94869*** | 5.4362 | 0.18 | 0.21 |
| Monthly expenditure, million Rials | -0.40419E-06** | -2.15 | -0.15 | $0.92 \times 10^{-7}$ |
| Monthly income, million Rials | 0.50110E-06*** | 3.0904 | 0.24 | $0.11 \times 10^{-6}$ |
| BID, Rials | -0.54037E-05 | -0.7253E-01 | $-0.51 \times 10^{-2}$ | $-0.12 \times 10^{-5}$ |

Note: Likelihood ratio statistic = 67.432, probability (LR statistic) = 0, McFadden square = 0.91, Percentage of right predictions = 89.85; ** – Statistical significance at 5 % level, *** – Statistical significance at 1 % level.

The results also show that variable of monthly expenditure was effective in accepting the bids at 5 % statistical level. As well, it should be noted that the variable of gender had a negative effect, while age, education, environmental opinion and income had a positive effect on the *WTP*.

Moreover, the variables age, gender, education, environmental opinion and income were statistically significant at one per cent level of significance and were the most important factors in *WTP* to conserve the landscape and biodiversity of rivers. Besides that, monthly expenditure was negatively significant at 5 % level. As the amount of the bid increased, *WTP* of people reduced substantially. This means that their elasticity to pay is inversely related with the price of perceived services provided, since their low income levels have a negative effect on their support to conserve the landscape and biodiversity of rivers.

In order to determine changes in the probability of *WTP* in estimating the landscape and biodiversity value due to one unit change in one of the independent variables, it was necessary to calculate their marginal effect. We also calculated elasticity to show the relative importance of descriptive variables of the model in response to changes in *WTP* for the landscape and biodiversity of river ecosystem.

The proposed bid was the most important descriptive variable for determining the probability of *WTP* for the landscape and biodiversity of rivers. It showed that one unit change in the amount of proposed bid changed the probability of accepting the bid by $0.51 \times 10^{-2}$ per cent. Furthermore, due to the marginal effect of this variable, one unit change in the amount of the proposed bid changed the probability of a positive response to the *WTP* by $0.12 \times 10^{-5}$ in favour of the landscape and biodiversity of rivers.

The estimated coefficient for the income variable was significant at 1 % statistical level. With its positive sign, as expected, it means that one per cent change in income, the probability of accepting the amount of the proposed bid would be changed by 0.24 per cent. Also, in terms of the marginal effect of this variable, one unit change in the income of the respondent, the probability of positive response to conserve the river, changed by $0.11\times10^{-6}$ per cent.

It is found that there is a positive relationship between age and probability of *WTP* that is significant at 1 % level. In other words, every one unit (year) increase in age, the probability of willingness to pay increases $0.58\times10^{-2}$ units. Besides, again as one percent increase occurs in age variable, willingness to pay increases 0.36 per cent.

Education and probability of *WTP* showed a positive relationship which is significant at 1 % level. In other words every one percent increase in Education, the probability of accepting the amount of the proposed bid would be increased by 0.41 per cent. Besides, one unit change in education (one year) the probability of positive response to *WTP* increases by 0.02027 units.

Sex variable was negatively significant at 1 % level and showed that female participants were more willing to pay than men. The probability of *WTP* among females was 0.16 units more than that of males. In other words, one percent increase in the number of male respondents, the probability of accepting of *WTP* decreases by 0.22071 per cent.

Environmental opinion showed a positive significant effect on *WTP*. It means that one percent change in environmental opinions of individuals, the probability accepting of *WTP* would be changed by 0.18 %. Besides, one unit change in environmental opinion the probability of positive response to *WTP* increases by 0.21 units.

The monthly expenditure was significant at 5 % level, but it was negative and with increasing one per cent of monthly expenditure, the probability of accepting *WTP* decreases by 0.15 %.

In addition, McFadden coefficient of determination was calculated as 0.91, suggesting that the explanatory variables of the model explained the dependent variable very well. Another useful criterion for goodness of fit of the model was the classification of the respondents in two groups, i.e., those who accepted the bid for river landscape and biodiversity and those who rejected it. The proportion of correct predictions of the model was 91 %, implying that 91 % of the respondents indeed correctly answered ’Yes‘ or ’No‘ when asked about their willingness to pay.

The expected average *WTP* according to the logit model, using maximum likelihood was calculated by numerical integration in the range of zero to the maximum amount of the proposed bid as follows (Equation 3):

$$WTP = \int_{0}^{40000} \frac{1}{1+\exp\left[-\left(-0.1930566-0.00000056A\right)\right]} dA = 21913 \quad (3),$$

Based on Eq. (3), the expected *WTP* per household for the landscape and biodiversity of rivers, was estimated to be 21,913 Rials per month.

The overall landscape and biodiversity value of the rivers (*LBV*) were calculated using the following relationship (Equation 4):

$$LBV = AAWH \cdot NHD \quad (4),$$

where: *AAWH* is the annual average of *WTP* per visitor and *NHD* is the number of tourists to visit the river annually.

The number of visitors of Khalkaei, Ghaleeroodkhan, Pasikhan and Shemroud rivers is annually 9,074, 58,245, 10,000 and 320 person per year, respectively (Cultural Heritage, Handicrafts and Tourism Organization 2013). Based on the number of visitors currently visited the rivers in Guilan we obtained conservation value for one year is shown in Table 5.

**Table 5. The overall conservation value of the rivers in Guilan (*LBV*).**

| River | *AAWH* | *NHD* | *LBV*, Rials |
|---|---|---|---|
| Khalkaei | 21913 | 9074 | 2,386,062,744 |
| Ghaleeroodkhan | 21913 | 58245 | 15,315,872,220 |
| Pasikhan | 21913 | 10000 | 2,629,560,000 |
| Shemroud | 21913 | 320 | 84,145,920 |

## Discussion

The econometric analysis shows that respondents with higher incomes, greater environmental values, and those who are older and female are more likely to be willing-to-pay. However this result is in contract by Loomis et al. (2000) who mentioned that age, income and education has not a significant effect on individual willing to pay for ecosystem conservation in South Platte river. They also showed that people who are in environmental group are more willing to pay for ecosystem conservation which is in agreement with this study. Abdullah et al. (2015) also stated that respondents who are familiar with the issues related to the environment would be willing to pay more.

Regards to the gender, the results showed that female are more willing to pay for river conservation and biodiversity compare to men which is in contract with (Mansouri et al. 2014) who found that men are more willing to pay for recreational value of forest park. In agreement with this study, Lee and Han (2002) found that the probability of WTP 'Yes' is likely to be higher in female than male respondents. The results of Eslamian et al. (2016) also showed that female participants were more willing to pay than men.

Age, education and income had the highest impact on the elasticity of *WTP*. In other words, as incomes rise, the tendency to pay more for the landscape and biodiversity of the river and elasticity for the *WTP* to preserve their environment increased. This result is in agreement with Kerna (2012), Tao et al. (2012), Amiri et al. (2015) and Abdullah et al. (2015) who mentioned that the higher the income, the more likely the respondents accept the proposed bid.

Education also had a positive effect on willingness to pay which shows the same result with Kolahi et al. (2013), Tao et al. (2012) and Mansouri et al. (2014). Jorgensen et al. (2001) also conducted that lower levels of education tended to be unwilling to pay. Compared to income, with increase of one unit of income (1 Iranian Rial) individual's willingness to pay increase by 0.11×10-6 units, but by increasing one year of education, the probability of WTP increases by 0.202 units.

The result of this study showed that older people are more willing to pay for environmental conservation. Jain et al. (2017) also found the same result in India and they concluded that the older people willing to pay due to the environmental security for their next generation. In contrast, Abdullah et al. (2015) found that when the age of the individuals increases, the probability to accept WTP decreases. Lee and Han (2002) also conducted that the probability of WTP 'Yes' is likely to be higher in younger people than that of older people.

Using Eq. (3), the mean *WTP* was calculated at the mean of the other independent variables. The resulting mean monthly *WTP* per individual was 21,913 Rials (0.734 $[1]) per month for landscape and biodiversity conservation value of rivers. Loomis et al. (2000) assessed the mean monthly willingness to pay per household to increase five ecosystem services (dilution of wastewater, natural purification of water, erosion control, habitat for fish and wildlife, and recreation) along 45 miles of South Platte River which was about 21 $ higher as water bill. It means that households are willing to pay 21 $ more in their monthly bill to increase ecosystem services. The differences between this two studies might be due to the differences in the purpose of the investigation. In our study, only the biodiversity and landscape valuation has been evaluated, but Loomis et al. (2000) asked five main aspects of river sides which is very important for rural and urban citizens. Besides that, stronger currency, higher income and education might be the reasons of differences in *WTP* in these two studies.

Mansouri et al. (2014) found the mean WTP of recreational value of forest park equal to 17,919 Rials per person. Apparently, this was because, in their study this amount is only for visiting the park, but in our study the mean WTP is for conservation of the rivers biodiversity and landscape which is more valuable for visitors.

The mean *WTP* of this study and Amiri et al. (2015) showed almost the same amount (0.79 $), this was because they evaluated the conservation value of myrtle (*Myrtus communis*) as a medicine species in Iran. The same result might be due to the same income and educational level, age and environmental opinion which has a main effect on *WTP*.

The mean monthly willingness to pay of recreational value of 33 parks across Iran from 2004 to 2011 showed the amount of 1.4 $ per person (Kolahi et al. 2013). The differences of *WTP* between previous study and our study might be due to the fact that their study was done 2 years earlier when the economic situation was better[2].

## Conclusion

This study determined the biodiversity and landscape value of four rivers in the North of Iran based on tourists *WTP* for rivers conservation through CVM model and a dichotomous questionnaire. Although the level of income in Iran is modest, 79.45 % of respondents are willing to contribute for rivers biodiversity and landscape conservation. It showed the highest potential and willingness of people to contribute to environmental conservation decision- making policies. The rest (20.55 %) who are not willing to pay, believe that paying for environmental quality is the responsibility of governments or local agencies not individuals or other social groups such as polluters or users should take responsibility for that. This finding is in accordance with Jorgensen et al. (2001) and Abdullah et al. (2015).

The mean *WTP* for rivers conservation was calculated as 21,913 Rials. The results showed that age, education, environmental opinion and income had a posi-

[1] 1 USD = 29854.8 IRR in the year of 2015

[2] 1 USD = 12285.6 IRR in the year of 2013

tive effect on the *WTP*, while the variables of gender and income had the highest effect on *WTP*.

The descriptive variables education and environmental opinion showed better assess in marginal effects which with changing one unit in education and environmental opinion, the willingness to pay increases by 0.202 and 0.218 units which are higher than other quantitative variables. Therefore, rising level of education and environmental awareness influence on environmental protection by individuals.

The result of this study revealed that the individuals were consciously aware of the role and the significance of rivers, and also they would like to contribute for natural resources conservation and willing to pay for its maintenance and protection. In addition, they were interested in protecting such ecosystems for next generation. Therefore, the effort and interest of individuals to preserve natural resources, must convince the government and local agencies to preserve natural resources and prevent them from destruction.

## References

Abdullah M., Mamat M., Yaacob M., Radam A., Fui L.H. 2015. Estimate the Conservation Value of Biodiversity in National Heritage Site: A Case of Forest Research Institute Malaysia. Procedia Environmental Sciences, Elsevier B.V., vol. 30: 180–185.

Amiri N., Emadian S.F., Fallah A., Adeli K., Amirnejad H. 2015. Estimation of conservation value of myrtle (*Myrtus communis*) using a contingent valuation method: a case study in a Dooreh forest area, Lorestan Province, Iran. Forest Ecosystems 2: 30 p. Available at: https://doi.org/10.1186/s40663-015-0051-6

Ciriacy-Wantrup S.V. 1947. Capital Return from Soil Conservation Practices. Journal of Farm Economics 29: 107–126.

Cochran W.G. 1977. Sampling techniques. 3rd edition. Whley and Sons, USA. 428 p.

Cultural Heritage, Handicrafts and Tourism Organisatoion 2013. The statistical report of residential units monthly capacity of Guilan province. Publishing hause. 87 p. (in Farsi).

Daily G.C., Polasky S., Goldstein J., Kareiva P.M., Mooney H.A., Pejchar L., Ricketts T.H., Salzman J., Shallenberger R. 2009. Ecosystem services in decision making: Time to deliver. Frontiers in Ecology and the Environment 7(1): 21–28.

Eslamian Z., Ghorbani M., Mesbahzade T., Rafiee H. 2016. Estimating participation and willingness to pay of local communities for preservation and reclamation of desert areas (Case Study: Abuzeidabad district of Aran Va Bidgol county). Desert 2: 205–212.

Farr M., Stoeckl N., Esparon M., Grainger D., Larson S. 2016. Economic Values and Indigenous Protected Areas across Northern Australia. Final Report. 83 p.

Gopal B. 2016. A conceptual framework for environmental flows assessment based on ecosystem services and their economic valuation. Ecosystem Services, Elsevier, vol. 21: 53–58.

Haghjou M., Hayati B., Pishbahar E., Molaei M. 2015a. Economic Valuation of Arasbaran Forests' Non-use Values in Iran. Indian Journal of Natural Sciences 6(31): 9526–9534.

Haghjou M., Hayati B., Pishbahar E., Molaei M. 2015b. The Economic Valuation of Arasbaran Forests' Animal Species in Iran. (An Application of Contingent Ranking Approach). Indian Journal of Natural Sciences 6(31): 9605–9615.

Haghjou M., Hayati B., Pishbahar E., Molaei M. 2016. Using the contingent ranking approach to assess the total economic valuation the of Arasbaran forests in Iran. Taiwan Journal of Forest Science 31(2): 89–104.

Jain A., Chandra G., Nautiyal R. 2017. Valuating intangible benefits from afforested areas: A case study in India. Economia Agraria y Recursos Naturales 17(1): 89–100.

Jorgensen B.S., Wilson M.A., Heberlein T.A.

2001. Fairness in the contingent valuation of environmental public goods: Attitude toward paying for environmental improvements at two levels of scope. Ecological Economics 36(1): 133–148.

Karimzadegan H., Rahmatian M., Dehghani Salmasi M., Jalali R., Shahkarami A. 2007. Valuing forests and rangelands-ecosystem services. International Journal of Environmental Research 1(4): 368–377.

Kerna A. 2012. Valuing Recreation and Environmental Flows in the Colorado River Delta Utilizing the Contingent Valuation Method. Master Thesis. University of Arizona. 57 p. Available at: https://www.climas.arizona.edu/sites/default/files/pdfkernasonoran-institute-report.pdf

Kolahi M., Sakai T., Moriya K. 2013. Ecotourism potentials for financing parks and protected areas: a perspective from Iran's Parks. Journal of Modern Accounting and Auditing 9(1): 144–152.

Lee C.K., Han S.Y. 2002. Estimating the use and preservation values of national parks' tourism resources using a contingent valuation method. Tourism Management 23(5): 531–540.

Lehtonen E., Kuuluvainen J., Pouta E., Rekola M., Li C.Z. 2003. Non-market benefits of forest conservation in southern Finland. Environmental Science and Policy 6(3): 195–204.

Loomis J., Kent P., Strange L., Fausch K., Covich A. 2000. Measuring the total economic value of restoring ecosystem\services in an impaired river basin: results from a contingent\valuation survey. Ecological Economics 33: 103–117.

Loomis J.B. 1989. Test-Retest Reliability of the Contingent Valuation Method: A Comparison of General Population and Visitor Responses. American Journal of Agricultural Economics 71(1): 76–84.

Mansouri M., Badehian Z., Adeli K., Vajari Abrari K. 2014. Estimating the Recreational Value of Forest Parks Using Contingent Valuation Method (Case Study: Hassan Gavyar Forest Park of Noorabad City). Agriculture Science Developments 3(5): 200–204.

Millennium Ecosystem Assessment 2005. Millennium ecosystem assessment. Island Press, Washington, D.C., USA. 245 p.

Nezami Balochi S., Khara H., Jamalzadeh Fallah F., Akbarzadeh A. 2007. The comparison of physical and chemical characteristics of Anzali Lagoon and its entrance rivers. Research and Invention in Natural Resource 73: 76–83 (in Farsi).

Tao Z., Yan H., Zhan J. 2012. Economic Valuation of Forest Ecosystem Services in Heshui Watershed using Contingent Valuation Method. Procedia Environmental Sciences 13: 2445–2450.

Venkatachalam L. 2004. The contingent valuation method: A review. Environmental Impact Assessment Review 24(1): 89–124.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 194–200

# RELATION OF SLOPE AND VEGETATION COVER WITH THE PROBABILITY OF LANDSLIDE OCCURRENCE NEAR FOREST ROADS

Alireza Ghomi Motazeh[1*], Roghaye Baniasadi[2], and Rosanna Gahler[3]

[1]University of Guilan, Department of Natural Resource, Iran. *E-mail: Alireza.Ghomi@yahoo.com
[2]University of Birjand, Department of Agriculture, Iran. E-mail: Roghaye.Baniasadi@yahoo.com
[3]University of Freiburg, Faculty of Natural Resources, Germany.
E-mail: Rosanna.Gahler@gmx.de

Received: 07 June 2018 Accepted: 18 January 2019

## Abstract

Many natural disturbances accrue in Iran because of its geographical condition. Mostly the recovery of this damage is impossible or requires a lot of time and cost. The general purpose of this research is to find out the relationship between slope of the terrain and the vegetation cover from one side and the mass movement of land from the other and to finally illustrate applicable data in the field of forest road construction. In this research, 39 cluster samples at a distance of 700 m along the 28 km of road were taken by systematic random method. In each cluster, the first sample was taken 50 m upward from the road; the second sample was taken 50 m downward from the road and the third sample was taken 10 m off the road. The number of landslides in each area and its relationship with road construction was analyzed in dependence of the terrain slope and the percentage of vegetation cover. Results showed that a road construction could be an effective factor for increasing mass movements. Moreover, excavated slope causes an increase of mass movement, too. Results of the research also indicated that there was an inverse relationship between an increased percentage of vegetation cover and the frequency of landslide occurrence.

**Key words:** cluster samples, forest, mass movement, road construction.

## Introduction

Because of special geographical, topological and climate properties of Iran, natural disturbances are accruing in this country frequently. Landslide is one of these damages which are defined as general and deep movement of layers of soil on bedrock. Every year, this phenomenon cause's environmental damages and sometimes the recovery of this disruption is impossible or takes a lot of time and costs (Khosrozadeh 1999). Slope stability in a region is the most sensitive and important issue in construction and route selection, especially for mountainous roads. Ignoring this issue could cause irrecoverable damages to projects. Mass movement is a natural disturbance which has been occurring because of ignoring road construction standards (Alexander 1995). In order to prevent increasing damage costs, detecting and classifying effective factors which cause landslides in forests is necessary (Pyles and Froehlich 1997). Zezere et al. (1999) reported that the most important effective factors for landslide occurrences could be geological and petrology structure, land use, ancient landslides and human activities. Krogstad (2001) made a general evaluation plan about the probability of landslide occurrences in planning forest roads in the forests of northern America and achieved a regression model through comparing landslide areas to controlled areas and then illustrated several models about the probability level of landslide occurrences using effective factors. Borga (2005) investigated the effects of forest roads on shallow landslide in four regions of north Italy. He showed how the road could be effective on landslide occurrence in sensitive areas. Results of this model indicated quantitatively the rate of road effects on shallow landslides in forests. Pascual (2001) investigated reasons and effects of landslides in Nepal. He divided the effective factors in 2 classes: manmade and natural factors. Rollerson et al. (2004) prepared a guide map regarding areas that are sensitive to landslides in Canada. He found out that most of the landslides took place on clear cuts and on road construction areas. The general purpose of our research is to find out the relationship between the terrain slope and vegetation cover from one side and the mass movements of lands and finally to illustrate applicable data in the field of forest road construction to optimize timber logging.

## Materials and Methods

The study area (1450 ha) is located in watershed number 7 in northern Iran (Fig. 1). This region is between 37°28′ to 37°32′ N and 48°59′ to 49°59′ E. Most of the study area has a small slope. Minimum altitude is about 100 m and the maximum is 1200 m.

Because of human activities over the last decades many disturbances accrued in that area. One sign of destruction is the reduction in percentage of vegetation canopy cover. In this research after studying the base maps, 39 cluster and 117 samples with a distance of 700 m along the 28 km road was taken via systematic randomize method (In each cluster 3 samples were taken). In a chosen area, one

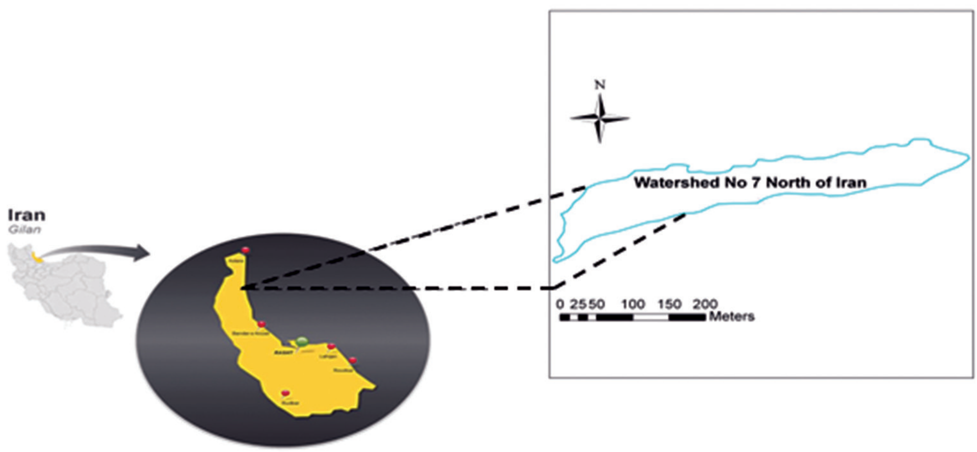



**Fig 1. The study area.**

sample was taken 50 m upward from the road; a second sample was taken 50 m downward from the road and a third sample was taken 10 m off the road axis. Figure 2 illustrates the location of the samples.

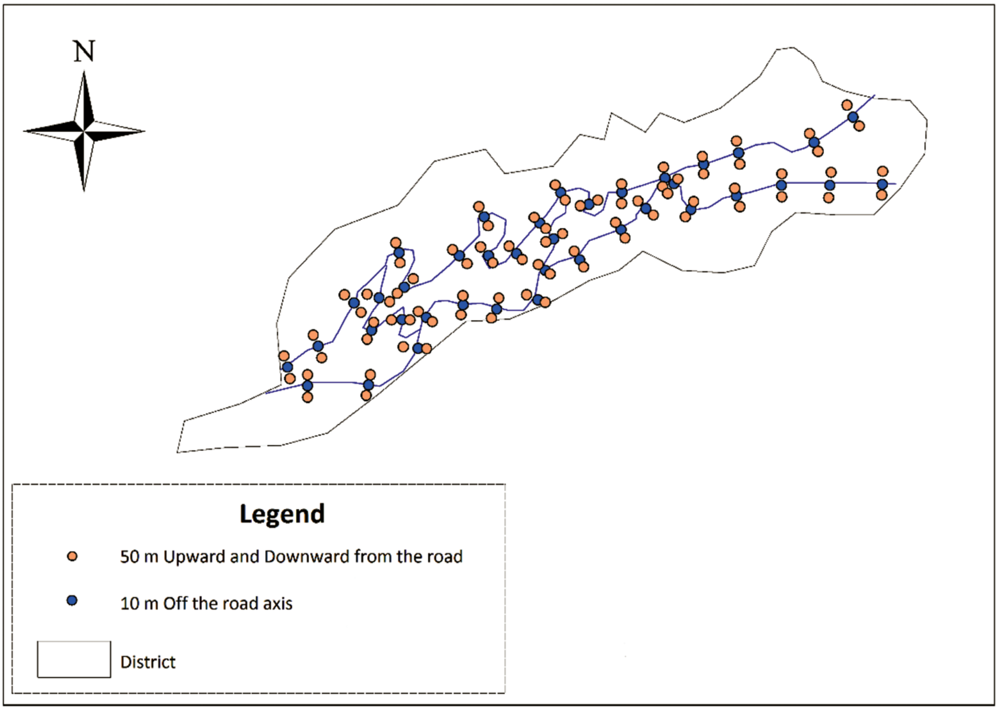



**Fig. 2. Sampling locations.**

Samples 50 m upward and downward from the road were considered as control plots which had the same terrain slope, slope direction and vegetation cover as the10 m samples had. No construction project took place in this area. Random systematic sampling method in shape of cluster is shown in Figure 3.

## Results

Approximately 80 % of the area has a grade of less than 60 %, and 20 % of the area has a grade of 60 % to 100 %. Samples 50 m upward from the road had 4 landslides and 2 landfalls but within this 10 m off the road axis, 16 landslides and 12 landfalls were recorded which occurred along the28 km of the constructed road. Just one landslide occurred downward from the road. Thus, it can be concluded that the number of movements increase, the closer you get to the road. To summarize, results of the total mass movement along the studied road network are shown in Table 1.

The frequency of mass movements along the 28 km of constructed road indicates that most mass movements have occurred within a short distances from the road (10 m off the road). This indi-

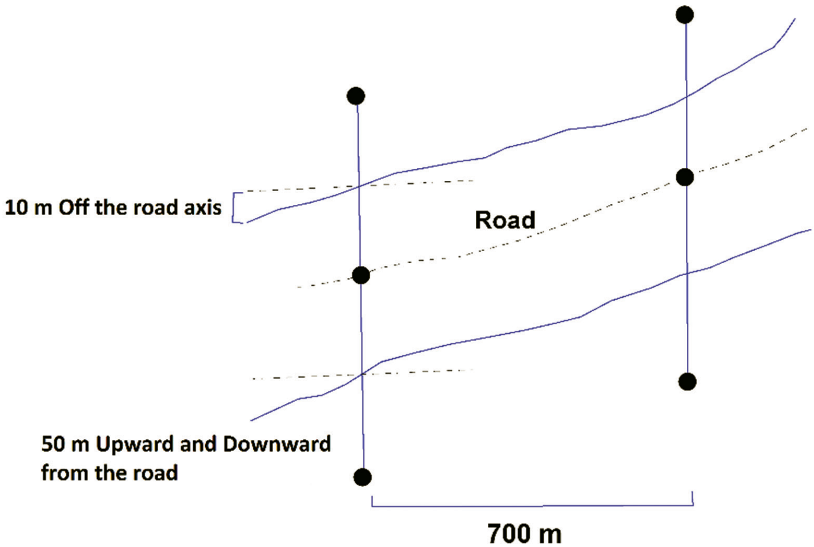



**Fig. 3. View the location of clusters.**

cates that road construction has an effect on landslides. In order to make results clearer, information is shown in percentage in Table 2.

**Table 1. Total mass movement in the studied road network.**

| Sample | Number of landfall | Number of landslide |
|---|---|---|
| 50 m upward from the road | 2 | 4 |
| 50 m downward from the road | - | 2 |
| 10 m off the road axis | 12 | 16 |
| Total | 14 | 22 |

**Table 2. Share of mass movement in sampling location.**

| Sample | Share of landfall, % | Share of landslide, % |
|---|---|---|
| 50 m upward from the road | 14.5 | 18.5 |
| 50 m downward from the road | 0 | 9 |
| 10 m off the road axis | 85.5 | 72.5 |

Landslide at the distance of 50 m downward from the road was 9 % but it was 72.5 % 10 meters off the road axis. No landfall had occurred downward the road. These results show that road construction in forests significantly increases the probability of landslides. In order to complete results, the effect of terrain grade on landslide occurrence in the study area was investigated too. The frequency of landslide and landfall and its relationship to grade classes is illustrated in Table 3.

**Table 3. Frequency of landslide and landfall in different slopes.**

| Division of grade, % | Share of landfall, % | Number of landfall | Share of landslide, % | Number of landslide |
|---|---|---|---|---|
| 0–30 | 0 | 0 | 0 | 0 |
| 30–60 | 0 | 0 | 20 | 4 |
| 60–80 | 33.3 | 4 | 20 | 4 |
| 80–100 | 66.6 | 10 | 60 | 14 |
| Total | 100 | 14 | 100 | 22 |

These values and percentages show that there was a significant positive relationship between the slope grade and the frequency of landslide. The landslide frequency increases an increasing terrain grade. In the next step, in each of the 117 samples the percentage of vegetation cover was measured and then classified into 5 classes to show the effect of vegetation cover on land movements. The frequency and percentage of the occurred landslides and landfalls and its relationship to classes of vegetation cover in study area is illustrated in Table 4.

**Table 4. Frequency and percentage of landslide and landfall occurrences in different vegetation classes.**

| Class of vegetative cover, % | Share of landfall, % | Number of landfall | Share of landslide, % | Number of landslide |
|---|---|---|---|---|
| 0–20 | 71.42 | 10 | 27.27 | 6 |
| 20–40 | 28.57 | 4 | 27.27 | 6 |
| 40–60 | 0 | 0 | 9.09 | 2 |
| 60–80 | 0 | 0 | 27.27 | 6 |
| 80–100 | 0 | 0 | 9.09 | 2 |
| Total | 100 | 14 | 100 | 22 |

According to Table 4, we concluded that there is an inverse relationship between the frequency of landslides and landfalls regarding the percentage of vegetation cover. Moreover, the rate of landslides and landfalls increase while the vegetation cover is decreasing.

## Discussion

In this research, the areas which were located along the studied road were investigated through sampling method. Results indicate that mass movement along roads was higher than the rate of natural areas which were far from road construction operations. This finding was similar to Sarikhani and Gorji (2003) and Ahmadi and Esmaeli (2003) findings. In this research it was proved that the mass movement within 10 m of the road was 4 times more than that 50 m upward the road and 8 times more than 50 m downward the road. The landfall movement within 10 m of the road was 6 times more than the 50 m upward the road. Investigations about effective factors on landslide were conducted by Gerayi (2006) who demonstrated that the percentage of landslide at a distance less than 200 m far from roads was higher in comparison to further distances. Roads could be considered as an effective factor on land movements. The slope parameter could be another effective factor which leads to instability and mass movement (Keefer 2000, Wang and Xu 2001). Slope is the most important effective factor on Pathogenesis processes on a regional scale (McDaniel et al. 1992). Steep slopes cause an increase in soil erosion because of more shallow movement (Hall 1983). Slope destructions during road construction and operations without considering standards are a reason of landslide occurrences. This result was similar to Swift (1985) findings. Usually material removal from the upward to the downward in sensitive lands can intensify danger. Vegetation cover has been also recognized as an effective factor in slope stability (Komac and Gerald 2006). Rollerson et al. (2001) proved that most landslides usually occurred in road construction areas and forest clear cuttings. Vegetation cover removal causes an increase in water infiltration and consequently increases landslides. Other investigations show~~s~~ that the frequency of landslide occurrences increase~~s~~ when a road is constructed, the forest ecosystem is changed and vegetation cover is removed (Pachauri 1992).

## Conclusion

Results of this study indicate that forest road construction has significant effect on an increase in landslide occurrences and increases it several times. Thus, the relationship among them is proved. According to the collected data from this research and in comparison to other studies the hypothesis that road construction in mountainous forests causes landslide occurrences in shape of mass movement and landfall is proved. Besides, the terrain slope factor causes an increase in the frequency of landslides which indicates that slope affects the occurrence of mass movements. Moreover, results showed that there was an inverse relationship between the increasing percentage of vegetation cover and the frequency of the occurred landslides.

This paper mainly discussed the number of landslides along forest roads in relation to slope, vegetative cover and the relative distance from road. Many environmental factors are involved with landslides but their weight of influence is quite different. This paper only focused on slope and vegetative cover condition. However road construction seems the main human activities that will cause shallow landslide for area like Iran which has no or little rainfall triggered landslide. So doing such studies about other effective factors and their relation to earth mass movement in Iran is necessary.

## References

Ahmadi H., Esmaeli A. 2003. Using GIS and RS in mass movements hazard zonation. International Symposium. 22–26 September, Gent (Belgium). Poster Session: 45–49.

Alexander D.E. 1995. A survey of the field of natural hazards and disaster studies. UCL Press Limited. 85 p.

Borga M. 2005. Evaluating the influence of forest road on shallow land sliding. Ecological modeling1 87(1): 85–98.

Gerayi P. 2006. Evaluation of a mass movement to provide a model for regional hazard zonation in the watershed is Lajymrud. MS thesis in forestry. Mazandaran University. Department of Natural Resources.85 p. (in Iranian).

Hall G.F. 1983. Pedology and geomorphology. In: Wilding L.P., Smeck N.E., Hall G.F. (Eds), Pedogenesis and Soil Taxonomy: I. Concepts and Interactions. Elsevier, NY:

117–140.

Keefer D.K. 2000. Statistical analysis of an earth quake induced landslide distribution the1989 Loma Prieta. California event. Engineering Geology 58: 231–249.

Khosrozadeh A. 1999. Studding the landslide in aspect of the earth shape. Case study; Arzfoon, Mazandaran wood and paper industry. The first International Conference on Environmental Changes in Caspian region. Mazandaran University.145 p. (in Iranian).

Komac M., Gerald F. 2006. A Landslide susceptibility model using the Analytical hierarchy process. Method and multivariate statistics per alpine Slovenia Geomorphology 74: 17–28.

Krogstad F. 2001. Incorporating Landslide Probability into Operations Planning, In Proceedings of the International Mountain Logging and 11th Pacific Northwest Skyline Symposium. Seattle, WA, December 10–12, 20 D. K 01: 71–77.

McDaniel P.A., Bathke G.R., Boul S.W., Falen A.L. 1992. Secondary manganese/iron ratios as petrochemical indicators of field-scale through flow water movement. Soil Science Society of America Journal 56: 1211–1217.

Pachauri A.K. 1992. Landslide mapping based on geological attributes. *Engineering Geology* 32: 81–100.

Pascual T. 2001. A Report on the Causes and Effects of Landslides in Dhunche, High Mountain Himalaya, Nepal. University of London. 53 p. Available at: http://lib.icimod.org/record/10822/files/ 621.pdf

Pyles M.R., Froehlich H.A. 1997. Discussion of: Rates of Land sliding as Impacted by timber management activities in North California. Bulletin of the Association of engineering geologists, vol. 24, No 3: 425–431.

Rollerson T., Millard T, Jones C, Trainor K, Thomson B. 2001. Predicting Post-Logging Landslide Activity Using Terrain Attributes: Coast Mountains, British Columbia. Vancouver Forest Region, Ministry of Forests Technical Report 11. Nanaimo, B.C. 20 p.

Rollerson T.P., Maynard D., Higman S., Ortmayr E. 2004. Klanawa landslide hazard mapping pilot project. A joint conference IUFRO S3.06.00: Forest operations under mountainous conditions and 12th International Mountain Logging Conference, June 13–16, Vancouver, B.C. 24 p. Available at: http://www.for.gov.bc.ca/hfd/library/ffip/Rollerson_TP2004.pdf

Sarikhani N., Gorji M.M. 2003. Possibilities of stabilizing landslide and mass movement in forest roads. Iranian Journal of Natural Resources 56(1–2): 29–37.

Swift L.W. 1985. Forest road engineering design to minimize erosion in the southern Appalachians. In: Blackmon B.G. (Ed.) Proceedings of Forest and Water Quality: a Mid-South symposium; Little Rock, Arkansas. Monticello, Arkansas: University of Arkansas, Department of Forest Resources: 141–151.

Wang R., Xu R. 2001. Zonation of the landslide the fore servitor region engineering. Geology74: 17–28.

Zezere J.L., Ferreira A.D., Rodrigues M.L. 1999. The role of conditioning and triggering factors in the occurrence of landslides: a case study in the area north of Lisbon (Portugal). Geomorphology 30: 133–146.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 201–207

# GAS-EXCHANGE RESPONSE OF NORWAY MAPLE (*ACER PLATANOIDES* L.) AND SILVER LIME (*TILIA TOMENTOSA* MOENCH) SAPLINGS TO FOREST THINNING

Svetoslav Anev* and Nikolina Tzvetkova

Department of Dendrology, Faculty of Forestry, University of Forestry, 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria. *E-mail: svetoslav.anev@ltu.bg

Received: 19 April 2018 Accepted: 20 January 2019

## Abstract

A species-specific initial response of gas-exchange and water use efficiency of Norway maple and Silver lime saplings were observed after a forest thinning. The photosynthetic rate increased significantly both in Norway maple and Silver lime leaves. The transpiration rate of Norway maple increased more intensively, in comparison to Silver lime. Norway maple saplings suffer both from intensive light and moisture deficit, while Silver lime saplings were more resistant to the patch opening. Stable water use efficiency in Silver lime leaves in response to the thinning may result from the better ability of this species to keep available water, which could be considered as the greater resistance to patch opening. These results may serve as a basis for improvement of forestry approaches in mixed deciduous forests with the presence of Norway maple and Silver lime.

**Key words:** patch, photosynthesis, transpiration, understory, water use efficiency.

## Introduction

Thinning is the main forestry practice to increase tree growth by reducing stand tree density and competition for environmental resources. Further, small group selection harvests (small patch cuts) may be employed to increase the heterogeneity of forest conditions in a management area (Grebner et al. 2012). The physical environment within a small open area surrounded by forest differs from that under the canopy or in a large open area (Runkle 1985). Forest thinning increase the amount of incident light below the canopy, causing changes in temperature and water regimes inside the stand (Tang et al. 2005), and probably can affect the nutrients availability (Blanco et al. 2005). Positive effects of thinning on tree growth are therefore caused by the reduction of a crown and belowground competition and the concentration of potential growth in only a reduced number of selected individuals (Martín-Benito et al. 2010).

Relatively few studies have compared plasticity in gas-exchange characteristics of woody plants in contrasting light environments after a forest thinning. The specific regimes of sub-canopy light, temperature, humidity, and nutrient availability within the patches can provide an advantage of shade-intolerant tree species, but at the same time can reduce the physiological potential for adaptation and survival of sapling of shade-tolerant species (Kobe and Coates 1997). Competitive dynamics can then be assessed in eco-physiological context, wherein plant performance and distribution are assessed in relation to fine-scale, competitor-induced environmental variation (Burton and Bazzaz 1995). Burton and Bazzaz (1995) and Sipe and Bazzaz (1994) showed that specific differences in the physiological performance and plasticity of tree species lead to differences in their ability to invade and compete in open patches. The light acclimatization begins initially on the primary physiological processes, such as photosynthesis and transpiration. According to Chazdon (1992), an accurate picture of the photosynthetic characteristics of forest understorey plants must incorporate transient photosynthetic responses. Chow et al. (1991) observe that shade-tolerant species tend to have low maximum rates of photosynthesis, even when grown under conditions of high light availability, due to intrinsic mesophyll factors. Köstner (2001) established a linear increase in transpiration rate with increasing net radiation for spruce and beech canopies. He suggests that daily maximum of vapour pressure deficit is the best single atmospheric predictor of daily rate of transpiration. While the transpiration of gymnosperm correlated strongly with stand age (Köstner et al. 2002), in angiosperm remained almost constant over a wide range of age (Köstner 2001). In accordance to Wuenscher and Kozlowski (1971) water-use efficiency (WUE), the ratio of $CO_2$-uptake to water-loss, decreased along the gradient from xerophytic to mesophytic species.

The aim of this study was to compare the initial response of gas exchange and WUE of Norway maple (*Acer platanoides* L.) and Silver lime (*Tilia tomentosa* Moench) leaves after a patch opening. Both species are categorized in the literature as a non-pioneer, shade tolerant and tend to grow near other species in dense woodlands (San-Miguel-Ayanz et al. 2016, Schütt and Roloff 1994). We aimed to determine whether these two species have a species-specific early stress response and light plasticity, which could be considered as an indicator of different adaptive mechanisms.

## Materials and Methods

### Site description and plant material

The experiment was conducted in the arboretum of the University of Forestry, Bulgaria (Table 1).

After a small patch opening in a mixed broadleaf bio-group, dominated by Norway maple and Silver lime, a part of the understory saplings of the experimental species were exposed to full sunlight, whereas the other part remained in a shade. Norway maple is a fast-growing species, which germinates and grows quickly in shade, even under closed canopy (San-Miguel-Ayanz et al. 2016). Silver lime is relatively resistant to persistently low humidity because the dense hairiness of the young leaves and shoots reduces transpiration. Young trees endure shadows, but older ones have high light requirements and must be free (Schütt and Roloff 1994).

**Table 1. Site and stand characteristics.**

| Site characteristics | |
|---|---|
| Latitude, ° ’ ” | 42° 39’ 09” N |
| Longitude, ° ’ ” | 23° 21’ 30” E |
| Altitude, m a.s.l. | 590 |
| Soil type (Jordanova and Jordanova 1999) | Pellic Vertisoil |
| Mean annual temperature, °C (Alexandrov et al. 2004) | 9.9 |
| Annual amounts of precipitation, mm (Alexandrov et al. 2004) | 571 |
| **Stand characteristics** | |
| Height, m | 17 |
| Diameter at breast height (DBH), cm | 20 |
| Leaf area index (LAI), $m^2 \cdot m^{-2}$ | 5.57 |
| Patch area, $m^2$ | 48 |

Note: Height and DBH were measured on ten Norway maple and ten Silver lime trees from the main stand. LAI was calculated in accordance to Beer’s law and following Monsi and Saeki (2005): $LAI=\cos\theta \cdot \ln(I/I_0) \cdot k^{-1}$, where $\theta$ is the zenith angle, $I_0$ is the incident radiation, $I$ is the radiation transmitted below canopy, $k$ is the extinction coefficient, and LAI is the leaf area index. According to Bréda et al. (2003) $k$ assumed to constant: $k$=0.50.

### Gas exchange measurements and micro-environmental conditions

The measurements of leaf gas exchange and recording of micro-environmental conditions were performed a week after thinning. Twenty randomly chosen saplings (five per plant species, both from the understory and from the patch) were used for the measurements. The values of examined variables were measured on the third and the fourth fully developed main stem leaves from the top of each sapling (Sesták 2012).

The photosynthetic rate ($A_N$, μmol$CO_2 \cdot m^{-2} \cdot s^{-1}$) and transpiration rate ($E$, mmol$H_2O \cdot m^{-2} \cdot s^{-1}$) of each leaf (two per sapling) were measured with a portable infrared gas analyser Li-6400 (Li-Cor Biosciences, Lincoln, NE, USA) equipped with shielded thermocouples, quantum sensor (LI-190) and red light-emitting diode light source (6400-02) in the chamber. Ambient photosynthetic photon flux density (*PPFD*, μE·$mol^{-1}$air), $CO_2$ concentration (μmol$CO_2 \cdot mol^{-1}$air), air temperature ($T_A$, °C) and relative humidity (*HD*, %) were recorded simultaneously during measurements through Li6400 sensors. The air pumped into the Li-6400 was passed through a buffering tank (10 L) with a constant flow rate (500 μmol air·$s^{-1}$) to reduce the time for measurement stabilization. Due to determine light-saturated photosynthesis, the PPFD in the chamber was maintained at 1000 μE·$m^{-2} \cdot s^{-1}$. The data were recorded after a stabilization time of minimum 5 minutes and lowering the total coefficient of variation to less than 0.5 %. Water use efficiency (*WUE*, μmol$CO_2$·mmol$^{-1}H_2O$) was calculated in each case of measurements as a proportion of $A_{N,}$ and $E$ (Barrs 1968).

### Statistical analysis

Shapiro-Wilk test ($P$-value < 0.05) was used to determine whether the outcome variables were normally distributed. Variables were reported as medians and quartiles because the hypothesis of normal distribution was rejected in each case. The Mann-Whitney rank sum test (*P*-value < 0.001) was used to test for differences between the medians of micro-environmental parameters in both patches. A Kruskal-Wallis one-way analysis of variance on ranks (*P*-value < 0.001) was used to determine differences in the median values of the investigated physiological parameters among the treatment groups. A multiple-comparison procedure (Tukey Test, *P*-value < 0.05) was used to isolate the group or groups that differ from the others. All statistical proceedings were performed with MS Excel (Office 2016, Microsoft, Redmond, WA, USA) and user-defined functions in Visual Basic for Applications (MS VBA 7.1, Microsoft, Redmond, WA, USA).

## Results

### Micro-climatic conditions

Photosynthetic photon flux density (*PPFD*) was the most varying micro-climatic factor between patch and understory. The *PPFD* increased almost 120 times in patch in compare to understory (Table 2).

**Table 2. Micro-environmental characteristics of understory (*U*) and patch (*P*).**

| Micro-climatic factors | *U* | *P* |
|---|---|---|
| *PPFD*, $\mu E \cdot m^{-2} \cdot s^{-1}$ | 4.0 a | 479.0 b |
| *Ta*, °C | 25.3 a | 26.2 b |
| *RH*, % | 49.1 a | 46.7 b |
| $CO_2$, $\mu molCO_2 \cdot mol^{-1}air$ | 384.6 a | 379.9 a |

Note: Values shown are medians (*n* = 20). The same letters on each row indicate that there is no statistically significant difference (Mann-Whitney rank sum test, *P*-value < 0.001) between medians in both areas.

Both the higher *Ta* and lowest *RH* in the patch are due to higher illumination in comparison to understory. The lack of variation in $CO_2$-concentration between two areas was presumably due to small area of the patch.

### Gas-exchange

The photosynthetic rate increased significantly after the patch opening both in leaves of Norway maple and Silver lime (1.9 and 1.7 times respectively). The understory saplings of Silver lime photosynthesize more actively than saplings of Norway maple and this difference has kept after a thinning (Fig. 1).

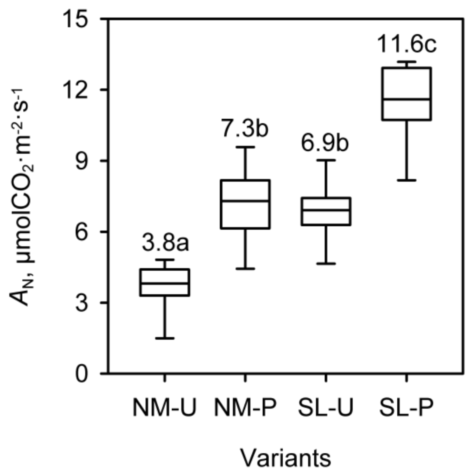



**Fig. 1. Photosynthetic rate ($A_N$) of Norway maple (*NM*) and Silver lime (*SL*) in the understory (*U*) and in the patch (*P*).**

Note: Medians and 25th and 75th percentiles are shown in boxes, and minimum and maximum values are shown as whiskers. The median values above boxes, indexed by the same letter, are not significantly different (Tukey test, *P*-value < 0.05).

After a patch opening the transpiration rate both of Norway maple and Silver lime also increased significantly. In the leaves of patch saplings of Norway maple, *E* increased 5.72 times, while in the Silver lime leaves this increase is only 2 times (Fig. 2).

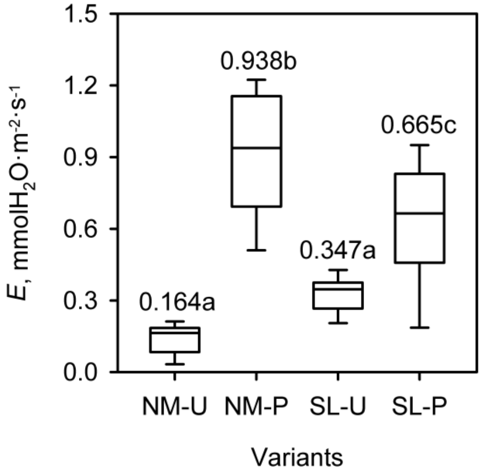



**Fig. 2. Transpiration rate (*E*) of Norway maple (*NM*) and Silver lime (*SL*) in the understory (*U*) and in the patch (*P*).**

Note: Medians and 25th and 75th percentiles are shown in boxes, and minimum and maximum values are shown as whiskers. The median values above boxes, indexed by the same letter are not significantly different (Tukey test, *P*-value < 0.05).

As a result, *WUE* of Silver lime was not significantly different between patch and understory, while the understory Norway maple saplings used water 3.15 times more effectively in comparison to patch saplings (Fig. 3).

## Discussion

The initial response in photosynthesis of two species to the patch opening was almost similar, while the response of transpiration was species-specific. Rapid light

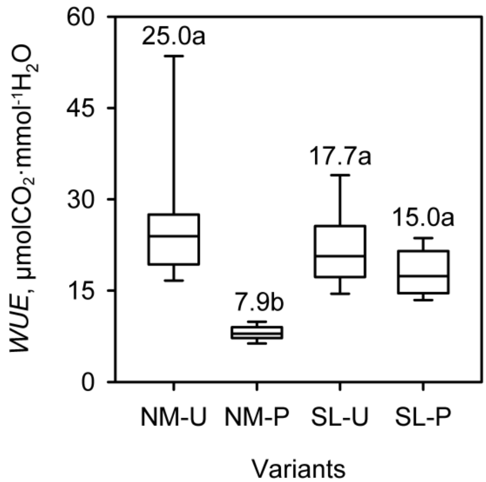



**Fig. 3. Water use efficiency (*WUE*) of Norway maple (*NM*) and Silver lime (*SL*) in the understory (*U*) and in the patch (*P*).**

Note: Medians and 25th and 75th percentiles are shown in boxes, and minimum and maximum values are shown as whiskers. The median values above boxes, indexed by the same letter are not significantly different (Tukey test, *P*-value < 0.05).

saturation of the leaves of these shade-tolerant species (San-Miguel-Ayanz et al. 2016, Schütt and Roloff 1994) was probably the leading factor of photosynthesis increase. Chow et al. (1991) even observe prone to photoinhibition in sudden exposure to high irradiance, which presumably leads to further limit the increase in photosynthesis when the understory opened. Despite of the higher rate of photosynthesis of Silver lime within the patch, Norway maple saplings may better cope with the high illumination. The established variation in photosynthesis agrees with the finding of Chazdon and Field (1987) that photosynthetic capacity shows a little variation among leaves of understorey plants, despite high variation in light availability among leaf microsites.

The transpiration rate of thin leaves in Norway maple respond much stronger, than in the morphologically more adapted leaves of Silver lime. Bréda et al. (2006) point out that during drought for most tree species, a more severe limitation occurred for $E$ than for $A_N$, and as a result, water use efficiency generally increases. However, the Norway maple saplings tried to maximize carbon assimilation by keeping stomata opened even in severe drought stress. Such strategy leads to dramatic decrease of WUE after patch opening. In the same time, stable WUE in Silver lime leaves in response to the changed conditions may result from the ability of this species to keep available water, which could be considered as the greater resistance to patch opening, probably due to xeromorphic features of the leaves.

## Conclusions

The short-term response of gas-exchange of tree saplings balances a complex set of site constraints to each microenvironment patch type. Immediately after the patch opening, the Norway maple saplings suffer heavily both from intensive light and moisture deficit. The Silver lime saplings showed better resistance to the increased amount of incident light and related changes in temperature and humidity. This study presents an early initial response of the Norway maple and Silver lime saplings to the suddenly increased light. Further research is necessary to understand the whole plant physiological response in the understorey for a longer period and to evaluate the effect of subsequent thinning practices on the balance between assimilation and transpiration of the two species.

## Acknowledgements

This study was supported by scientific project No 93/2015 of the University of Forestry, Bulgaria.

## References

Alexandrov V., Schneider M., Koleva E., Moisselin J.M. 2004. Climate variability and change in Bulgaria during the 20th century. Theoretical and Applied Climatology 79(3): 133–149.

Barrs H.D. 1968. Effect of Cyclic Variations in Gas Exchange under Constant Environmental Conditions on the Ratio of Transpiration to Net Photosynthesis. Physiologia plantarum 21(5): 918–929.

Blanco J.A., Zavala M.A., Imbert J.B., Castillo F.J. 2005. Sustainability of forest management practices: Evaluation through a simulation model of nutrient cycling. Forest Ecology and Management 213(1–3): 209–228.

Bréda N. 2003. Ground based measurements of leaf area index: a review of methods, instruments and current controversies. Journal of Experimental Botany 54(392): 2403–2417.

Bréda N., Huc R., Granier A., Dreyer E. 2006. Temperate forest trees and stands under severe drought: a review of ecophysiological responses, adaptation processes and long-term consequences. Annals of Forest Science 63(6): 625–644.

Burton P.J., Bazzaz F.A. 1995. Ecophysiological Responses of Tree Seedlings Invading Different Patches of Old-Field Vegetation. Journal of Ecology 83(1): 99–112.

Chazdon R.L. 1992. Photosynthetic plasticity of two rain forest shrubs across natural gap transects. Oecologia 92(4): 586–595.

Chazdon R.L., Field C.B. 1987. Determinants of photosynthetic capacity in six rainforest Piper species. Oecologia (Berlin) 73: 222–230.

Chow W.S., Adamson H.Y., Anderson J.M. 1991.

Photosynthetic acclimation of Tradescantia albiflora to growth irradiance: Lack of adjustment of light-harvesting components and its consequences. Physiologia plantarum 81(2): 175–182.

Grebner D.L., Bettinger P., Siry J.P. 2012. Introduction to Forestry and Natural Resources. 1 ed. Elsevier Science, USA: 496 p.

Kobe R.K., Coates K.D. 1997. Models of sapling mortality as a function of growth to characterize interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. Canadian Journal of Forest Research 27(2): 227–236.

Köstner B. 2001. Evaporation and transpiration from forests in Central Europe – relevance of patch-level studies for spatial scaling. Meteorology and Atmospheric Physics 76(1): 69–82.

Köstner B., Falge E., Tenhunen J.D. 2002. Age-related effects on leaf area/sapwood area relationships, canopy transpiration and carbon gain of Norway spruce stands (*Picea abies*) in the Fichtelgebirge, Germany. Tree Physiology 22(8): 567–574.

Jordanova D., Jordanova N. 1999. Magnetic Characteristics of Different Soil Types from Bulgaria. Studia Geophysica et Geodaetica 43(3): 303–318.

Martín-Benito D., Del Río M., Heinrich I., Helle G., Cañellas I. 2010. Response of climate-growth relationships and water use efficiency to thinning in a *Pinus nigra* afforestation. Forest Ecology and Management 259(5): 967–975.

Monsi M., Saeki T. 2005. On the Factor Light in Plant Communities and its Importance for Matter Production. Annals of Botany 95(3): 549–567.

Runkle J.R. 1985. Disturbance regimes in temperate forests. In: Pickett S.T.A., White P.S. (Eds), The Ecology of Natural Disturbance and Patch Dynamics, Academic Press: 17–33.

San-Miguel-Ayanz J., Rigo D.D., Caudullo G., Durrant T.H., Mauri A. 2016. European Atlas of Forest Tree Species. Publication Office of the European Union, Luxembourg. 197 p.

Schütt P., Roloff A. 1994. Enzyklopädie der Holzgewächse: Handbuch und Atlas der Dendrologie, vol. III. Wiley-VCH. 5388 p.

Sesták Z. 2012. Photosynthesis during leaf development. Springer Netherlands: 396 p.

Sipe T.W., Bazzaz F.A. 1994. Gap Partitioning among Maples (*Acer*) in Central New England: Shoot Architecture and Photosynthesis. Ecology 75(5): 2318–2332.

Tang J., Qi Y., Xu M., Misson L., Goldstein A.H. 2005. Forest thinning and soil respiration in a ponderosa pine plantation in the Sierra Nevada. Tree Physiology 25(1): 57–66.

Wuenscher J.E., Kozlowski T.T. 1971. Relationship of Gas Exchange Resistance to Tree Seedling Ecology. Ecology 52(6): 1016–1023.

FORESTRY IDEAS, 2018, vol. 24, No 2 (56): 208–216

# ROCK PARTRIDGE (*ALECTORIS GRAECA*) RECOVERY PROGRAM: FIRST EVIDENCES ON SURVIVAL AND DISPERSION RATE OF SEMI-NATURAL REARED BIRDS IN 'VRACHANSKI BALKAN' NATURE PARK

Christo Mihajlov, Gradimir Gruychev*, Stoyan Stoyanov, and Evlogi Angelov

Wildlife Management Department, University of Forestry, Sofia 1797, 10 Kliment Ochridski Blvd., Bulgaria. *E-mail: gradi.val@gmail.com

Received: 09 October 2018 Accepted: 20 January 2019

## Abstract

Rock Partridge (*Alectoris graeca* Meisner, 1804) is endemic to Europe, occurring only in the Alps, the Apennines, Sicily and the Balkans. It is suspected to be declining moderately rapidly, particularly in the Balkans which hold a substantial proportion of the species population and range, based on a balanced assessment of the available evidence. Survival rates of 50 released rock partridges in typical habitats in 'Vrachanski Balkan' Nature Park were studied during the re-introduction program. Almost all released birds were monitored for 110 days. Twenty of them were marked with radio transmitters, which allowed the survival rate to be determined, dispersion and habitat preferences. Birds mortality reached 70 % at the end of survey period and only 6 (30 %) of them survived and bred in the next spring. Most birds (65 %) died in the first month after release due to predation. The main predators were mammals (92 % of mortality) while the avian raptors caused an insignificant part of mortality (8 % of mortality). In cold winter days with temperatures lower than -25 °C only one dead bird was found. The survival rates of Rock Partridges did not depend on sex ($\chi^2$ = 0.05, $p$ = 0.82, $df$ = 1) and age ($\chi^2$ = 0.1, $p$ = 0.9, $df$ = 1). The birds' dispersion varied from 35 m to 1.3 km. However only single birds moved more than 1 km away from the release point.

**Key words:** mortality, radio telemetry, survival rates.

## Introduction

Rock Partridge (*Alectoris graeca* Meisner, 1804) is endemic to Europe, occurring only in the Alps, the Apennines, Sicily and the Balkans. It is suspected to be declining moderately rapidly, particularly in the Balkans which hold a substantial proportion of the species's population and range, based on a balanced assessment of the available evidence (Griffin 2011, Staneva and Burfield 2017).

Rock Partridge in Bulgaria belongs to the nominate subspecies *Alectoris graeca graeca* (Meisner, 1804) and is unique in the world due to the presence of a hybrid zone with Chukar Partridge (*Alectoris chukar kleini* J. E. Gray, 1830) in native range of the species (Petrov et al. 1969, Bernard-Laurent and Boev 1997, Nikolov et al. 2007).

The species is Near Threatened (NT) classified in SPEC 1 with declining population trends (Staneva and Burfield 2017).

Rock Partridge is a species from the Red Data Book of Republic of Bulgaria. It falls into endangered category by applying the IUCN criteria at regional level (Boev and Nikolov 2011). Population size is estimated to be between 800–1500 breeding pairs. It is a priority of conservation (Biodiversity Act, Annex 2) and under regime of protection and regulated use (Nikolov et al. 2007, Staneva and Burfield 2017).

Rock Partridge has been widely distributed in Bulgaria during the 19th and early 20th centuries (Nikolov et al. 2007). The population decline began in the 1960s of last century (Donchev 1961, Simeonov et al. 1990). The beginning of the 1990s, the Rock Partridge number as about 20,000 individuals (Simeonov et al. 1990). The population size decreases from 5–10,000 breeding pairs to 1995 to 800–1500 pairs by 2002 (Staneva and Burfield 2017). This decline is also reported in 2007 (Nikolov et al. 2007). As limiting factors for Rock Partridge in other parts of the range are mentioned genetic hybridization (Triantafyllidis et al. 2005), predation (Vavalekas et al. 1993) and the abandonment of extensive agriculture and livestock, leading to increased canopy cover (Papaevangelou et al. 2001, Rippa et al. 2011). The slope, the distance of forest and the presence of bare rocks are important factors for its reproductive zones (Amici et al. 2009). Rock Partridge preferred open areas with meadow and pastures at high altitude with south steep slopes with bare rocks (Cattadori et al. 1998, Sorace et al. 2013). The decline of mountain farming and hybridization with farm Chukar Partridge are one of the probable reasons for disappearance of Rock Partridge in most of habitats in Bulgaria (Nikolov et al. 2007). No specific studies have been conducted in Bulgaria on these cases.

The purpose in this study is to establish the survival rate, causes for losses and dispersion of Rock Partridges, reared under semi natural conditions.

## Material and Methods

### Field methods

At the beginning of November (09.11.2016), 20 Rock Partridges with radio transmitters (RI-2B, Holohil systems LTD) weighting 8 grams were released in 4 parts in 'Vrachanski Balkan' Nature Park (NW Bulgaria) (Fig. 1). The average weight of the birds was 510 g (420–570, $n$=50). The transmitter averaged 1.6 % of the weight. Almost all released birds were monitored for 110 days. They were released with another 30 unmarked Rock Partridges. The idea was to create a few flocks to be monitored. The birds were divided into IV groups (Fig. 1). In groups I, III and IV, we marked one bird over 1 year old and 3 at the age of 150 days, along with 8 non-marked birds aged 150 days. Only in group II were 2 birds over 1 year, 6 at 150 days and with them we released another 4 unmarked birds at 150 days of age. The release groups are consistent with the flocks in the breeding facilities.

All birds were reared under semi-natural conditions. In aviaries with an area as about 300 m$^2$ 4 males and 4–5 females were settled. In each aviary, rocks occupy 15–30 % of the area and natural shelters offering nesting sites. In addition, artificial shelters and nests were built. The aviary were equipped with automated feeders and water slots which do not require a daily human presence. The human presence was directly monitored once a week. During the rest of the time, the birds were monitored by video control. The habitats in which they were released fall into the

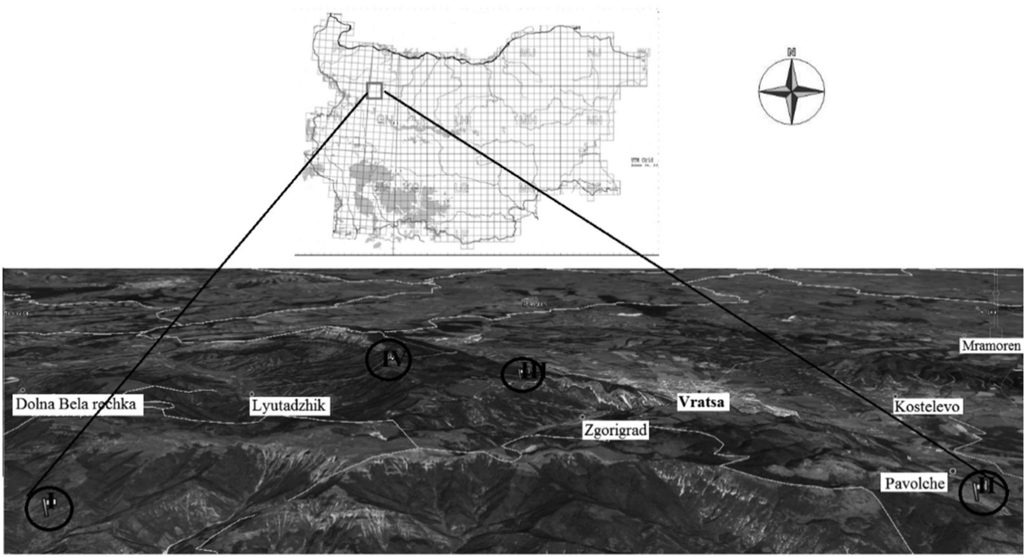



**Fig. 1. Study area and places of release of radio tagged Rock Partridge (pointer I to IV – place of release of four groups Rock Partridge).**

natural range of Rock Partridge and include typical areas.

Initially, Rock Partridges were located at a 3-day interval in the first month. The goal was to accurately determine the cause of losses. They were then located within 6 days until the end of the study because the losses decrease after the first month. Survival probability decreased very fast during the first 50 days from the capture and then more slowly (Meriggi et al. 2002). Each bird or flock found was observed visually during each telemetry. When not detected during the telemetry, the protocol was reported as non-localized. All distances were measured using the Garmin eTrex Legend Global Positioning System and the program MapSource, Version 6.11.6 (Garmin Ltd.).

### Mortality

Losses were classified according to cause of mortality in the following categories: predatory mammals; birds of prey; hunting activity and unknown. The reason for the death of birds has been established by using the traces left on the transmitter and the remains of feathers and bones around it.

The dispersion of birds after release was established as the mean arithmetic distance of each tagged bird from the release point for the entire monitoring period.

### Statistical methods

The differences in bird dispersion at different release sites were tested with Mann-Whitney U test with Bonferroni corrected p values. Survival rates were estimated using Kaplan-Meier nonparametric analysis or product-limit estimator (Kaplan and Meier 1958, Pollock et al. 1989) and parametric survival curve analysis with Weibull distributed errors (Pinder et al. 1978, Crawley 2013). The differences in survival rates between age and sex of released birds and the interaction between age and sex were tested by log-rank test (Krebs 1999), Cox proportional hazards model (Cox and Oakes 1984) and parametric model with Weibull errors (Pinder et al. 1978). A parametric survival curve analysis is less subject to the sensitivities of small sample sizes and stochastic variability observed in Kaplan-Meier nonparametric analysis (Kaplan and Meier 1958, Skalski et al. 2005). All statistical analyses were performed using R (R Core Team 2014) and package survival, v. 2.37-7 (Therneau and Grabsch 2000, Therneau 2014).

## Results

### Mortality

Overall mortality amounts to 70 % (Fig. 2). In the first month after release, 13 (65 %) of the tagged Rock Partridges died (Table 1). The main reason of death is predatory mammals – 12 from 14 dead birds (six birds killed by Red Fox *Vulpes vulpes* (Linnaeus, 1758); two killed by Wild Cat *Felis silvestris* (Schreb., 1777); 2 killed by Mustelidae and 2 was with undetermined mammals. Birds of prey are the cause of the dead of single partridges (one killed by a Goshawk *Accipiter gentilis* (Linnaeus, 1758)). Losses during the cold winter days, including temperatures of -25 degrees, amount to one dead bird (row 6 in Table 1) with cause for death – predatory mammal. Thirty percent of Rock Partridges survived after 110 days and bred in the spring of 2017.

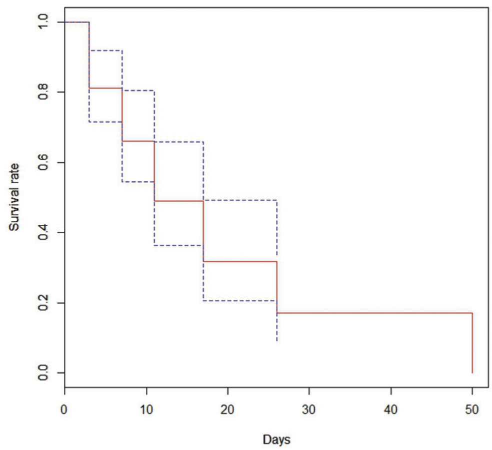



**Fig. 2. Kaplan-Meier survival rates. Dashed lines show the 95 % confidence interval limits.**

Note: mortality was shown during the first 50 days after release because there were no dead birds between the 50–110 days.

**Table 1. Losses after release by sites of release and sex of birds.**

| Sites, days | I | | II | | III | | IV | | Total by sex | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | male | female | male | female | male | female | male | female | male | female | |
| 3 days | 0 | 0 | 2 | 2 | 0 | 1 | 1 | 2 | 3 | 5 | 8 |
| 7 days | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 3 |
| 11 days | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 |
| 17 days | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 days | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 |
| 50 days | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 |
| 110 days | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 6 | 8 | 14 |

There is no difference in the survival rate by sex ($\chi^2$=0.05 on 1 degrees of freedom, $p$=0.82) and by age ($\chi^2$=0.01 on 1 degree of freedom $p$=0.9) (Fig. 3).

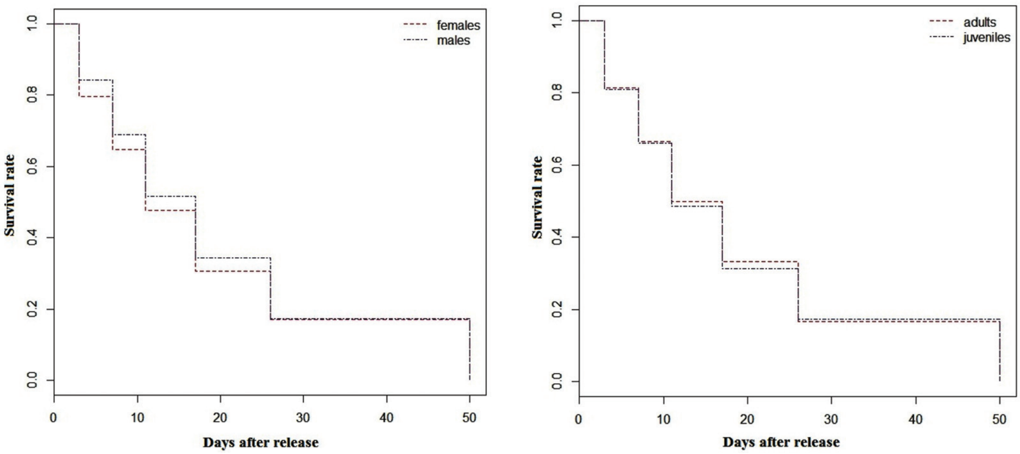



**Fig. 3. Kaplan-Meier rates.**

## Dispersion

The dispersion varies from 35 m to 1.3 km but only single birds move more than 1 km away from the place of release (Table 2).

The dispersion of partridges released in place II and III is considerably smaller than that in other places (Table 3).

**Table 2. Dispersion of Rock Partridges from points of release.**

| Place of release | Dispersion – Mean±Std Dev (min–max), m |
|---|---|
| I | 500.7±70.3 (385–605) |
| II | 276.4±150.4 (35–464) |
| III | 504.3±291.1 (72–1300) |
| IV | 339.3±222.1 (56–748) |

**Table 3. Results from Mann-Whitney U test with Bonferrroni corrected p values between dispersion of rock partridges (p; U).**

| Places of release | I | | II | | III | | IV | |
|---|---|---|---|---|---|---|---|---|
| | p | U | p | U | p | U | p | U |
| I | - | - | **0.0018** | 8 | 0.633 | 59 | 0.072 | 22.5 |
| II | **0.0018** | 8 | - | - | **0.0081** | 31 | 0.549 | 46 |
| III | 0.633 | 59 | **0.0081** | 31 | - | - | 0.11 | 46 |
| IV | 0.0723 | 22.5 | 0.549 | 46 | 0.114 | 46 | - | - |

Note: in bold there are values where there is statistical significance at the corresponding value of U.

## Discussion

### Mortality

The results show the large losses in the first days after release (Fig. 2). There are no differences between by age and sex. The results obtained in confirm some already known ones in the other gallinaceous bird (Bernard-Laurent 1989, Bernard-Laurent and Léonard 1998). Losses after release are highest in the first week. The main causes for dead are predatory mammals – Red Fox, Wild Cat and different mustelids. Birds of prey have no significant impact on survival of partridges in this study. Similar results have been obtained from Chukar Partridge (*Alectoris chukar*) in Bulgaria (Gruychev 2012). In this study, a higher survival rate was found, in contrast to that found in other partridges in Bulgaria (Gruychev 2012). The probable cause is the semi-natural breeding and rearing of birds.

The survival rate found in this study is similar to that found by Duarte and Vargas (2004) for Red-legged Partridge (*Alectoris rufa*). High survival rate of gallinaceous birds reared in semi-natural environment was found in previous studies (Dowell 1990a, b; Buner and Schaub 2008; Slaugh et al. 1992; Alonso et al. 2005). This requires natural and semi-natural breeding to be preferred methods for reintroduction of a species into nature. The releasing of hand-reared gallinaceous birds remains common method for sustaining higher hunting bags and supporting wild populations (Game conservancy 1994, Ellis et al. 1978, Slaugh et al. 1992, Buner and Shaub 2008).

### Dispersion and habitats

Our results indicate a relatively small dispersion of the released Rock Partridges. Only a single birds move more than one kilometer away. Various studies in gallinaceous birds provide different information about the distance from the marker. In France, *Alectoris graeca saxatilis* (Bechstein 1805) ranged between 4 and 25 km depending on the season, and these distances increased significantly after the beginning of the breeding season and subsequently the birds returned again near the marked point (Bernard-Laurent 1991). A number of studies indicate a relatively small area of the inhabited area of partridges (Lindbloom 1998; Walter 2000, 2002; Gruychev and Mihaylov 2015). Results of dispersion of released Chukar Partridge and Pheasant (*Phasianus colchicus*), also reported small distance of the birds from the place of marking (Gruychev 2012, 2014; Mihaylov et al. 2014). The probable cause for our results may be the high habitat suitability of the release sites characterized by presence of numerous vertical rocks in which birds find shelter. There they are undisturbed and remain almost throughout the day, except for the time they forage. Other possible could be that the partridges tend to stay near feeders. Unlike previous studies on partridges and pheasants in Bulgaria (Gruychev 2012, 2014; Gruychev and Mihaylov 2015), this study provides their importance. The released birds regularly visited the feeders during the cold winter days. This probably reduced the dispersion.

The raised of Rock Partridge in semi-natural environment is one of the possibilities for recovery of the species in 'Vrachanski Balkan' Nature Park.

## Conclusion

This study presents first results of recovery program of Rock Partridge in Bulgaria. The results show the large losses in the first days after release. There is no relation between losses by age and sex. Our results indicate a relatively small dispersion of rock partridges. Only a single birds move more than 1 km away. The predation remains the main cause of losses. The dispersion is relatively small and probably due to the vertical rocks that are important for the birds survival. Further research is needed to confirm the success of the recovery program in 'Vrachanski Balkan' Nature Park.

## Acknowledgements

The investigations were carried out under grant: 'Implementation of planning and management activities of 'Vrachanski Balkan' Nature Park' part of Operational Programme Environment.

## References

Alonso M., Perez J., Gaudioso V., Diez C., Prieto R. 2005. Study of survival, dispersal and home range of autumn released red-legged partridges (*Alectoris rufa*). British Poultry Science 46: 401–406.

Amici A., Pelorosso R., Serrani F., Boccia L. 2009. A nesting site suitability model for rock partridge (*Alectoris graeca*) in the Apennine Mountains using logistic regression. Italian Journal of Animal Science 8: 751–753.

Bernard-Laurent A. 1989. Importance de la predation sur une population de perdrix rochassieres (*Alectoris graeca saxatilis* × *Alectoris rufa rufa*) des alpes mridionales. Gibier Faune Sauvadge 6: 361–382.

Bernard-Laurent A. 1991. Migrant rock partridges (*Alectoris graeca saxatilis*) in the southern French Alps. Journal of Ornithology 132: 220–223.

Bernard-Laurent A., Boev Z. 1997. *Alectoris graeca* Rock Partridge. In: Hagemeijer W.J.M., Blair M.J. (Eds). The EBCC Atlas of European Breeding Birds. Their Distribution and Abundance. T & A D Poyser, London. 207 p.

Bernard-Laurent A., Léonard P. 1998. Phénologie de la reproduction de la perdrix bartavelle (*Alectoris graeca saxatilis*) dans les Alpes. Game & Wildlife Science 15: 379–395.

Boev Z., Nikolov S. 2011. Rock Partridge *Alectoris graeca* In: Golemanski V. (Ed.). Red Data Book of the Republic of Bulgaria. Volume 2. Animals. IBEI – BAS & MOEW, Sofia. 372p.

Buner F., Schaub M. 2008. How do different releasing techniques affect the survival of reintroduced grey partridges *Perdix perdix*? Wildlife Biology 14: 26–35.

Cattadori I., Pandini V., Cistoldi E., Meriggi A. 1998. A model of habitat suitability for the rock partridge (*Alectoris graeca saxatilis*) in the Trentino Alp: preliminary results. Gibier Fauna Sauvage 15: 397–406.

Cox D., Oakes D. 1984. Analysis of Survival Data. Chapman and Hall, London. 208 p.

Crawley M.J. 2013. The R Book. John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England. 977 p.

Donchev S. 1961. The Birds of Vitosha Mountain. Bulletin of Institute of Zoology and Museum 10: 59–137 (in Bulgarian).

Dowell S.D. 1990a. Differential behaviour and survival of hand-reared and wild gray partridge in the United Kingdom. In: Church K.E., Warner R.E., Brandy S.J. (Eds). Perdix V: Gray Partridge and Ring-necked Pheasant Workshop. Kansas Department of Wildlife and Parks, Emporia, Kansas: 230–239.

DOWELL S.D. 1990b. The development of anti-predator responses in grey partridge and common pheasants. In: Hill D. A., Garson P. J., Jenkins D. (Eds). Pheasants in Asia 1989. World Pheasant Association: 193–199.

DUARTE J., VARGAS J. 2004. Field interbreeding of released farm-reared red-legged partridges (*Alectoris rufa*) with wild ones. Game and Wildlife Society 21(1): 55–61.

ELLIS D., DOBROTT S., GOODWIN J. 1978. Reintroduction techniques for masked bobwhites. In: Temple S.A. (Ed.) Endangered birds: Management for Preserving Threatened Species, Madison. University of Wisconsin Press: 345–354.

GAME CONSERVANCY 1994. Gamebird Rearing. Game Conservancy Limited, UK. 127 p.

GRIFFIN C. 2011. Rock Partridge *Alectoris graeca* population assessment. Methodology for Bird Species Recovery Planning in the European Union. Final Report to the European Commission. FACE and BirdLife International for the European Commission, Cambridge, UK. 396 p.

GRUYCHEV G. 2012. Result from Radio-Telemetric Monitoring of Hand-Reared and Released Chukar Partridges (*Alectoris chukar* Gray, 1830). Acta Zoologica Bulgarica 64(1): 59–65.

GRUYCHEV G. 2014. Radio telemetric Tracking of Farm Pheasant (*Phasianus colchicus*) Released in the Pazardzhik Region, Bulgaria. Acta Zoologica Bulgarica 66(3): 425–429.

GRUYCHEV G., MIHAYLOV CH. 2015. Habitat preferred and home range of hand-reared and released Chukar Partridge (*Alectoris chukar* Gray, 1830) in SE Bulgaria. Forestry Ideas 21(1): 67–73.

KAPLAN L., MEIER P. 1958. Non-parametric estimation from incomplete observations. Journal of the American Statistical Association 53: 457–481.

KREBS C. 1999. Ecological Methodology. 2nd edition, Benjamin Cummings, Menlo Park. 620 p.

LINDBLOOM J. 1998. Habitat use, reproduction, movements, and survival of Chukar Partridge in west-central Idaho. Master thesis. University of Idaho, Moscow. 131 p.

MERIGGI A., BRANGI A., CUCCUS P. 2002. High mortality rate in a re-introduced grey partridge population in central Italy. Italian Journal of Zoology 69: 19–24.

MIHAYLOV CH., GRUYCHEV G., STOYANOV S. 2014. Survival of spring released, hand reared Common Pheasants (*Phasianus colchicus colchicus* L. 1758) and Chukar partridges (*Alectoris chukar* J. E. Gray 1830) in natural habitats in Bulgaria. Balkan Journal of Wildlife Research 1(1): 55–61.

NIKOLOV ST., BOEV Z., DELOV V. 2007. Rock Partridge (*Alectoris graeca*). In: Iankov P. (Ed.), Atlas of Breeding Birds in Bulgaria. Bulgarian Society for the Protection of Birds, Conservation Series, Book 10. Sofia, BSPB: 198–199 (in Bulgarian and English).

PAPAEVANGELOU E., THOMAIDES C., HANDRINOS G., HARALAMBIDES A. 2001. Status of partridge (*Alectoris* and *Perdix*) species in Greece. Game and Wildlife Science 18: 253–260.

PETROV P., DRAGOEV P., GEORGIEV ZH. 1969. On the subspecies belonging of the Rock Partridge (*Alectoris graeca* Meisner) in the Eastern Rhodopes. Forestry science 5(3): 91–106 (in Bulgarian).

PINDER J., WIENER J., SMITH M. 1978. The Weibull distribution: a new method of summarizing survivorship data. Ecology 59: 175–179.

POLLOCK K., WINTERSTEIN S., CONROY M. 1989. Estimation and analysis of survival and distributions for radio-tagged animals. Biometrics 45: 99–109.

RIPPA D., MASELLI V., SOPPELSA O., FULGIONE D. 2011. The impact of agro–pastoral abandonment on the rock partridge *Alectoris graeca* in the Appenines. Ibis 153: 721–734.

SIMEONOV S., MICHEV T., NANKINOV D. 1990. Fauna of Bulgaria. Vol. 20. Part I. Sofia, BAS. Marin Drinov. 350 p. (in Bulgarian with English Summary).

SKALSKI J., RYDING K., MILLSPAUGH J. 2005. Wildlife Demography: Analysis of Sex, Age, and Count Data. Elsevier Science, San Diego, California. 656 p.

SLAUGH B.T., FLINDERS J.T., ROBERSON J.A., JOHNSTON N.P. 1992. Effect on rearing method on chukar survival. Great Basin Naturalist

52(1): 25–28.

Sorace A., Guglielmi S., Properzi S., Riga F., Trocchi V., Scalisi M. 2013. Rock Partridge *Alectoris graeca* in Lazio region (Central Italy): Status and Action Plan. Avocetta 37: 141–144.

Staneva A., Burfield I. 2017. European birds of conservation concern: Populations, trends and national responsibilities. Gui-Xi Young (Ed.). Cambridge, UK, BirdLife International. 172 p.

Therneau T. 2014. A Package for Survival Analysis in S. R package version 2.37-7. Available at: http://CRAN.R- project.org/package=survival.

Therneau T., Grambsch P. 2000. Modeling Survival Data: Extending the Cox Model. Springer, New York. 350 p.

Triantafyllidis A., Karatzas D., Georgiadou A., Drikos I., Andreakou E., Lappa M., Chatzinikos E., Manios N., Papageorgiou N., Triantafyllidis C. 2005. Genetic identification of Greek partridges *Alectoris graeca* and *Alectoris chukar*. In: Extended Abstracts of the XXVII Congress of the International Union of Game Biologists. K. Pohlmeyer (Ed.). Edition Natur Life, Hamburg: 188–190.

Vavalekas K., Thomaides C., Papaevangelou E., Papageorgiou N. 1993. Nesting biology of the rock partridge *Alectoris graeca graeca* in northern Greece. Acta Ornithologica 28: 97–101.

Walter H. 2000. Ecology of the Chukar in Eastern Oregon. Mastrer's thesis, University of Idaho, Moscow. 132 p.

Walter H. 2002. Natural history and ecology of the Chukar (*Alectoris chukar*) in the Northern Great Basin. Great Basin Birds 5(1): 28–37.